**CACHE Modules on Energy in the Curriculum**

**Energy Topic: Solar Energy**

**Module Title:** Energy Payback Time

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**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. *ScienceDirect*. Web.

Knapp, K., and T. Jester. "Empirical Investigation Of The Energy Payback Time For Photovoltaic Modules." *Solar Energy -Phoenix Arizona Then New York-* 71.3 (2001): 165-172. *British Library Document Supply Centre Inside Serials & Conference Proceedings*. Web.

H. C. Kim, et al. "Energy Payback And Life-Cycle CO2 Emissions Of The BOS In An Optimized 3·5 MW PV Installation." *Progress In Photovoltaics* 14.2 (2006): 179-190. *Environment Complete*. Web.

V.M., Fthenakis, and Kim H.C. "Photovoltaics: Life-Cycle Analyses." *Solar Energy* 85.Progress in Solar Energy 1 (n.d.): 1609-1628. *ScienceDirect*. Web.

**Key concepts:** Energy of production, insolation, balance of system (BOS).

**Introduction:** Energy Payback Time (EPBT) is the period required for a system to generate an amount of energy which is equal to energy used to produce the system. EPBT is one of the common metrics used in life cycle analysis of a system. It is very difficult to get an exact generalized EPBT since it is dependent on multiple variable factors like insolation, source of electricity for production, method of manufacturing, design of system etc. A decade ago, the EPBT for crystalline silicon solar PV systems was about 6-8 years. Due to rapid advancement in manufacturing and efficiency of these systems, the production energy required has lowered down and the energy output has increased. Some life cycle assessments now depict an EPBT as low as 0.8-1yr. The EPBT for residential roof-top installations is much higher than that of commercial PV systems because of their lower size. In this module we would look at only silicon PV system, since other PV systems using CIGS/CIS (CaInGaSe/CaInSe) or CdTe solar panels have not been thoroughly studied yet.

**Formulae:**

*ES, E*: Embodied energy of PV module

*EBOS, E*: Embodied energy of balance of system

*BOS*: All other components of a PV system except the PV modules.

*Ep*: Embodied energy in processing and purification of silicon.

*Es*: Embodied energy in slicing the silicon ingot to form wafers.

*Ef* : Embodied energy in formation of PV modules.

*Et*: Embodied energy in transport of all components.

*Ed*: Embodied energy in disposing the PV modules.

**Example Problems:**

1) What is the EPBT of a PV system having a total production energy requirement of 5500 kWh/kWp through its lifecycle and annual energy output of 2150 kWh/kWp?

Solution:

2) The nationally accepted U.S. average conditions for assessment of PV installations are 1800 kWh/m2/yr insolation, rated module efficiency of 12.2% and a system efficiency of 80%. If a system has a production energy requirement of 600MJ/m2, find its EPBT using these conditions.

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Solution:

3) 1m2 of mono-crystalline silicon solar cell contains 1.5 kg of mono-crystalline silicon. The conversion of silica into mono-crystalline silicon requires the following steps: Conversion of silica into MG-Si (metallurgical grade silicon), conversion of MG-Si to EG-Si (electronic grade silicon) and conversion of EG-Si to mono-crystalline silicon. Consider that the energy required to produce MG-Si is 21kWh/kg. The energy required to produce EG-Si is 105kWh/kg with a 89% loss of mass in the process. The energy required to make mono-crystalline silicon from this EG-Si is 280kWh/kg with 70% loss of mass.

a) Find the embodied energy for silicon purification and processing (Ep) in units of kWh/m2.

b) After purification and processing, the silicon ingot needs to be sliced to form wafers. This process requires 115kWh/m2 of energy (Es). Interconnecting these wafers to form PV modules requires around 185kWh/m2 of energy (Ef). Neglecting the energy required in transportation (Et) and end-of-life disposal(Ed), calculate the total embodied energy of PV modules (ES, E)

c) If the energy required to make its support structure for rooftop installation is 180kWh/m2, in production of inverters would be 30kWh/m2 and for operation and maintenance is 120kWh/m2, then find the total embodied energy of BOS. Also, find the EPBT of the entire PV system under average U.S. conditions.

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Solution:

a)

b)

c)

**Homework Problem Statement:**

1. Find the amount of insolation for a system in kWh/m2/year if its EPBT is 1.5years, production energy requirement is 1000MJ/m2, module efficiency is 85% and cell efficiency is 16%.

2) Consider example problem 3. Find the percentage of mass lost in the two conversion processes if the percentage of mass lost in converting MG-Si to EG-Si is 20% more than the percentage of mass lost in conversion of EG-Si to mono-crystalline silicon ingot. Take Ep as 900 kWh/m2.