Globally Sustainable Energy - Four Slow Paradigm Shifts
Paper for Sea of Faith Conference 2018

Summary

The sun powers the Earth's biosphere, has done for billions of years, and will do for billions to come. Our civilisation has developed in the last 5,000 years, but now has an existential dilemma due to the way we harness the sun's energy and have inadvertently been trapping too much of it.

Four paradigm shifts about energy have been slowly unfolding since the 1970s:

- Fossil solar energy needs to transition to sustainable solar energy
- Excess solar energy is being trapped by the products of burning fossil solar energy causing "global warming"
- That warming is causing temperature rise (and in turn more energetic weather events), but also sea-level rise which may be more of a threat to civilisation
- The abundance of solar energy means that the problem of (and hence solution to) global warming is more economic than technical.

This paper sets out the background to these paradigm shifts, which will continue to unfold. However the process remains slow because of societal inertia, fuelled by denial. A sustainable solar energy future will arrive, but the transition could be tempestuous and diluvian for human civilisation unless collectively decided actions effect a rapid, peaceful transition. There are some signs of hope that Generation X and the Millennials will act with more urgency than the Baby-Boomers have to date.

The Oil Crises of the 1970s

As early as the 1970s it was clear that fossil solar energy would run out one day and we need to transition to sustainable solar energy. The price of oil rose dramatically as OPEC nations exercised market power after the USA reached peak conventional oil extraction and became a major oil importer. This gave renewable energy a boost in some nations, even though prices fell away in the early 1980s and complacency replaced the urgency of the oil crises.

The Greenhouse Effect made headlines in 1988

Excess solar energy is being trapped by the products of burning fossil solar energy causing "global warming". This enhanced greenhouse effect had been predicted in the 19th century, but only hit the headlines in 1988. Back then atmospheric carbon dioxide (CO2) was 350 parts per million (ppm), now it is 400. This has not been natural for many epochs. For a million years, 200 to 300 ppm have been the norm, while Sapiens has taken over, an even narrower range around 280 ppm in the last ten thousand years, when stable climate has allowed civilisation to develop.

So Earth's energy balance has been disturbed. The sun pours 178,000 terawatts (TW) on Earth, and 178,000 normally leaves. For millennia the net gain has averaged zero. Since 1900 it has grown to 400 TW. Global warming's 400 dwarfs the 30 TW used by humanity, a rate itself many million times faster than some biofuel has fossilized over a billion years. Some 'good news' here arises from the fact that the solar resource (178,000 TW) is about 5,000 times humanity's needs.

In 1989 a Scientific American article on the "Greenhouse Effect" stated that "Estimated reserves of recoverable fossil fuels in themselves are enough to increase the atmospheric concentration of carbon dioxide by a factor of from five to 10." In other words we have to stop burning fossil fuels long before they run out, because that would take CO_2 to between 1500 and 3000 ppm.

The Ice is Melting

400 TW of global warming is mainly being taken up by the oceans, causing temperature rise (and in turn more energetic weather events), but also sea-level rise due to ice-melting which may be more of a threat to civilisation. Not much global warming has been going into the ice, but in future the ice will take it more. Melting ice takes a lot of energy: local temperature doesn't change but for one kilogram, the energy is enough to raise a kilogram of water's temperature by eighty degrees Celsius, or reduce eighty kilograms' by one. So ice-melting could happen instead of significant further temperature rise.

As a result large sea level rise may be more of a threat in the 21st century (at least to coastal cities) than large temperature rise. A way to express this point graphically is with a shaded chart showing what global warming (being the rate of thermal energy accumulation, in terawatts, TW) breaks down into:

Global Warming (Net Response to Extra GHGs – not to scale)

Latent Warming (Ice-melt, no temperature rise)	Sensible Warming (Temperature Rise)	
Floating Ice (no sea-level rise)	Ocean	Air (including GMST)
Land-based Ice (sea-level rise)		

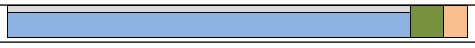
Global Warming 1900-2025

Quarter Century		GMST (°C)	Sea-level rise (m)
1900-1925		13.6	0.02
1925-1950		13.7	0.05
1950-1975		13.9	0.09
1975-2000		14.2	0.15
2000-2025		14.5	0.23

Using the same colour key as above, the following chart is indicatively scaled to show that mainly ocean warming has taken place in the four quarters of the 20th Century and in the first quarter of the 21st Century. The bars are also indicatively scaled to the changing rate of global warming (note that the CO_2 concentration drives the amount of warming, hence the bars for the early 20th century are a lot smaller). At the right of each bar is the resulting approximate value of GMST, based on a 19th Century value being estimated at 13.5°C, and sea-level relative to the 19th Century.

