Geoff Henderson

7 July 2018

Ministry for the Environment
PO Box 10362
WELLINGTON 6143

Dear Sirs,

Submission on the June 2018 Discussion Document "Our Climate Your Say"

I am Managing Director of Windflow Technology Ltd, which has established local manufacturing of innovative, synchronous wind turbines that have been installed in New Zealand and Scotland. I am a registered mechanical engineer in New Zealand and California, a Fellow of Engineers NZ and a life member of the NZ Wind Energy Association. I am making this submission as an individual.

My commitment to wind power for New Zealand dates back to 1976 when I returned to Christchurch from Australia as an 18-year old to study at Canterbury University. I have worked in wind power since travelling to California in 1984 then moving on to London in 1986. After working overseas in the wind industry for seven years, I returned again to Christchurch in 1991.

Since then I have worked continuously to establish Windflow Technology Ltd, raising over $150 million to build several companies and 106 turbines (53 MW total) between 2001 and 2016. Very little of this funding has come from the New Zealand government or SOEs, who have bought turbines from Denmark to date. Windflow turbines have been technically successful but the companies have been commercially challenged primarily because of inconsistent pricing and policy signals in New Zealand and Britain. A level-playing field for renewable energy would be zero-net vs zero-net emissions, but for 26 years since the FCCC and the RMA, procrastination has ruled, to the detriment of our efforts to "do the right thing".

My submission is in respect of "getting emissions trading right" and is simply that:

- **Users/wholesale providers of fossil fuels (and other sources of GHG emissions) need to bear the cost of absorbing CO_2.**

The late Professor Peter Read called this economic instrument the tradeable absorption obligation (TAO), a name which sums up the concept very well. Government should set the allowed quantum of net emissions each year and administer the system for trading the obligations (equivalent to emission permits and absorption credits). Other complementary measures should be adopted as appropriate (especially while the cap on net emissions is allowed to be greater than zero), but nothing else will be as effective as the TAO at:

- Absorbing CO_2 so as to control atmospheric GHG concentrations now and into the future,
- Incentivising long-term investments in energy efficiency and renewable energy (direct solar, wind, hydro, and biofuels),
- Incentivising the fossil fuel industry to make the transition to sustainable biofuel production, and
- Minimising the cost of achieving any required trajectory for net GHG emissions.

I enclose a 15 page summary of my thoughts on global warming. Centred on three 1-page "statements", this document sets out the intellectual contributions I believe I can make to this global issue, including the science, which I have not previously presumed to address, and understand is outside your scope of work, but I include it for your interest. In particular I urge the New Zealand government to consider carefully the work of Dr James Hansen whose paleo-climate expertise leads him to conclude that 350 ppm is the safe value. His magnum opus paper of 2015 flags the prospect of multi-meter sea level rise this century and that 1.5° or 2°C is not (in his phrase) a "safe guardrail". Global warming is an issue of energy gain, and temperature is the wrong parameter to be tracking. With my engineering thermodynamics background, I feel compelled to try to translate this science (as best I can) into a few hundred words and some graphs.

But I would draw your attention to pages 9-14 of the attached which focus on the TAO. Whether you adopt this name or not, New Zealand's ETS is well-suited to being strengthened and clarified in terms of the principle of "polluter-pays to absorb". In terms of specific comments on your Discussion Document and the proposed Zero Carbon Bill, I am generally supportive but (as mentioned above) remain impatient to see real action, 26 years after the FCCC was signed.

In particular, I would make the following specific submissions:

1. The target should be zero net GHG emissions (all gases) by 2050. The FCCC and the Paris Agreement were framed in terms of achieving zero net GHG emissions, and there are internationally agreed ways of converting between the different gases to reflect their time-weighted greenhouse effect. Of course, as the international science progresses and these conversion factors are revised from time to time, New Zealand should adopt these amendments in line with the global community. But New Zealand should not embarrass itself by being economically disingenuous about the need for all sectors of the economy to take responsibility for their emissions. Most nations can claim, as validly (or not) as New Zealand can, that GHG emissions are key to their economy. We need to do better than fall into the logical trap of equating "business-as-usual" (BAU) with the economy of the future.
2. The Zero Carbon Bill should set the "what" to the ETS's "how". That is, the Zero Carbon Bill should set the targets (both the end target and intermediate stepping stones) while the ETS (or its successor legislation) should set out the principle method for achieving any particular net emissions target. Note that the "T" in ETS (or TAO) is an acknowledgement that tradeability is the key to cost-minimisation, which in turn will be the key to long-term acceptance by the private sector (both progressive and BAU elements) and thus long-term durability.
3. Specifically the Zero Carbon Bill should set the target of zero net emissions by 2050, and a straight-line decline from 2020 (or the Bill's enactment date). Thus if NZ's net GHG emissions in 2020 are 60 Mt/yr CO_2-equivalent, the Zero Carbon Act should require that to reduce by 2 Mt/yr/yr. Whether this is structured as an annual decrement or at 5-year intervals (as 10 Mt/yr decrements) is a matter of detail which officials are perhaps best to advise on.

