**CACHE Modules on Energy in the Curriculum**

**Module Title:** Greenhouse Gas Emissions

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**Introduction**: It is a widely accepted fact that the emission of greenhouse gases (GHG) causes global warming. Low GHG emission is a major reason for utilizing alternative energy sources. Just like Energy Payback Time (EPBT), the concept of Greenhouse gas Payback Time (GPBT) is used as one of the metrics for life cycle assessments of energy generating systems. GPBT varies according to the domestic fuel mixture used for electricity production. Carbon dioxide, Methane and Nitrous Oxide are the main three greenhouse gases which are harmful after emission into the atmosphere. For uniformity, GHG emissions are expressed in gram or kilogram equivalent of carbon dioxide. Through this module, students will become acquainted with the various emission data for different types of energy sources. They would also learn to calculate the GPBT and the GHG emissions saved by a system.

**References:**

L., Lu, and Yang H.X. "Environmental Payback Time Analysis Of A Roof-Mounted Building-Integrated Photovoltaic (BIPV) System In Hong Kong." *Applied Energy* 87.(n.d.): 3625-3631.

Moomaw, W., P. Burgherr, G. Heath, M. Lenzen, J. Nyboer, A. Verbruggen, 2011: Annex II: Methodology. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlomer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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Emissions & Generation Resource Integrated Database (eGRID) version 1.0, 2009. Developed for the U.S. EPA / Climate Protection Partnerships Division / State and Local Climate and Energy Program.Web. Accessed June 2013. <http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html>.

**Key Concepts:** Global Warming Potential, GPBT (Greenhouse gas Payback Time)

 **Background Data:** The Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energy Sources and Climate Change Mitigation provides the following values for Global Warming Potential based on time zone in years:

|  |  |  |  |
| --- | --- | --- | --- |
|  | 20 years | 100 years | 500 years |
| CO2 | 1 | 1 | 1 |
| CH4 | 72 | 25 | 7.6 |
| N2O | 289 | 298 | 153 |

The Fourth Assessment Report of IPCC provides the following GHG emission estimates for various energy sources in g CO2eq/KWh:

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Values | Bio-Power | Solar PV | Solar CSP | Geothermal Energy | Hydropower | Ocean Energy | Wind Energy | Nuclear Energy | Natural Gas | Oil | Coal |
| Minimum | -633 | 5 | 7 | 6 | 0 | 2 | 2 | 1 | 290 | 510 | 675 |
| 25th Percentile | 360 | 29 | 14 | 20 | 3 | 6 | 8 | 8 | 422 | 722 | 877 |
| 50th Percentile | 18 | 46 | 22 | 45 | 4 | 8 | 12 | 16 | 469 | 840 | 1001 |
| 75th Percentile | 37 | 80 | 32 | 57 | 7 | 9 | 20 | 45 | 548 | 907 | 1130 |
| Maximum | 75 | 217 | 89 | 79 | 43 | 23 | 81 | 220 | 930 | 1170 | 1689 |
| CSS min | -1368 |  |  |  |  |  |  |  | 65 |  | 98 |
| CSS max | -594 |  |  |  |  |  |  |  | 245 |  | 396 |

**Example Problems**

1) Find the total kg CO2eq of emissions if a system emits 600 kg of CO2, 0.1 kg of CH4 and 0.004 kg of N2O. Take a time horizon of 20 years.

Solution:

$$GHG emission in kg CO\_{2eq}=GHG emission in kg×GWP$$

$$600 kg CO\_{2}×1=600 kg CO\_{2eq}$$

$$0.1 kg CH\_{4}×72=7.2 kg CO\_{2eq}$$

$$0.004 kg N\_{2}O×289=1.156 kg CO\_{2eq} $$

$$Total GHG emissions= 600 kg CO\_{2eq}+7.2 kg CO\_{2eq}+1.156 kg CO\_{2eq}=608.36 kg CO\_{2eq}$$

$ $

2) U.S. Environmental Protection Agency states that the SERC Mississippi Valley region has following estimates of annual total output emission rates: 1002.41 lb/MWh carbon dioxide, 19.45 lb/GWh methane and 28.98 lb/GWh nitrous oxide. If a solar power PV installation produces 35,000 KWh of electricity annually, then

a) Find the total GHG emissions saved by the installation in kg CO2eq.

b) If the PV manufacturing, installation and other GHG emissions are 100,000 kg CO2eq, the find the GPBT of the system.

