Sort out your source of energy and take particular care before storing it*

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What kind of energy and at what price? The guaranteed price recently agreed between the UK Government and the builders of the nuclear power station at Hinkley Point C for the electricity that it will generate was set at £92.50 per megawatt-hour. Rating energy against money over periods of time is problematic. While energy plays a role as a transient utility, money has a lasting value though not itself intrinsically useful. But why are some kinds of energy more useful than others, and how easy - and how safe - is it to make energy last by storing it somehow? Rather than just hoping that technical solutions will be developed, why not study for yourself what is scientifically possible?

When energy is *used*, it changes form and there are many of these: the readiness of objects to fall from a height; the motion of objects and their rotation; heat; light; the stretching of materials and the compression too. Over the centuries we have learnt more and acquired the technologies to manage these changes usefully: the moving water of a stream into a rotating water wheel; a falling weight into a working clock; a light weight lowered through a large distance used to raise a heavy one by a small distance with a lever.[1] We learnt to use mathematical measures to compare energy in different forms, and in the 1840s James Joule showed how heat could be incorporated in a unified energy account. Thus was born the First Law of Thermodynamics that says, *although changes may occur, the total amount of energy, mechanical plus heat, is constant (in an isolated system)*. In the following years light and electrical energy were also added. Finally nuclear energy, discovered in 1896, was included in the story. The conclusion is that the total energy remains the same when all forms of energy are taken into account,. So energy is like gold - it does not increase or disappear. Ideally then we ought to be able to store it and keep it for a rainy day. That would mean that we should not need to spend money buying energy and only need to manage what we already have.

But there is a catch. Although the *exchange rate* between different forms of energy is fixed, not all such exchanges are happy to *go.* The only ones that take place on their own are *downhill*, as it were. For example, two similar flasks of hot water at the same temperature do not become the one hotter and the other colder when left to themselves. It is the Second Law of Thermodynamics that shows which changes can go on their own and which cannot. Omitting the technical details, it is the highest concentrations of stored energy that can push their way downhill and become useful mechanical or electrical energy. For example, this puts a premium on a hydroelectric plant with the greatest height difference between the top and the bottom of the dam. Similarly an engine with the greatest temperature difference between the burning fuel and the exhaust is the most efficient - this is why diesel engines are more efficient than petrol ones.

So we should look for *concentrations* of energy, not simply for energy. Wind blowing at 30 mph has a density of 90 joules per kg, but we can find better than that. Water at the top of a dam 100 m high has an energy density of 1000 joules per kg relative to water at the bottom. But this is very small compared to the energy of a giga-watt power station. That needs as much as a *million* kg of water per second to flow down from the top to the bottom of a 100 m high hydro-electric dam. Alternatively it would need more than ten times as much air blowing at 30 mph. Coal has an energy density of up to 35 *million* joules per kg. So a gigawatt power plant needs only 30 kg of coal per second or 100 tonnes per hour. Actual efficiencies are only about 30% so the need is nearer 300 tonnes per hour. When that much coal burns, it picks up 700 tonnes of oxygen and releases 1000 tons of CO_2 per hour. But the atmosphere is quite small - only ten tonnes per square metre of the Earth's surface. It is not hard to see that this pollution should build up. The use of fuels based on carbon (coal, oil, gas and biofuels) should cease. Evidently wind turbines require more than 10

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* More is explained in two accessible books by Wade Allison: *Radiation and Reason* and *Nuclear is for Life*. Follow @*radiationreason* on Twitter. Find recent articles, videos and lectures at www.radiationandreason.com

1 See the classic book by David MacKay: *Sustainable Energy without the hot air* ISBN 978 0 9544529 3 3

million kg of air blowing at 30 mph to compete. That is a huge number of turbines and, anyway, the wind is not always blowing. If nothing with energy denser than wind were available the electricity supply would often fail.

