The Feasibility of a Solid Carbon Dioxide Pressure Engine as an Energy Source for Mars Exploration and Colonization

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Abstract

Solid carbon dioxide, or dry ice, is plentiful on the surface of Mars, accumulating in vast deposits near the poles and undergoing a cycle comparable to water's on Earth. Because such quantities are available, a method of deriving energy from dry ice could have significant implications for powering human colonization of Mars. A particularly desirable property of dry ice is its ability to sublimate, or change directly from a solid to a gas at only -78℃. That sublimation within a closed container allows for enormous pressures to be reached by relatively small quantities of dry ice. Pressure engines have been used on Earth for centuries, and though conventional pressure engines are driven by compressed air or steam, carbon dioxide might be an adequate substitute. Components of a rudimentary pressure engine were assembled. An Arksen bead seater, chosen for its large valve, was used as the pressure vessel through which dry ice could be inserted quickly. An air hose connected a valve on the bead seater to an angle die grinder, which spun a DC motor, generating power. Current was measured by a multimeter wired in series, while voltage was measured by a Vernier LabQuest wired in parallel, and a 2.5 Volt, 200 mA light bulb from acted as a resistor. Electricity was produced in amounts comparable to these tests with compressed air, causing the light bulb to shine brightly, and, showing that, with further development, a dry ice pressure engine could be used to generate power.

Introduction

Humankind is on the precipice of a great leap forward, the culmination of decades of research and preparation, that will forever change the way humanity views itself. This extraordinary endeavor is the 2026 Mars One mission to our neighbor planet. To send people from Earth to Mars is a task of staggering complexity and involves a journey fraught with dangers, both known and unforeseen. Chief amongst the challenges involved in Martian colonization is the selection of a fuel source that is both reliable and efficient, a new method of generating energy to power humankind's first steps across the cosmos.

Every decision must be carefully calculated when choosing from the numerous energy sources that could function as power source for Martian settlements. Conventional fossil fuels are inadequate, as they further burden spacecraft already filled to capacity. Though one could employ a source of energy used previously on extraterrestrial missions, such as solar power, unique issues exist for solar panels on the rugged Martian surface. Solar panels on Earth have a high initial cost but require little in terms of long-term upkeep and are remarkably easy to maintain. This is not the case on Mars. While our neighbor planets lacks atmospheric phenomena as on Earth, dust storms would perpetually blanket the panels in a layer of obscuring debris, which would have to be routinely removed (M. K. Mazumder, 2003). In addition to this, because Mars is farther from the Sun than is the Earth, less solar energy would have a chance to be harnessed.

An alternative energy source has been proposed which exploits a unique property of solid carbon dioxide, colloquially referred to as dry ice. Dry ice is a favorable "fuel" material partially due to its incredible availability on Mars: vast deposits of dry ice exist near Mars's poles (Malin *et al.* 2001), with one reserve possessing the volume of Lake Superior, 12,100 cubic kilometers (Cohen, 2011). One property of dry ice that differentiates it from other substances is its ability to undergo what's known as the Leidenfrost Effect. The Leidenfrost Effect is a phenomenon in which a substance is suspended atop a layer of its own vapor. This can be exploited to spin a turbine-like surface, generating power (Wells, 2015). Another relevant property of dry ice is its ability to sublimate, or change directly from solid to gaseous form, at low temperatures. Dry ice under Martian pressure and existing at Martian temperatures is just on the brink of sublimating.

The ability to easily change to a gaseous state is particularly important because it is a property integral for use in a pressure engine. The majority of our power today comes from some variety of pressure engine, most, if not all, harnessing steam. Other gases, such as carbon dioxide, can be used in place of water vapor, though carbon dioxide is not a viable alternative on Earth because Earth's atmospheric pressure requires lower temperatures than Mars for dry ice to sublimate. The quantity of dry ice required to reach arbitrary pressures can easily be predicted by using formulae such as the Ideal Gas Law, which establishes a relationship between volume, temperature, pressure and the amount of the substance. On Mars, as opposed to Earth, a pressure engine harnessing dry ice's expansion could be a feasible source of power.