The next chart illustrates what could happen in the 21st Century, now that the air and ocean have warmed up a bit, if this is sufficient to drive rapid ice break-up from Greenland and West Antarctica. A simplifying assumption is that the net global warming (~400 TW) somehow remains constant. Note that this is for illustrative purposes

Global Warming 2000-2100?

Quarter Century		GMST (°C)	Sea-level (m)
2000-2025		14.5	0.23
2025-2050		14.6	0.75
2050-2075		14.7	1.75
2075-2100		14.8	3+

only. Predicting the TW requires knowing the non-equilibrium combination of CO_2 concentrations (which "force"

the warming), and GMST, ice-melt and the other response functions, requiring models which are beyond this author's expertise, and arguably remains an elusive goal of the best climate models.

At 14.8°C, GMST would have only risen 1.3°C since 1900, illustrating how a 2°C or even 1.5°C limit may not protect us from sea-level rise that we have now "locked in" for subsequent centuries, even if not as rapid in the 21st century as indicated above. This would be very costly for countries like New Zealand that are highly urbanised around the coast.

Urgent and radical action is needed in any event, with focus needed on parameters other than GMST; being CO_2 concentrations, TW of warming and metres of sea-level rise. These may become decoupled from GMST (°C) because ice-melting occurs at constant temperature.

Solar Energy is abundant - the Problem and Solution are Economic

The abundance of solar energy means that the problem of (and hence solution to) global warming is more economic than technical.

Global warming is an economic problem. We use fossil fuels because they seem low-cost, and the energy released by oxidising their carbon and hydrogen has powered 300 years of human industry. Fossil fuels are solar energy stored over hundreds of millions of years that we are burning in hundreds, a million times faster than they can be sustained. They provide a massive bank account, whose principal we deplete and, in so doing, return the atmosphere toward its Paleozoic state. The technical solution is to use sustainable solar energy: direct solar, wind, hydro and biofuels (the latter two providing storage). It is an abundant resource: the sun pours 178,000 TW on Earth 24 hours a day, 365¼ days a year, more than 5,000 times more than humanity "uses", or more accurately "converts more or less wastefully to low-grade heat" before Earth re-radiates it to space.

