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A1_4 An Earthly Heat Sink

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Abstract

This paper examines the possibility of using the Earth's crust as a heat sink to remove heat from the Earth's surface. The paper determines that it is possible to sink energy into the Earth at a rate which is bigger than the rate it will conduct back to the surface. The feasibility of storing 1% of the energy the surface of the Earth receives is considered, and it is found that this could be done for about 5,500 years. However the cost would be too expensive to consider it practical.

Introduction

There are currently many proposed techniques to combat global warming. There are many passive ideas such as burning less fossil fuels, but there are also more active methods. One of the methods is to build mirrors [1] on the surface of the Earth to reflect radiation back into space. The problem with building mirrors on the Earth is that the radiation will be absorbed by the atmosphere as it leaves, reducing the efficiency.

In this article the possibility of capturing the solar energy with mirrors and storing it in the Earth crust is discussed. Eventually the energy will be conducted back to the surface of the Earth limiting the effectiveness of this method, however this will take considerable time. This paper determines how much energy can be stored in the Earth and how quickly it will be transmitted to the surface.

Discussion

The first step is to determine how much energy has to be stored in the crust. In this report it is assumed heat is collected from the surface of the Earth by focusing solar energy from mirrors to heat water to $T_{\mathrm{w}} = 368\ \mathrm{K}$ (just below its boiling point, to store as much energy as possible without risking a phase change to steam). The water will then be sent 3.9 km underground (the depth of the deepest mine [2]) and there it will cool in the relatively cold rock. In order to do this it is assumed that all the rock at this depth is composed of granite, a very common igneous rock, that the water is thermally insulated from the rock until it reaches a depth of 3.9km and that the system delivers water to all of the granite uniformly.

To analyse the effectiveness of this, the plausibility of removing 1% of the solar energy that reaches the surface of the Earth is considered. We first have to work out the energy the Earth receives from the Sun. To do this the Earth is considered as seen from the Sun. This is a disk of area of πr_{E}^2, where $r_{\mathrm{E}} = 6371\ \mathrm{km}$ is the radius of the Earth [3]. Now the energy the Earth receives is calculated as being πr_{E}^2 times the solar flux ($198\ \mathrm{W\,m^{-2}}$ [4]) giving a value of 2.52×10^{16} W. So over one year the Earth receives 7.96×10^{23} J. Of this 7.96×10^{21} J needs to be stored.

To determine the amount of granite needed to store this energy, the heat capacity equation is used [5]

$$\Delta E = mC\Delta T, \quad (1)$$

where ΔE is the change in energy, m is the mass of granite, ΔT is the temperature change of the granite and $\mathrm{C} = 790\ \mathrm{Jkg^{-1}K^{-1}}$ [6] is specific heat capacity of granite. At a depth of 3.9 km $T_{\mathrm{g}} = 328\ \mathrm{K}$ [2], giving $\Delta T =$

$T_g - T_w = 40$ K. This means that each kilogram of granite can store about 31.6 kJ of energy. With a density of $\rho_g = 2691 \text{ kg m}^{-3}$ [7], granite can store 85.0 MJ m^{-3}. This means that $93.6 \times 10^3 \text{ km}^3$ of granite is needed. Between 3.4 and 4.4 km below the Earth's surface there is $5.11 \times 10^8 \text{ km}^3$ of granite (assuming this entire volume consists of granite) so this volume could in theory store energy for 5,460 years.

The heat that will be conducted through the crust back to the surface of the Earth from the granite is now considered. It is assumed that after a year the sink of granite is approximately a cuboid 1 km in height with sides of 3.06×10^5 m. Only the heat flowing through the top of the cuboid directly to the crust is considered. The equation for heat flow I is [8]

$$I = -kA\frac{dT}{dx}, \quad (2)$$

where $k = 2.1 \text{ W m}^{-1} \text{ K}^{-1}$ [9] is the coefficient of thermal conductivity for granite, $A = (3.06 \times 10^5)^2 \text{ m}^2 = 9.36 \times 10^4 \text{ km}^2$ is the area through which heat flows and $dT/dx = 0.012 \text{ K m}^{-1}$ is the temperature gradient. This gives I to be 2.36 GW. With the energy in equalling 7.96×10^{21} J per year and the energy out being 7.45×10^{16} J per year, this could be done to store energy. Therefore after 106,846 years the area of the heated granite would have increased so that the energy out would equal the energy in. However it was previously calculated that there is only enough granite to store energy for 5,460 years.

A solution to this would be to extend the height of the block of granite. There are problems with this approach, as the deeper down under the Earth's crust one goes, the higher the initial temperature of the granite. This reduces the ΔT term in Equation 1 reducing the energy stored per cubic meter. Digging up will increase the dT/dx term in Equation 2, increasing the heat flow, I. An alternative would be to use oil instead of water so that ΔT could be increased however this would increase dT/dx negating this.

Conclusion

This report has determined that in theory it is possible to store heat underground to counter global warming. The 1.98 W m^{-2} of energy stored would be enough to offset the 1.66 W m^{-2} [10] emitted due to carbon dioxide. However capturing 1% of all the incoming solar energy requires one 400th of the Earth to be covered in a system to capture the energy. Assuming the energy will be collected in a way similar to a concentrated solar power station the cost would be $198 trillion a year, larger than the GDP of the world, making this system too expensive (based on the cost and surface area of the Nevada Solar One power station [11][12]).This problem is increased as the mirrors would not reflect light while facing away from the Sun reducing the effectiveness of the system.

References

[1] http://news.mongabay.com/2008/1223-desert.html (03/11/2011)
[2] http://www.mining-technology.com/projects/tautona_goldmine/ (03/11/2011)
[3] http://solarsystem.nasa.gov/planets/profile.cfm?Object=Earth&Display=Facts&System=Metric (03/11/2011)
[4] J.J. Remedios and A. Battaglia (2010), University of Leicester, Earth Observational Science: Lecture 6, slide 3
[5] Paul A. Tipler & Gene Mosca. 2007."Physics for Scientists and Engineers", Sixth Edition, chapter 18
[6] http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html (08/11/2011)
[7] http://www.simetric.co.uk/si_materials.htm (03/11/2011)
[8] Paul A. Tipler & Gene Mosca, Physics for Scientists and Engineers, Sixth Edition, chapter 20
[9] http://www.monachos.gr/en/resources/Thermo/conductivity.asp (03/11/2011)
[10]L. Bernstein et al (2007), Climate change 2007: synthesis Report, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (05/11/2011)
[11] http://tinyurl.com/cgsrmtq (22/11/2011)
[12] http://tinyurl.com/bvjnhj8 (22/11/2011)