   On the related question of counting absorption credits from afforestation, there is a logic in "softening the transition" by allowing forward banking of these. In other words, the actual absorption need not happen in the year a forest is established: provided the credit is accompanied by binding commitments to see the new forest through to maturity. But New Zealand is, I believe, well versed in this kind of carbon accounting by now. As with financial accounting, care needs to be taken to eliminate scams and double-counting. Probably this sort of issue should be addressed (if it is not already) in the ETS.
4. Political durability is an essential aspect of the Zero Carbon Bill. Thus it will be commendable if the Opposition is fully involved in good faith consultation on the Bill. I would submit that strong **scientific integrity** and **economic responsibility** be the watchwords to ensure long-term durability. By this I mean that:
   a. the drafters must keep the focus firmly on achieving net GHG emissions targets. For example, an important fact about conservation forestry needs to be addressed which is that a conservation forest reaches equilibrium and stops absorbing CO_2. The energy cycle within it is useful thereafter to the plants and animals (vertebrate and invertebrate) within it, but no use to humanity at that point. In terms of the language of "sinks", it becomes like a kitchen sink with no outlet pipe, good for one use but no more. Those particular hectares can no longer help humanity's efforts to close the carbon-energy cycle – they yield no kilowatts per hectare thereafter. By contrast a production forest for biofuel is more like a carbon/energy "sponge" which can be wrung out and re-used rotation after rotation, averaging about 5 kW/ha for the long term. I believe the environmentally responsible approach will be to prevent conversion/deforestation of existing conservation forests (including national parks of course), and to maximise plantation forestry of production species on land selected for afforestation to provide carbon offsets.

b. concepts like "polluter-pays", "eliminating free-riders" and even "picking up after oneself like a good tidy Kiwi" should be embodied in this Bill so as to appeal to the best in our national self-image. A significant role of the Climate Commission (which should be funded appropriately) should be public education including TV advertisements in the same way that government departments have funded TV campaigns on seat-belt wearing, drink-driving etc.

5. Taxpayer funding of afforestation (eg the "billion trees" target) should be minimised. It is essential for political durability and long-term effectiveness that the emitters fund afforestation and the creation of other biomass feedstocks. For example, this will incentivise the fossil fuel industry to make the transition to different forms of industrial scale organic chemistry than the petro-chemical industry they have such expertise in. The impact on their balance sheets of having to leave fossil fuels in the ground is one of the biggest political impediments to moving those companies beyond lip service. The TAO (or ETS with forestry offsets) will put something else on their balance sheets that can be "banked" as a resource in future decades.

As a related point, in the case of forestry that is funded by the private sector (whether that be fossil fuel companies, farmers or other investors), decision-makers need to learn the lesson of the mistake made by the previous Labour Government, whereby they convinced themselves that Treasury owns the forestry credits, thus alienating the land-owners and foresters who truly owned them and set about proving that with chainsaws. Yes, carbon credits can be separated from the wood itself as an asset. No, the ownership of the carbon credits cannot rightly be appropriated away from the owner of the trees, other than by a fair, transparent and well-regulated trading system.

I trust that the rationale for my submission is clear, but if you need me to enlarge on any of these points, I would be happy to do so.

Addressing this issue will require a strong macro-economic vision that will not be swayed by the tropes and platitudes of BAU thinking. That will require great leadership, communication skills and ability to bring the people with them. As your Discussion Document says, "the transition will need to be deep and broad." New Zealand can do this. If we can't, the future for global civilisation is bleak.

One statement I would take issue with is that "the year 2050 is a long way away". Yes a lot has changed with the internet since 1988 thirty years ago, but unfortunately too little has changed with climate policy. I wrote my first submissions on climate policy in 1988 (the old-fashioned way, by airmail to Wellington from London, in the year that Margaret Thatcher, addressing the Royal Society, said "we have unwittingly begun a massive experiment with the system of this planet itself… the increase in the greenhouse gases…").

My career in wind power (34 years so far) is longer than the time remaining till 2050, a year when (if still around) this 60-year old will be 92. The Prime Minister's new daughter (to pick a symbol of the next generation) will be 32, at the height of her creative powers and coming into full maturity in whatever career path finds her. 2050 is not that far away, and we need to get cracking!

I believe this new government has the visionary leadership to get this message across and bring New Zealanders with them through this "nuclear-free moment". I wish the government well and have taken the liberty of copying this submission to Ministers James Shaw and David Parker with my best wishes.

Yours sincerely,

G M Henderson

Cc: Minister for Climate Change James Shaw
Minister for the Environment David Parker

Three Statements on Global Warming:

Science of Ice Melting, Fallacy of Denial and the Economic Solution

Background: I wrote two papers in 1998, about the fallacy of scepticism (denial) and the logical solution to climate change/global warming. These summarised what I had been saying and writing since 1988, that we can and should act to minimise climate disruption, and phase out fossil fuels (as we must inevitably, but shouldn't risk waiting for depletion to force us to). Given the abundance and proven status of sustainable solar energy (direct solar, wind, hydro and biofuels), the problem is clearly economic, not technical. We choose to burn fossil fuels because they seem cheaper. Therefore the solution must be economic, and the polluter-pays-principle leads one logically to Prof. Peter Read's TAO (tradeable absorption obligation).