Solution:

a)
$$1002.41\frac{lb CO\_{2}}{MWh}×1×\frac{0.453kg}{lb}×\frac{MWh}{1000 KWh}=0.454\frac{kgCO\_{2eq}}{KWh} $$

$$19.45\frac{lbCH\_{4}}{GWh}×72×\frac{0.453kg}{lb}×\frac{GWh}{10^{6 }KWh}=0.00063\frac{kgCO\_{2eq}}{KWh}$$

$$28.98\frac{lbCH\_{4}}{GWh}×289×\frac{0.453kg}{lb}×\frac{GWh}{10^{6 }KWh}=0.0038\frac{kgCO\_{2eq}}{KWh}$$

$$Total GHG emissions per year=\left(0.454+0.00063+0.0038\right)\frac{kgCO\_{2eq}}{KWh} =0.45843\frac{kgCO\_{2eq}}{KWh}$$

$$Total GHG emissions saved in kg CO\_{2eq}per year=0.45843\frac{kgCO\_{2eq}}{KWh}×35,000 KWh=16,045.05 kg CO\_{2eq}$$

b) $GPBT=\frac{(GHG\_{module}+ GHG\_{BOS})}{GHG\_{output}}=\frac{100,000 kg CO\_{2eq}}{16045.05\frac{kg CO\_{2eq}}{year} }$ = 6.23 years

*GHGmodule* : GHG emissions produced throughout the manufacturing process of the PV module.

*GHGBOS* : GHG emissions produced while manufacturing and interconnecting all other components apart from the PV modules in a PV system. BOS means Balance of System.

*GHGoutput* : GHG emissions saved by using the PVsystem.

3) A fuel mixture from CLP Power Hong Kong Limited has a composition of 39% Coal, 1% Oil, 31% Natural gas and 29% Nuclear. If a PV system generates 150,000 KWh of electricity every year, find the GHG emissions it saves in kg CO2eq. Use 50th percentile GHG emissions.

Adapted from:

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Solution:

$$GHG emissions saved from use of a fuel=(Percentage of that fuel in fuel mixture composition×PV output×GHG emissions by that fuel in kg CO2eq/KWh)$$

$$GHG emissions saved from Coal=0.39×150,000 kWh×1.001\frac{kgCO2eq}{KWh}=58,558.5 kg CO2eq$$

$$GHG emissions saved from Oil=0.01×150,000 kWh×0.840\frac{kgCO2eq}{KWh}=1260 kg CO2eq$$

$$GHG emissions saved from Natural Gas=0.31×150,000 kWh×0.469\frac{kgCO2eq}{KWh}=21,808.5 kg CO2eq$$

$$GHG emissions saved from Nuclear=0.29×150,000 kWh×0.16\frac{kgCO2eq}{KWh}=6960 kg CO2eq$$

$$Total GHG emissions saved= 58,558.5 kg CO2eq+1260 kg CO2eq+21,808.5 kg CO2eq+6960 kg CO2eq=88587 kg CO2eq$$

**Homework Problem Statement:**

**Background Data:** The Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewable Energy Sources and Climate Change Mitigation provides the following values for Global Warming Potential based on time zone in years:

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
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| Maximum | 75 | 217 | 89 | 79 | 43 | 23 | 81 | 220 | 930 | 1170 | 1689 |
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1) Perform a sensitivity analysis of the total GHG emission for a change of 1% in fuel mixture composition stated in example problem 3. Use maximum values of GHG emissions. Find the mixture compositions which will have lowest and highest emission.

Here we define sensitivity analysis as an analysis of the change in the output due to an increase and decrease of a factor in an equivalent amount. In this case, the output is the GHG emission by a fuel and the factor responsible for it is the percentage of the fuel in the mixture composition.

Solution: To begin with, we would need to find the GHG emission of a fuel by increasing and decreasing its composition by 1%.

2) Find the total kg CO2eq of emissions if a system emits 950 kg of CO2, 0.3 kg of CH4 and 0.007 kg of N2O. Take a time horizon of 100 years.