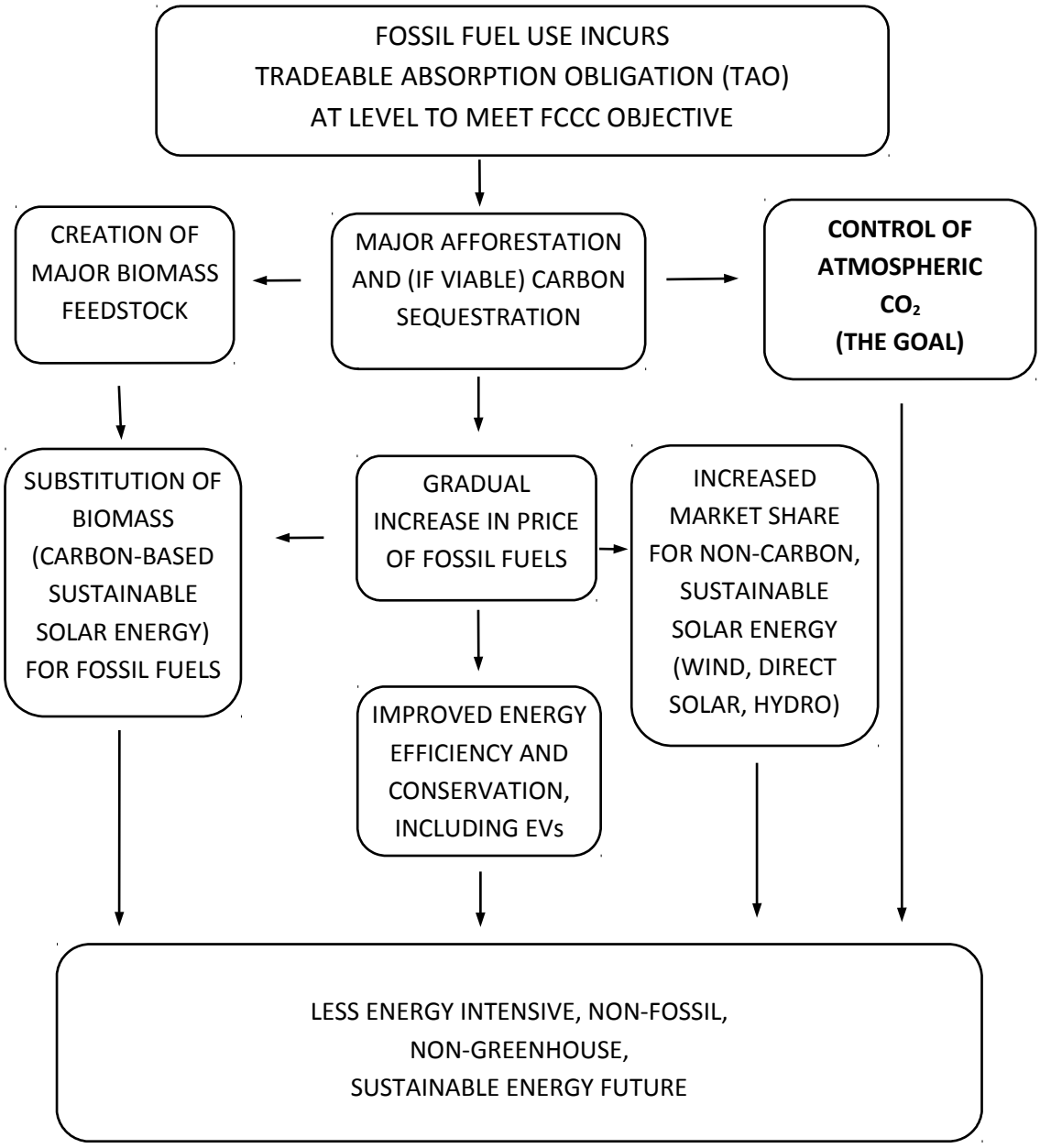
With such abundance, five billion times the rate that solar becomes fossil energy, why do we use fossil solar instead of sustainable solar? I'll say it again – because the fossil solar seems cheaper. More than that, fossil solar is cheaper in the short term, because nobody has to pay the cost of harnessing the solar energy and storing it in a conveniently dense form. Sustainable solar having to compete with fossil solar is like an honest beekeeper having to sell honey in a market where you can buy stolen honey: the stolen honey will always be cheaper. Until one notices that the stolen honey causes long-term problems and the market regulator steps in to level the playing field by internalising those problems. To burn fossil fuels without absorbing their emissions is to free-ride at the expense of the climate security of future generations. This is the economic problem of global warming: how to regulate the market so that long-term costs are properly accounted for, or in the parlance "externalities are internalised" so as to avoid a "tragedy of the commons".

The economic solution to this economic problem is to ensure the polluter pays to absorb emissions, which will create a level playing field for the "honest beekeepers", the sustainable solar businesses. Zero-net emissions needs to compete with zero-net emissions. This idea has had many names since 1988: my favourite name is the one given by Prof. Peter Read, the Tradeable Absorption Obligation or TAO.

The TAO will push everything in the right direction. First it will cause major afforestation and (if viable) other forms of carbon sequestration. In turn that will cause three things to happen: atmospheric CO_2 levels will actually be controlled (which is the most urgent and important overall goal); a large biomass feedstock will be created (which will be able to be substituted for fossil fuels); and the price of fossil fuels will gradually, but faster and faster, increase by the Law of Supply and Demand. The increasing price of fossil fuels will also cause two things to happen: it will increase the market share for sustainable solar energy, both carbon-based (biomass) and non–

carbon forms (wind, direct solar and hydro), and it will stimulate energy efficiency and conservation. Overall these responses will lead to a less energy intensive, non-fossil, non-greenhouse, sustainable energy future.

In summary, regulation so that the polluter pays the cost of achieving zero-net emissions, by the TAO or by any other name, will provide a least-cost, durable transition to a future of stable climate and sustainable energy. Its foundational rationale is as simple as the duty to clean up one's mess, not leave it for others, especially our children and grandchildren, to have to clean up.