The early 90s seemed hopeful that this message would be picked up globally and in NZ. Some landmark events:

- 1992: the United Nations Framework Convention on Climate Change (FCCC) and New Zealand's Resource Management Act (RMA)
- 1994: the Stratford hearings recommended the 400 MW Taranaki Combined Cycle (TCC) station go ahead only if they accepted a tree-planting obligation at 100% mitigation (but Minister Upton emasculated that recommendation and no trees have been paid for by TCC)
- 1997: the Kyoto Protocol, which clarified the "gross vs net" issue from the FCCC.

Since then two more decades have come and gone with little progress except the Kyoto Protocol achieved its limited aim among some developed nations (proof of concept, including afforestation as a mitigation measure being valued by nascent carbon markets) and inadvertently accelerated the development of the developing nations (carbon leakage, writ large). Paris 2015 was a sunny day in December, but still, we have the grotesque spectacle of powerful people appealing to society at large by promising that global warming is a hoax.

So I have added a statement about the science of global warming, being my attempt at a "zeroth" paper to act as a prequel to the other two. It provides this engineer's understanding of the science, based on undergraduate engineering thermodynamics and astronomy, combined with general reading over the years. That understanding is necessarily incomplete about the future (like everyone's) and cannot claim professional climate science expertise, but is perhaps better than average. Importantly it is informed by a professional engineer's appreciation of risk and probability.

All three statements herein are as accurate as I can make it, while staying within a limit of one page per statement (in the interests of brevity). However the word "isothermal" needs more explanation.

The first statement on the science uses the term "isothermal warming" in two senses. "Isothermal" applied to heat transfer processes means heat transfer that occurs across a zero temperature difference. While it is a theoretical ideal that mathematically requires infinite area across which the heat is transferring, it is an everyday reality that occurs at the phase boundary in any process where substances change state (e.g. water boiling to steam, refrigerants evaporating and condensing, and ice melting to water). Engineers thus use the term for system processes which involve circulating fluids which change state as they circulate.

The first statement, which is very much about ice melting, extends this idea to describe as "isothermal" how global warming, seen over a decadal time scale, could be an almost constant temperature process, rather than the relentless upwards trend of the thermometer. It is not sufficiently appreciated that ice melting and sea level rise could dominate in the 21st century, with further temperature rises (as measured by the atmosphere's global mean surface temperature - GMST) being relatively muted.

It seems plausible that GMST could stabilise temporarily in coming decades in a scenario where:

- Ice melting and sea-level rise take off exponentially
- Viewed on a decadal time scale, global warming will appear "isothermal" in the sense that I use the word
- Policy decisions based on a target to stabilise GMST will seem very foolish retrospectively.

Having said that, I would stress that currently only around 5% of net warming is going into ice melting. In future this could increase many times, and my purpose is to explain how and why it could, not to assert any certainty that it will.

In any event, it needs to be borne in mind that my use of the term "isothermal" is an engineering approximation in the context of an averaging period for which, as with the question of GMST rise, decade-long or longer average changes in the parameter (% of net global warming going into ice-melting) are most appropriate. For example, the third and fourth graphs below statement 1 illustrate how temperature could go up and down depending on how quickly the ice melts. In the third graph two points that are 300 years apart have the same temperature but sea level is 23 metres higher. One might say that represents 300 years of isothermal warming, although temperature is always changing during that time. Similarly in the fourth graph two points that are 70 years apart have the same temperature but sea level is 6 metres higher.

In the way that idealised processes (especially those that approximate natural processes) can be useful to our understanding, it is useful to ask "what if it were 100% isothermal", "what would it look like if it were significantly isothermal[1]", "could it become more so" and "could it approach or temporarily exceed[2] 100%". Engineering thermodynamics emphasises the efficiency of isothermal heat transfer, making it a preferred outcome for heat flows if the geometry allows and temperature and pressure are right for a phase change to occur.

The important message is to explain how large sea level rise may be more of a threat in the 21st century (at least to coastal cities) than large temperature rise. I hope these pages help to explain

[1] Melting ice in a pot on a stove is significantly, but not completely, isothermal. The temperature of the water does not stay perfectly at 0°C, but goes up and down depending on how well it is mixed with the ice, how close the thermometer is to a piece of ice, and how much ice remains to be melted. But the resulting graph of temperature versus time is much closer to a horizontal line while the ice is melting, than it is subsequently when all the ice has melted and the water can then heat up linearly towards boiling point. Similar things may happen to the planetary temperature-time trace as the oceans slowly heat and ice-melt rates vary up and down around an accelerating trend line. **The slope of the temperature-time trace will be lower than what it would be in an ice-free planet.**

[2] Temporarily exceeding 100% is quite possible in principle. As an example, a "thermal bank account" of (say) five decades of 90% of the 400 TW going into ocean temperature, could suddenly be drawn down if very large amounts of formerly land-based, now floating ice, melt over one decade. If only a third of that "thermal bank account" were withdrawn, it would be 150% of the net global warming for that decade and would result in global ocean temperature reducing temporarily, though not to current levels. It would take a 10-fold or 20-fold increase in the water-ice area interface for ice-melting to account for 100% of net global warming, how much weight do we attach to news reports (around a large iceberg off Newfoundland) that iceberg counts in Atlantic sea-lanes in April 2017 were about six times the average for April? A sign of things to come?

how atmospheric temperature and sea level are to some extent interchangeable threats of global warming. The atmosphere may not warm this century as much as the IPCC is saying, but if so it will be because ice is melting and sea level is rising. And conversely sea level may not rise this century as much as Jim Hansen is saying, but if so it will be because the energy is all going into temperature rise and hasn't yet soaked through to the ice. And in either case, there could be temperature pauses while ice-melting dominates for a while. As the little poem on the next page says, "ice has no agenda – it just melts".