Materials and Methods

Calculating Quantity of Dry Ice: The amount of dry ice necessary to reach 621 kPa was calculated by using the Ideal Gas Law, $PV = nRT$ (Nave). R was set to $8.314\frac{J}{mol\,K}$, and the other parameters were converted to compatible units. P was set to 621 kPa, or approximately 90 psi, the maximum capacity of the component acting as our turbine, V was set to 18.92 liters or 5 gallons, the volume of our pressure vessel, n unknown, and T was set equal to 293.15 K, or room temperature, an estimation because the exact temperature of the tank's interior could not be determined. Reorganizing the Ideal Gas equation to $n = \frac{PV}{RT}$ and substituting the calculated values yields $n = 4.821$, with units of kPa L mol K J^{-1} K^{-1}, and cancelling out equivalent units present in both the numerator and denominator and when the units are replaced by their SI base units, kPa by 10^{-3} kg m^{-1} s^{-2}, liters by 10^{3} m^{3}, and J by kg m^{2} s^{-2}, the two constant terms simplify to 1 and the unit becomes mol kg m^{-1} s^{-2} m^{3} kg^{-1} m^{-2} sec^{2}, which, after corresponding units are removed from the numerator and denominator, is simply moles. This value of 4.821 mol can be converted to mass by multiplying it by carbon dioxide's molar mass of 44.01, yielding a final value of approximately 212 grams of carbon dioxide.

Assembling Components of System: An Arksen bead seater was employed as the pressure vessel, with an air hose connected to a .375 inch ball valve on the exterior of the tank. Attached to the other end of the air hose was an air angle die grinder, which served the purpose of converting the pressure into kinetic rotational energy. The die grinder possessed a maximum speed of 20,000 RPM at the highest pressure it could withstand, 90 psi (621 kPa). The grinder rotated a metal shaft

which, in turn, spun a DC motor salvaged from a 12 volt cordless drill.

Performing Tests

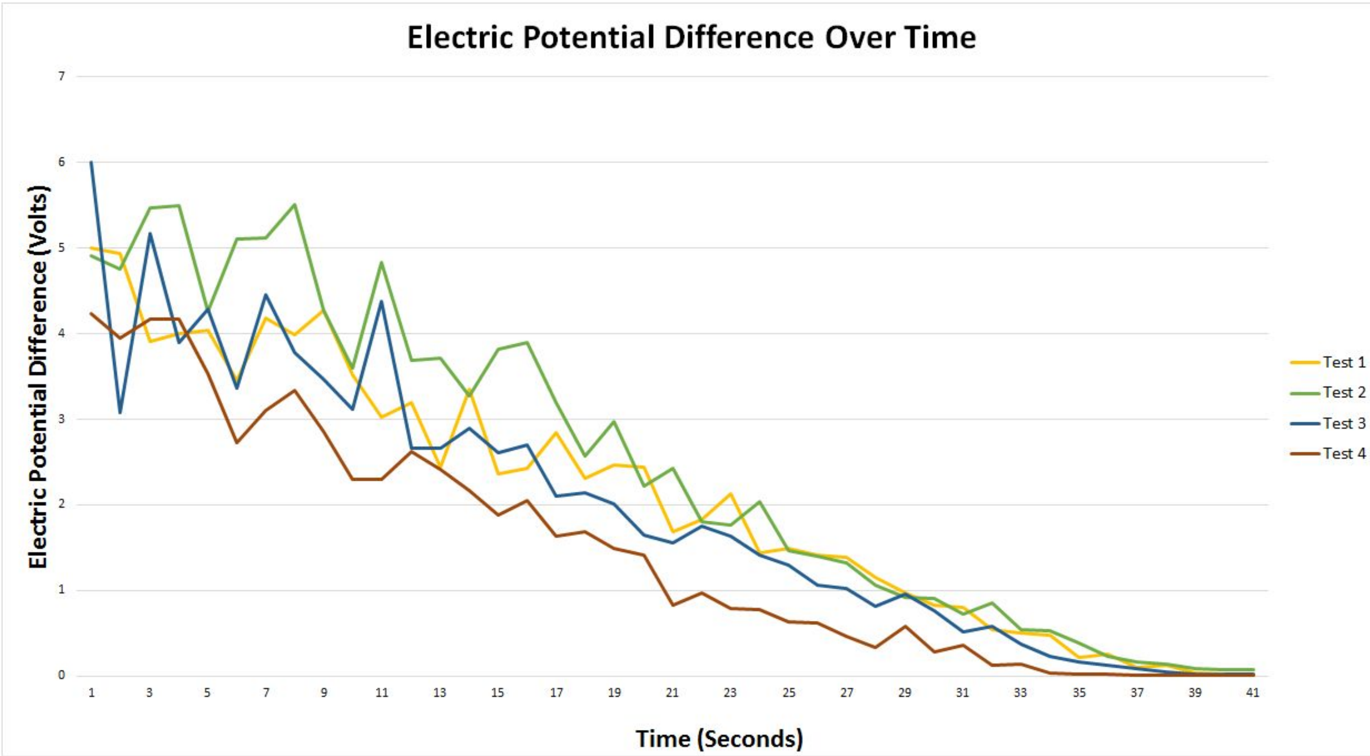
Compressed Air: Until dry ice was acquired, compressed air was used in its place. The bead seater was filled with <the calculated quantity> of dry ice and was sealed. Time was allowed for the dry ice to sublimate, which was indicated by the desired pressure being reached on the bead seater's pressure gauge, and then the air tube from the air compressor was replaced with another connected to the angle die grinder. The pressure was then allowed to flow through the air tube, spinning the angle die grinder and generating power via the DC generator.