The TAO pushes everything in the right direction.

Action has been slowed by Denial

Climate denial uses uncertainty about climate modelling to justify international inaction on reversing emission trends. This is not a respectable position. Uncertainty over climate outcomes from 400 terawatts of energy imbalance is an argument for action, not inaction. Uncertainty means different scenarios are possible in the 21st century. Proper risk analysis requires the full range of probabilities to be considered. The outcomes (rationally) must be some measure of cost:benefit ratio, the cost of inaction versus the benefit of inaction to the economy. The probabilities (rationally) must add to 100%.

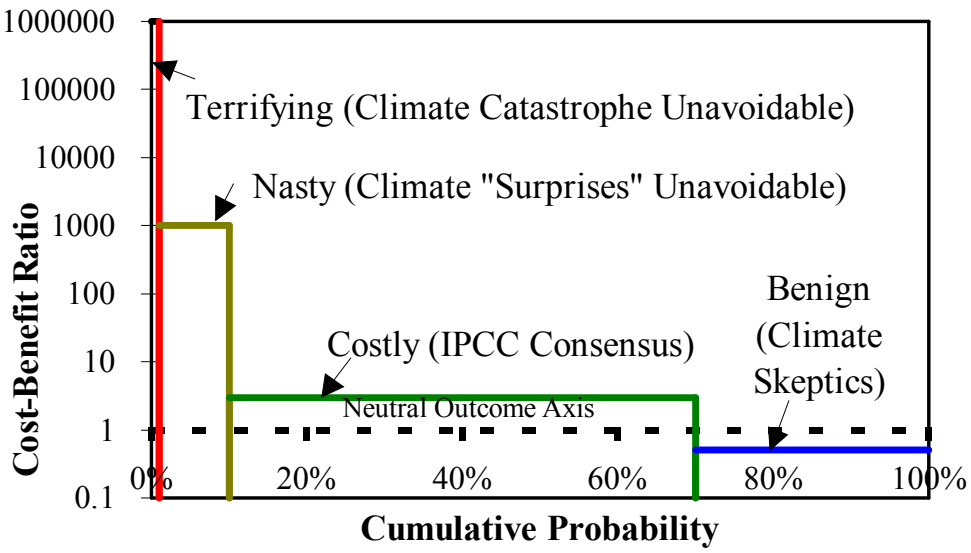
The fallacy of climate denial is that it assumes only a benign scenario. Another common, related fallacy, is that action is macro-economically costly. But creating new industries will offset the phase-out of old industries. We didn't leave the Stone Age 'cos we ran out of stones. We won't leave the Fossil Age 'cos we're running out of fossils.

Will we do the right thing?

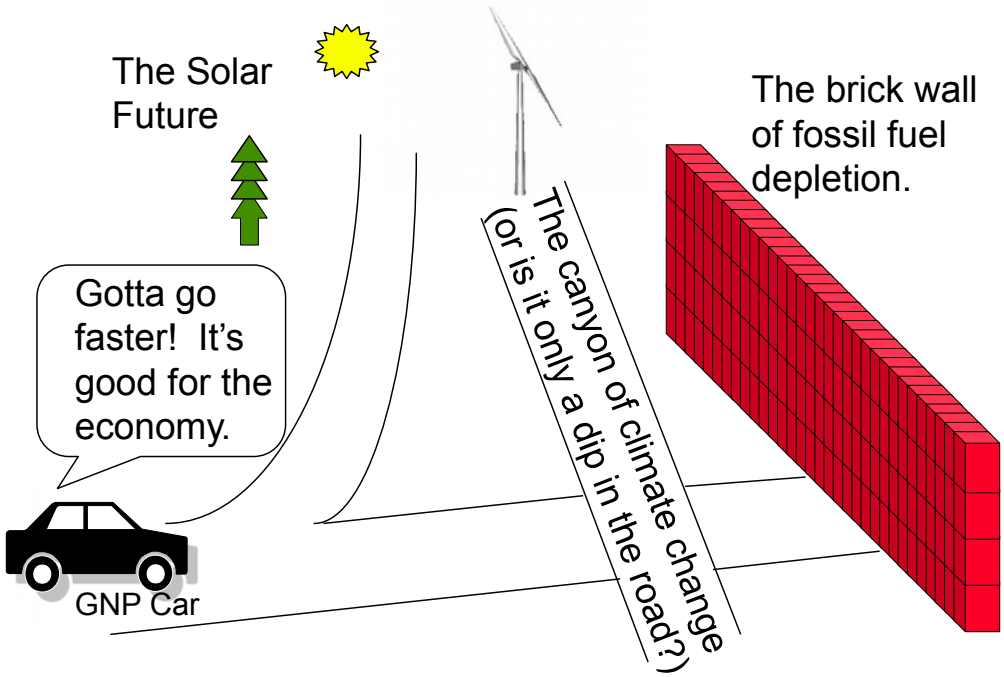
As Churchill famously said of the Americans, people (not just the Yanks) can be relied on to do the right thing "but only after they have exhausted every other possibility". A sustainable solar energy future will arrive, but the transition could be tempestuous and diluvian for human civilisation unless collectively decided actions effect a rapid, peaceful transition. There are some signs of hope that Generation X and the Millennials will act with more urgency than the Baby-Boomers have to date. Our prime minister has called it the "nuclear issue of her generation".