Another 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

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 13.5ºC, and sea-level relative to the 19th Century.

Global Warming 1900-2025

Quarter Century		GMST (ºC)	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

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 (as the great scientist, James Hansen, maintains) 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 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.

Global Warming 2000-2100?

Quarter Century		GMST (ºC)	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+

At 14.8ºC, GMST would have only risen 1.3ºC since 1900, illustrating how a 2ºC or even 1.5ºC 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 (ºC) because ice-melting is an isothermal process.

Structure of this Document: With the background and its explanation of how the word "isothermal" is used in Statement 1 behind us, the rest of this 15-page document consists of:

- A very brief poem about ice (below) to introduce Statement 1
- Three 1-page statements, each accompanied by a page of illustrations, so 6 pages total
- 4 pages of frequently asked questions about Statement 3, the Economic Solution
- 1 page of bibliography/suggested further reading and viewing.

Every sentence is as accurate as I can make it. I chose 1-page statements in the interests of brevity. If anyone finds an error of logic or fact, please let me know.

Geoff Henderson, July 2018

Ice has no agenda – it just melts.

Ice asks no questions, presents no arguments, reads no newspapers, listens to no debates.
It's not burdened by ideology, and carries no political baggage
as it crosses the threshold from solid to liquid.
It just melts.

Dr Henry Pollack
Emeritus Professor of Geophysics, University of Michigan
Author of "A World without Ice", 2009
https://www.youtube.com/watch?v=ZY-pO_zTVvU

1. Climate Science: Warming = Heat Transfer, Ice Melts and Temperature Barely Changes

400 parts carbon dioxide per million has not been natural for many epochs. For a million years, 200 to 300 parts per million have been the norm, while Sapiens has taken over, an even narrower range in the last ten thousand, when stable climate has allowed civilisation to develop. So Earth's energy balance has been disturbed. The sun pours 178,000 terawatts on Earth, and 178,000 normally leaves. For millennia the net gain has averaged zero. Since 1900 it has grown to 400 terawatts. Global warming's 400 dwarfs the 30 terawatts used by humanity (a rate itself many million times faster than some biofuel has fossilized over a billion years).
How then is the warming not sensible, and so many people not sensible to it?

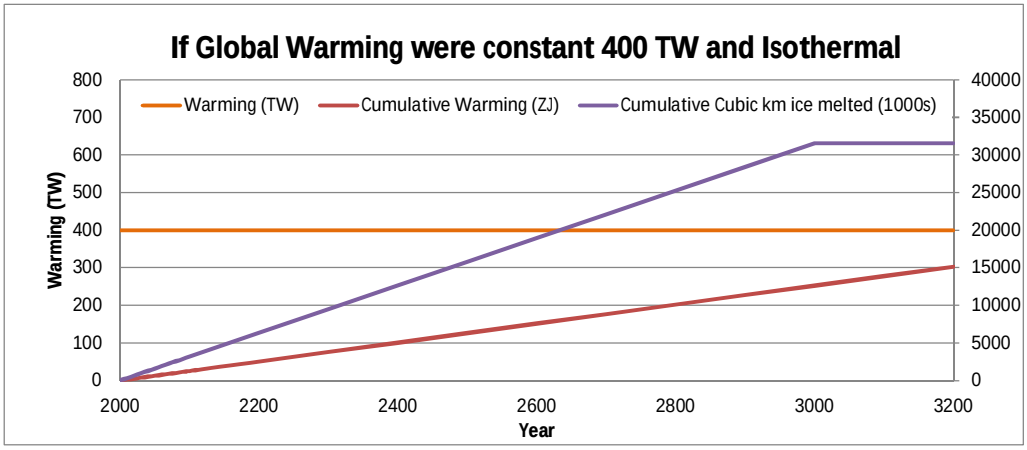
"Warming", "heating", "cooling" are words about energy, not necessarily temperature. The oceans keep the air cool, and the ice keeps them both cool while melting isothermally. The 400 terawatts is mainly being taken up by the oceans. Were global warming all isothermal, (in part it is), it would always all go to the ice. To date it's a small part, in future the ice will take it more. And 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 zero Celsius is a dynamic attractor at some latitudes.