Solid Carbon Dioxide: If a quantity of carbon dioxide greater than necessary to reach 90 psi (621 kPa) was added, excess pressure could easily be released, so it was only necessary to ensure that at least the calculated amount was added, as opposed to being required to insert a precise amount. It was decided that approximately 50 grams more than the calculated amount would be added, in order to compensate for sublimation during the insertion of the dry ice into the pressure vessel. Excess quantities could simply be let out after the dry ice sublimated, so this number was chosen as an overestimation of the likely quantity necessary. Dry ice was crushed in a hand crank ice crusher. A balance was zeroed to the weight of the ice crusher's collection container, and amounts of dry ice approximated to be in the desired range were crushed. This quantity was weighed, and amounts were removed or added as necessary. When the dry ice was ruled close enough to the desired amount, it was quickly placed into the Arksen bead seater through a 1 1/2 inch ball valve via a cardstock funnel. The input area was then sealed and the dry ice was left to sublimate until full pressure was achieved. The excess pressure was let off slowly until the gauge read precisely 90 psi. The connection to the air hose was then opened, pressurizing the air line. The grinder's valve to regulate speed was pushed completely down, allowing the compressed carbon dioxide gas to turn the rotor inside the angle grinder, and power was generated until all of the pressure from the tank was released.

Electrical Measurements: A multimeter measured current, and was wired in series. A video camera was clamped into place over the readout from the multimeter and filmed while the test was going on. The film was then reviewed in Windows Movie Maker and results were recorded in one second increments and put into a line graph. A Vernier LabQuest 2 was able to record the voltage in set increments, one data point per second, and was wired in parallel. A singular 2.5 volt/ 200 mA Christmas light bulb acted as a resistor.