We have the technologies, we have an abundant solar resource, enough to power and feed 10 billion people. Over the next few decades we need to price fossil fuels out of the market. If today's politicians show resolve and urgency, and if they can ignore the ongoing resistance of those who want the "easy" path of fossil fuels and an infinite planet, it can be done. Otherwise the three "riders of the apocalypse" (or four if you need to believe in gods of good and evil) will have their day. As James Lovelock has pointed out, our planet is a self-regulating system. In one of his books he explains that plants enjoy warmer, wetter conditions than animals do, so the ice-age cycle can be seen as a long-period oscillation between two equilibria that alternately favour the plant and animal kingdoms. In this paradigm, the three riders become part of the well-exercised tools of Gaia to shift from one equilibrium to another, not to mention the odd flood of "Biblical" proportions.

No-one can predict the future, but I hope humanity (in "exhausting every other possibility") discovers the wisdom to avoid the harsh lessons of rapid sea-level rise, war, pestilence and famine. One can only try to think globally, act locally.



Atmospheric Carbon Dioxide >450 ppm by 2100: Possible Outcomes from Inaction



Sums it up really ….

Bibliography/Suggested Further Reading and Viewing

1998 Papers by Geoff Henderson:

https://www.windflow.co.nz/news/published-papers/Economic_Climate_Change_Solution.pdf/view

https://www.windflow.co.nz/news/published-papers/Fallacy_of_Climate_Skepticism.pdf/view

"The Man who planted Trees" – a 30-minute video animation of Jean Giono's inspirational story:
https://www.youtube.com/watch?v=KTvYh8ar3tc

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Pearce D., Markyanda A. and Barbier E.B. (1989). "*Blueprint for a Green Economy*." Earthscan Publications Ltd, London.

Read P. (1994). "*Responding to Global Warming: The Technology, Economics and Politics of Sustainable Energy.*" Zed Books Ltd, London.

Falconer W. (1996). "*Climate Change and CO_2 Policy: A Durable Response."* the Discussion Document of the Working Group on CO_2 Policy, Ministry for the Environment, Wellington.

James Hansen's web-site and magnum opus, "*Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous":*

http://www.columbia.edu/~jeh1/

https://www.atmos-chem-phys.net/16/3761/2016/

Dr Kevin Trenberth (National Center for Atmospheric Research, Colorado) web-site and video, "*Extreme Weather and the Changing Climate":*

http://www.cgd.ucar.edu/staff/trenbert/

http://www.cgd.ucar.edu/staff/trenbert/Presentations/Trenberth_Steamboat_Jan18.pptx

Professor Jennifer Francis (Rutgers University, New Jersey) web-site and video, "*Crazy Weather and the Arctic Meltdown: how are they connected?":*
https://www.jenniferafrancis.com/
https://www.youtube.com/watch?v=wtmuBoolHQg

Professor Paul Beckwith (University of Ottawa) web-site and video, "*Zero Arctic Sea-Ice by 2020?":*
https://paulbeckwith.net/
https://www.youtube.com/watch?v=ezdiqPEDXKE

The Black Sea deluge hypothesis - how rapid ice-melt in North America 8,000 years ago filled the Black Sea:
https://en.wikipedia.org/wiki/Black_Sea_deluge_hypothesis
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5840179/