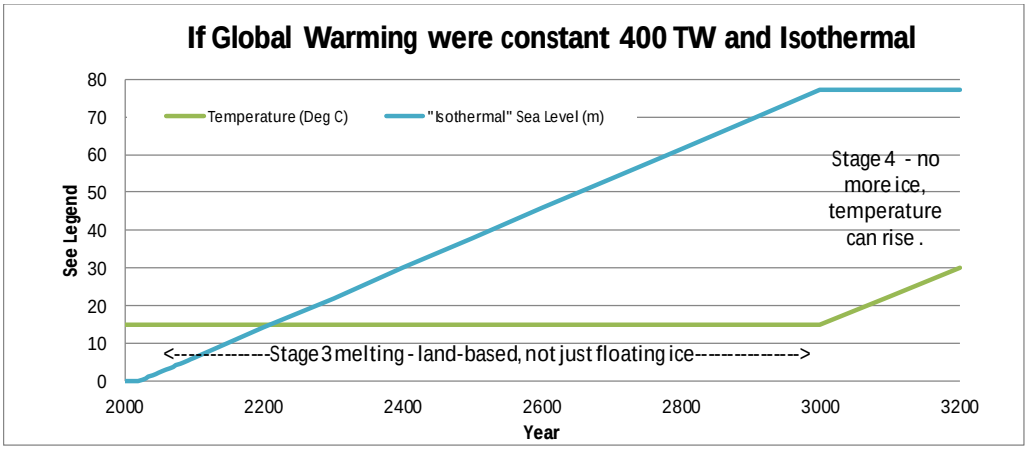
Isothermal warming of Earth would have four stages: 1) it would require a small temperature rise to get it started; 2) only floating ice would melt, while temperature and sea level would barely change; 3) the land-based ice would also melt, temperature would barely change, sea level would increase eighty metres; 4) with all ice gone, the warming no more isothermal, the world Jurassic again, temperature would ramp up more quickly – like the esky when the ice pads have thawed. The 20th century's warming has been a lot like stages one and two. Any wonder we find pauses in temperature and argue about millimetre measurements on tide gauges? Are we now moving into stage three as the 20th century has become the 21st?

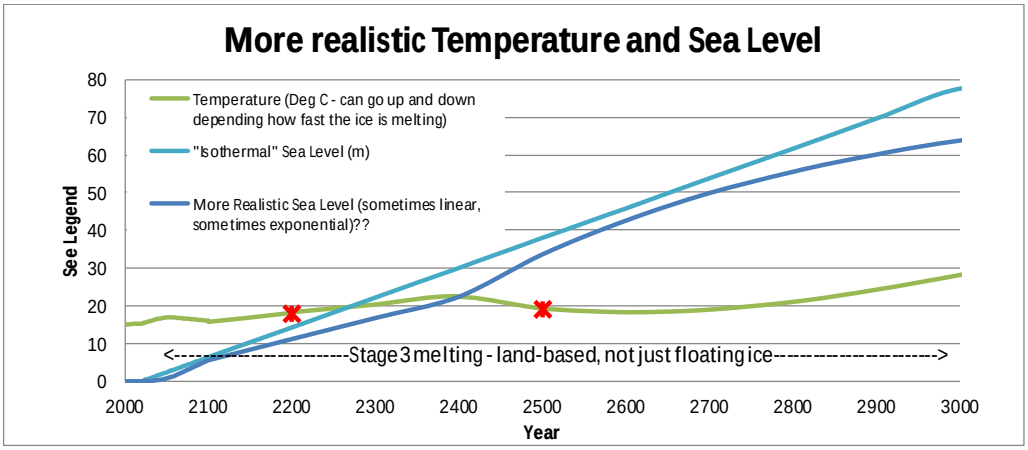
The planet, an oblique, orbiting rotisserie, mixes the heat around better than the atmosphere and oceans (each a millimetre deep for every metre across) could otherwise. Large ice shelves and bits of ice sheets melt and refreeze each year. How much then is global warming isothermal? How much will it be? These are big questions, the same as asking how quickly all ice would melt if we don't phase out fossil fuels quickly.

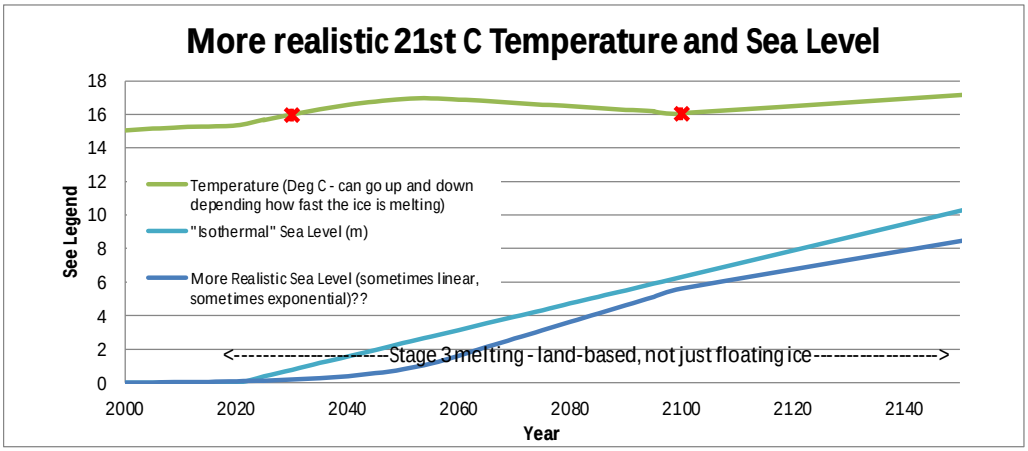
Air-ocean models can't model this, air-ocean-ice ones are a work-in-progress. Gravity satellites can measure the melting from land: Greenland looks exponential. The doubling period will be clear with another decade's data. Without strong action now, Jim Hansen says sea level will rise, by 2100, five metres from Antarctic and Greenland ice. I'd not bet against this great scientist. 400 terawatts is enough to do it. While the ice/water interface area needs to increase more than twenty-fold, there's more than one mechanism for that to happen. Ironically (for those politicians whose ignorance of science leads them to think this would disprove global warming), global air temperature may change little, may reduce at times. Mid-latitudes may get more snow, as the poles shed great chunks of ice.