Results

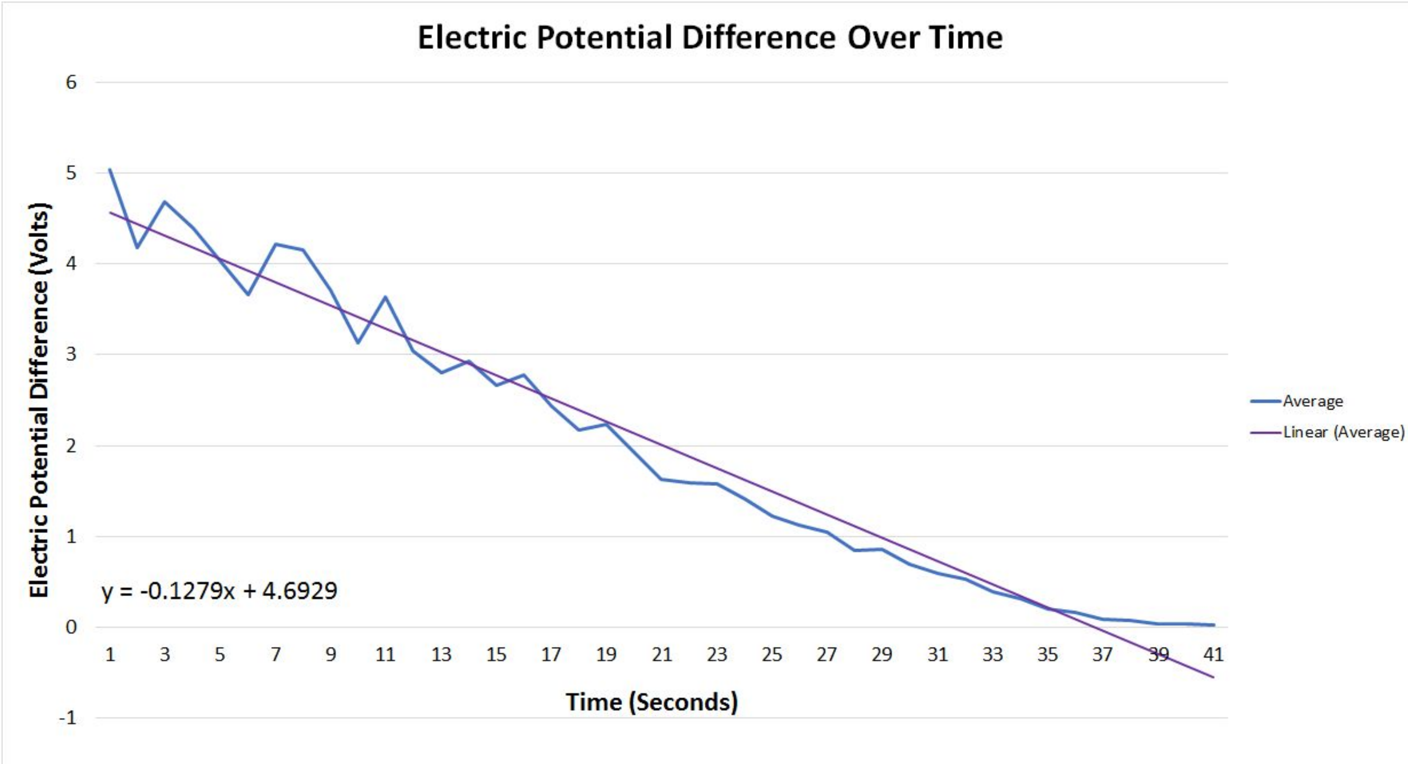
Four tests were carried out with dry ice, bringing the bead seater to 621 kPa for each. A Vernier LabQuest measured and recorded the voltage every second. The voltages were fairly consistent among the four tests.



(Figure 1: Electric potential difference over time for each of four tests.)

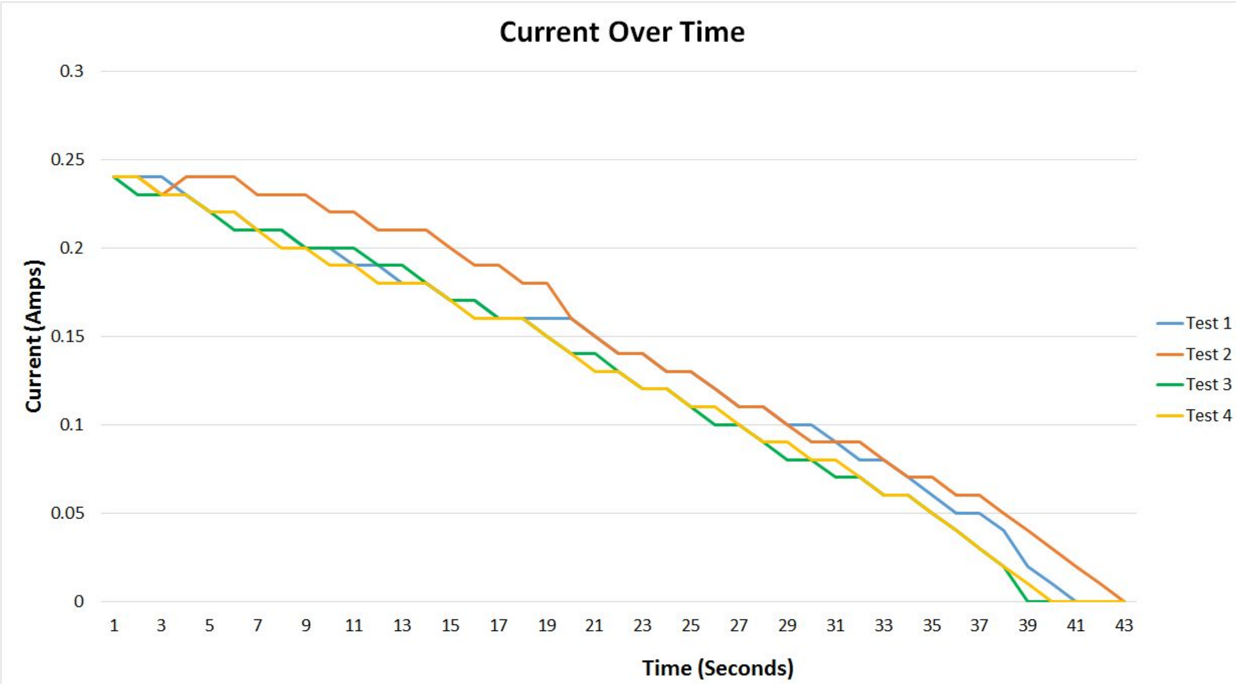
The x-axis depicts time and the y-axis displays electrical potential difference. Each of the four tests is represented by a line, all of which tending downward because the electricity production was not regulated, and for that reason the voltage reached zero very quickly.