So we need either more concentrated sources of energy or else some way of storing extra energy when it is available to provide for times when the sun does not shine or the wind stops blowing. There is no shortage of stored energy in the world but the obvious sources are not concentrated and so not useable. For example, the oceans contain a lot of water and in the tropics it is hot, but we cannot use the heat because everything else is hot too and the energy will not flow downhill. As well as being concentrated, a useful energy store should be able to release its energy quickly and efficiently. Unfortunately this adds up to a good description of a very large and effective bomb! The energy density of the explosive TNT (tri-nitro toluene) is 4.6 million joules per kg, so a TNT bomb of 1000 tonnes stores as much energy as a gigawatt power station delivers in just over an hour. This would be very dangerous but would not back-up the power station for long enough. Instead of TNT hydro-electric pumped storage systems can be used but they need large lakes in a mountainous region and these are not widely available. Because energy cannot be destroyed a safety problem arises if the stored energy needs to be dumped for any reason. This task becomes like the disposal of a very large bomb. The release of the stored energy if a large dam collapses can threaten hundreds of thousands of lives, and fatalities on such a scale have occurred.[2] [3]

Many people expect that advances battery technology should provide the solution sooner or later. A battery is basically chemical, as first shown by Faraday, and its maximum energy density can be calculated for a typical ionisation potential for the lightest ions. Current values are 0.5-0.8 million joules per kg for a lithium battery. Future increases will improve the viability of electric cars somewhat but a bank of several thousand tonnes of batteries to store giga-watts hours of energy is fundamentally unrealistic. The race to build dense batteries will become haunted by the bomb problem. Already there have been accidents with lithium batteries overheating in the Boeing Dreamliner, various mobile phones and laptops. It is quite likely that there will be further instances of fire in the development of electric cars although the media have not yet realised this.

Though no great leap forward is possible for energy storage, there is no lack of high density energy sources already developed. Present nuclear fission power could be improved marginally including the use of thorium instead of uranium as fuel [4]. but the Fukushima accident demonstrated that even a plant of old design overwhelmed by an exceptional natural accident resulted in no loss of life from radiation. The traditional fear of ionising radiation is social but the relevant biology has been fully explored [5] The energy density of nuclear fuel (if fully burnt up) is 80 tera-joules per kg. The reason for the factor of a million over and above TNT and other chemical (or battery) energy sources can be explained in a few lines of student physics, see pages 160-161 of *Nuclear is for Life*. As a result a nuclear fission plant uses less than a millionth of the fuel needed by any other power plant for the same electrical output, but it also leaves less than a millionth of the waste too. Put another way, the energy stored in one kg of nuclear fuel is the same as in 100,000 tonnes of fully charged lithium batteries. There is no merit in waiting for the next generation of fission reactors to achieve the full efficiency that they promise when a gain of nearly a million over carbon is available now. The way that many nations are currently trashing their nuclear power plants is lemming-like suicide in the face of climate change. This crowd behaviour is irrational and a denial of science.

If civilisation survives long enough, there is the promise of fusion power with density 600 tera-joules per kg. This process that powers the Sun was understood already early in the 20th Century. It has been demonstrated on Earth at the JET Laboratory and no new scientific breakthrough is

2 A dam failure in 1975 in China with the loss of 171,000 lives https://en.wikipedia.org/wiki/Banqiao_Dam

3 A recent rapid evacuation in USA due to threatened dam failure http://www.ibtimes.com/california-oroville-dam-evacuation-update-nearly-200000-people-evacuate

4 https://www.researchgate.net/publication/316167573_Nuclear_Power_for_the_Sake_of_Humanity_and_the_Environment

5 http://link.springer.com/article/10.1007/s13752-016-0244-4

required. The advances in material science needed to build a viable power reactor will be studied at the ITERE Laboratory now being built in France. However, if we are to survive the era of climate change, the most important need is a stable educated society that can trust and distinguish benign scientific truth from the ersatz science too often offered by the media as stimulating armchair entertainment.