That's how ice melts: it perforates and breaks into smaller pieces, and turns to water while temperature barely changes. Who wants to risk 5 metres by 2100? Cui bono est? Will the fossil fuel companies pick up the tab, if all those coastal city-dwellers are forced inland?


If Global Warming were constant 400 TW and Isothermal
Warming (TW)
Cumulative Warming (ZJ)
Cumulative Cubic km ice melted (1000s)
Warming (TW)
Year
800
700
600
500
400
300
200
100
0
40000
35000
30000
25000
20000
15000
10000
5000
0
2000
2200
2400
2600
2800
3000
3200


If Global Warming were constant 400 TW and Isothermal
Temperature (Deg C)
"Isothermal" Sea Level (m)
Stage 4 - no more ice, temperature can rise .
<----------Stage 3 melting - land-based, not just floating ice---------->
See Legend
Year
80
70
60
50
40
30
20
10
0
2000
2200
2400
2600
2800
3000
3200


More realistic Temperature and Sea Level
Temperature (Deg C - can go up and down depending how fast the ice is melting)
"Isothermal" Sea Level (m)
More Realistic Sea Level (sometimes linear, sometimes exponential)??
<----------Stage 3 melting - land-based, not just floating ice---------->
See Legend
Year
80
70
60
50
40
30
20
10
0
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000


More realistic 21st C Temperature and Sea Level
Temperature (Deg C - can go up and down depending how fast the ice is melting)
"Isothermal" Sea Level (m)
More Realistic Sea Level (sometimes linear, sometimes exponential)??
<----------Stage 3 melting - land-based, not just floating ice---------->
See Legend
Year
18
16
14
12
10
8
6
4
2
0
2000
2020
2040
2060
2080
2100
2120
2140

2. The Logic of Action - Based on 1998 paper – "The Fallacy_of_Climate_Skepticism".

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%. Let's consider four types of outcome of inaction, and estimate the probabilities.

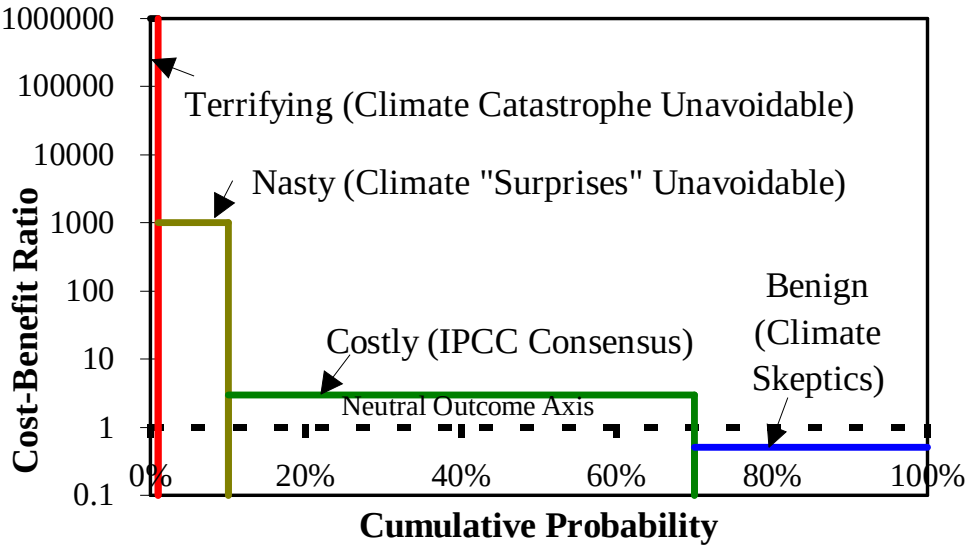
Denial amounts to asserting the outcome will be benign, a cost:benefit ratio less than one because we'll be better off allowing it (more than 450 ppm or whatever) to happen than acting to reverse it. So give "Benign" the first bar on the cumulative probability graph, and the benefit of the doubt that Benign is a serious probability, say 30%.

The second type of outcome is "Costly", a cost:benefit ratio greater than one, whereby we'll be worse off allowing it (more than 450 ppm) to happen than acting to reverse it. This is what the scientists whose job it is, commissioned by the governments of the world to advise us, are saying. I suppose the Intergovernmental Panel on Climate Change (IPCC) could just be job-creating public servants, but let's give them the benefit of the doubt that they know what they're doing and they don't have obvious conflicts of interest. (Or read Statement 1 if you want to understand more of the science for yourself.) They should be more correct than the denialists who are driven by their personal interests to wilful ignorance and wishful thinking. (And who doesn't wish at times for an infinite planet, and the easy road of fossil fuels?) Call the probability of "Costly" 60%.