We also averaged the voltages recorded in each test for each second, yielding Figure 2:



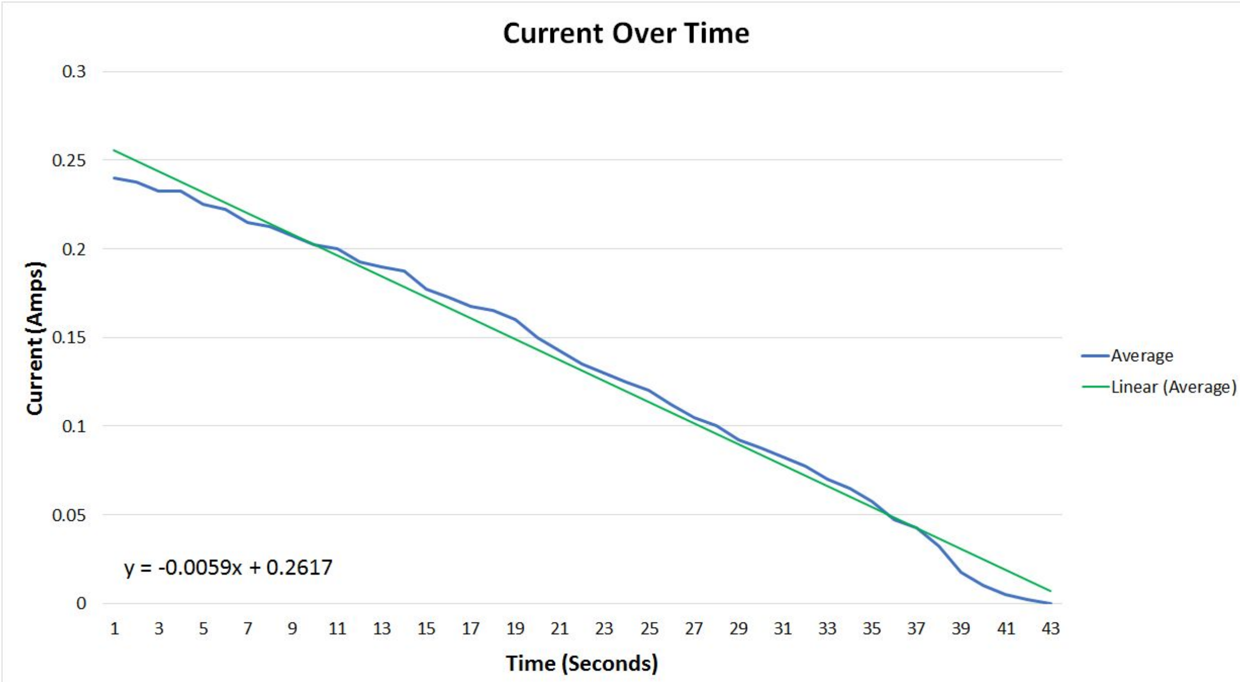
(Figure 2: Average of four tests' electrical potential differences for each second, and associated linear regression line)

A trend line was added to emphasize overall tendencies, and there was very little discrepancy between the average line and its line of best fit. The trend line had the equation y = -.1279x + 4.6929. The equation of the line of best fit had a negative slope, which corresponded to the general decrease in electrical production we expected.