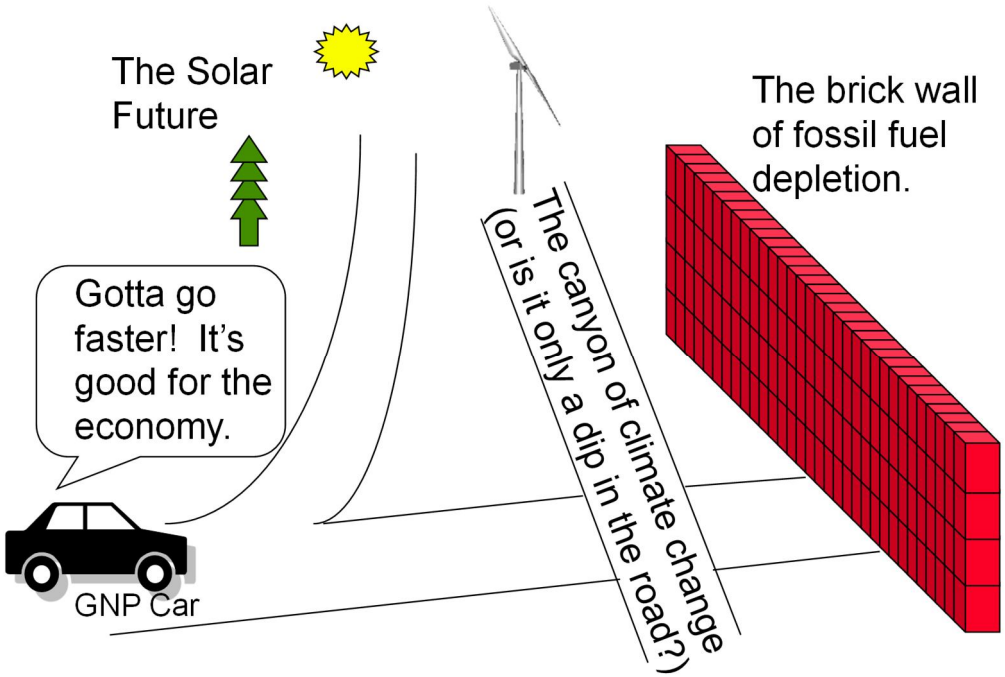
Then there is "Nasty". There are top scientists outside the IPCC (like Jim Hansen) who were saying 350 ppm is the safe limit long before the IPCC said 450 might be safer than 600. Some top scientists were less surprised than the IPCC that the ice is melting faster than their models say. Five metres sea level rise this century (as Jim Hansen predicts if inaction continues) would displace hundreds of millions of people and destroy millennia of human history in London, Shanghai and the rest. The bar on the cost:benefit graph is much higher (costlier - and note that the scale is logarithmic to accommodate this) - so costly we are talking about breaking the bank of human civilisation - though we'll call the probability (in deference to the IPCC's rigorous work estimating 1 m) only 9%.

That leaves a 1% probability to remind us that they have to add up to 100% and (like responsible engineers who design planes and boilers this way) we have to ensure Murphy's Law doesn't bite us when the consequences are high. Call it "Terrifying" and, if you like, break it up further into fractions of a percent for Lovelock's "population less than 1 billion", or "Mass extinction" or "Runaway Greenhouse Effect". The bar is very skinny, but very tall - an experiment in logarithmic consequences we should not be messing with – though planet Earth is less at risk than our 'civilisation', built (as the Latin derivation suggests) by citizens of coastal cities.

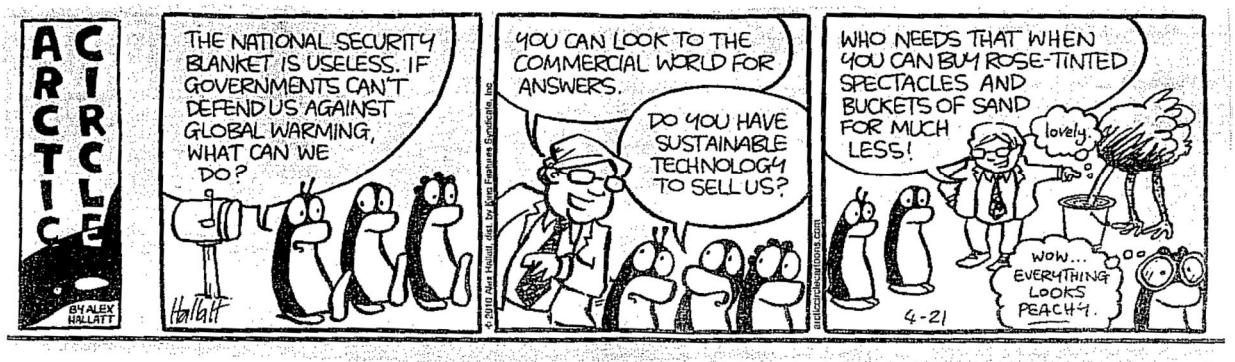
The fallacy of climate denial is that it assumes only one of these scenarios. Another common, related fallacy, is that action is macro-economically costly. But creating new industries will offset the phase-out of old industries. We didn't leave the Stone Age 'cos we ran out of stones. We won't leave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



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



How about a change of direction?