(Figure 3: Current over time for each of the four tests.)

Amperage was measured with a multimeter, and recorded by a clamped camera above the multimeter. The x-axis depicts time while the y-axis displays current in amps. Each of the four lines represents one of the four tests. Though the intervals were the same, even more regularity can be observed in the amperages recorded in each test.



(Figure 4: Average of four tests' currents for each second, and associated linear regression line)

An average line and its linear regression line were added so that minute discrepancies from the overall trend were more easily ignorable. The average line also has little variation from its linear regression line, which means it is easy to predict with some accuracy the current at any point in time. The line of best fit has the equation y = -0.0059x + 0.2617.

Conclusion

Because carbon dioxide functioned adequately as a substitute for conventional gases in a pressure engine, it is now apparent, that with further research and refinement, a dry-ice-powered pressure engine has the potential to power humankind's advance on our neighbor planet, Mars, due to the vast quantities present at its poles.

Discussion and Future Work

More Convenient Methods of Measuring and Recording: In the setup it was necessary to use two measuring devices: a multimeter for amps and a LabQuest for current. The LabQuest automatically recorded the voltage at one-second intervals, but a camera had to be clamped above the multimeter to record the amperage, and the reading at each second had to be entered into a spreadsheet. This is undesirable because of the slim chance that errors may have crept in during the recording process and because discrepancies likely emerged between the times the amperage was recorded and the times the voltage was recorded. Because of the latter issue, power (current * electric potential difference) couldn't be accurately calculated for any time, because the voltage and amperage used could be seconds apart. It would have been more convenient to have one device recording both voltage and amperage to ensure that measurements didn't become slightly offset.

Engine Modifications: Several features present in the initial designs weren't implemented in the final engine. Adding an airlock, as had originally been planned, would make repeated analysis of the pressure engine's output easier by allowing extra dry ice to be added, should an amount less than intended be present in the engine. If our engine was ever implemented, it would be necessary to have the capacity to input dry ice without waiting for all of the contained pressure to release. Another potential addition is a thermometer within the tank, with the readout visible outside so that temperature wouldn't have to be assumed.

Comparison with Other Energy Sources: Output of the pressure engine could be compared to other sources used on past extraterrestrial missions, or more radical methods of generating power, such as the engine harnessing the Leidenfrost Effect (Wells, 2015).

Determining Net Gain: A necessary future step is determining whether the energy required to acquire dry ice to power the engine exceeds the energy produced by it. If it is shown that the dry-ice-powered pressure engine doesn't provide enough power to offset the collection of its fuel, methods could be designed to capture and reuse the output carbon dioxide, as it would redeposit into dry ice during the frigid Martian nights.

References

Cowen, R. (2011, May 21). Dry ice suggests recently wet mars. Science News, 179, 8. Retrieved from http://search.proquest.com/docview/868712702?accountid=14388

Curiosity Overview. NASA, 30 July 2015. Web. 17 Nov. 2015.

Jakosky, B. M., Haberle, R. M., & Arvidson, R. E. (2005). The changing picture of volatiles and climate on mars. *Science,310*(5753), 1439-40.

Leighton, R. B., Murray, Bruce C.. (1966). Behavior of Carbon Dioxide and Other Volatiles on Mars. *Science, 153*(32732), 136-144.

Malin, M. C., Caplinger, M. A., & Davis, S. D. (2001). Observational evidence for an active surface reservoir of solid carbon dioxide on mars. *Science, 294*(5549), 2146-8.

Nave, Rod. "Ideal Gas Law." Hyperphysics. Department of Physics and Astronomy of Georgia State University, n.d. Web. 20 Mar. 2016.

Mazumder, M. K., et al. "Solar panel obscuration in the dusty atmosphere of mars." *Proceedings ESA-IEEE Joint Meeting on Electrostatics*. 2003.

"Roadmap." Mars One. N.p., n.d. Web. 20 Mar. 2016. <http://www.mars-one.com/mission/roadmap/2024>.

Wells, G. G. (2015). A sublimation heat engine. Nat. Commun. 6:6390 doi: 10.1038/ncomms7390.