Sums it up really ....

3. The Solution is Economic - 1998 Paper – "Creating the Right Climate: The Economic_Solution".

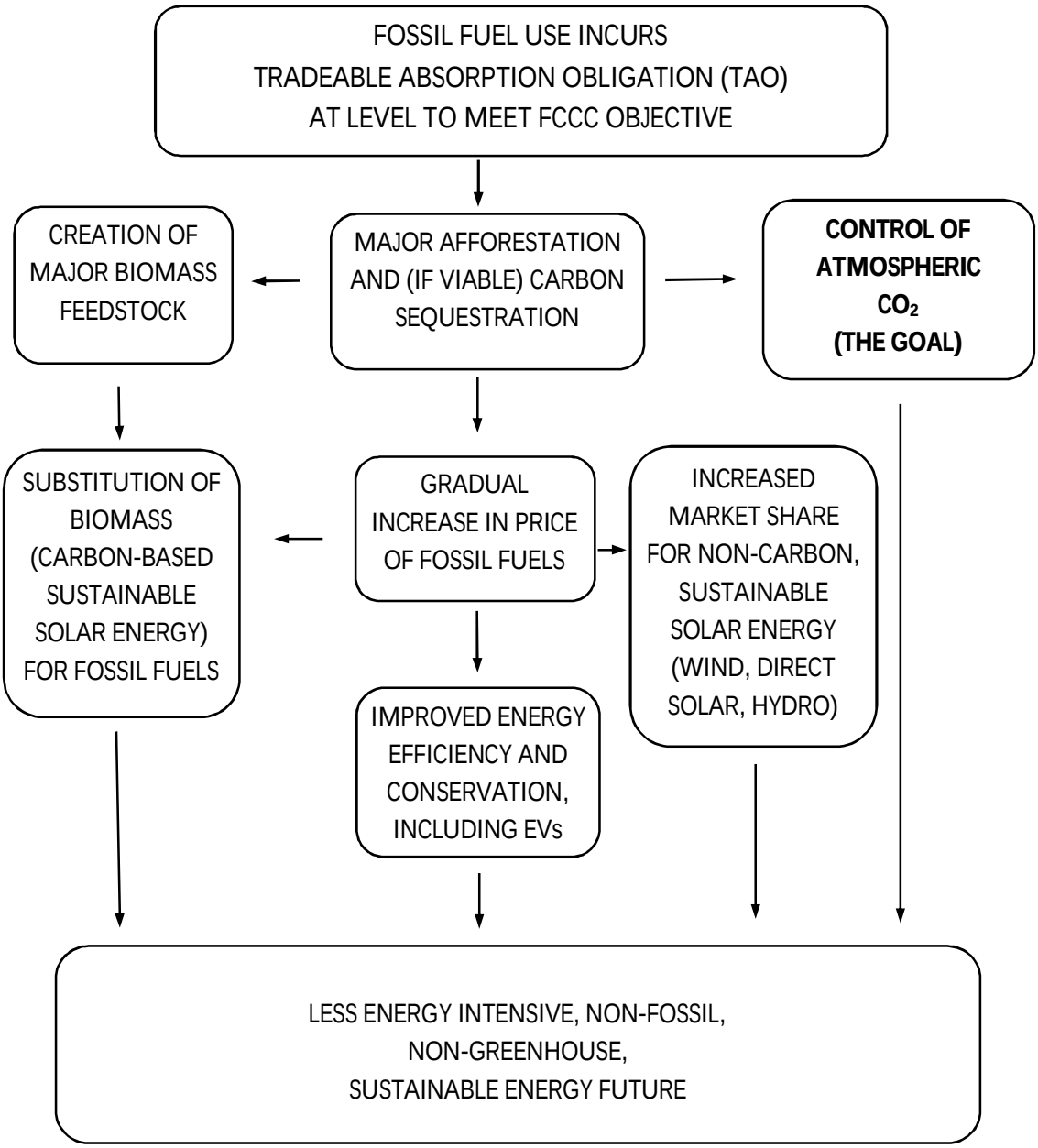
Global warming is an economic problem. We use fossil fuels because they seem low-cost, and the energy released by oxidising their carbon and hydrogen has powered 300 years of human industry. Fossil fuels are solar energy stored over hundreds of millions of years that we are burning in hundreds, a million 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 terawatts 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. 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: 100% remediation in accordance with the Resource Management Act, as recommended by the commissioners for the Taranaki Combined Cycle power station (but subverted by the NZ Government in 1994 so that not one tree has been planted by the station's owners), a carbon tax applied to afforestation, tradeable carbon certificates or emissions trading with sink credits. 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.

Frequently Asked Questions about the TAO

1. Isn't forestry just a temporary solution?

No. This is a misunderstanding of the dynamics (flows, stocks, feedbacks) of the economic solution which has transient and steady-state elements. The transient will apply while we continue to burn fossil fuels, the steady-state will apply when we are using biofuels for our combustion fuel requirements instead (together with non-carbon sustainable solar energy, i.e. wind, hydro and direct solar power). The transient will require increasing amounts of land in forest, the steady-state won't. The power of this solution is that it internalises into the human economy the unsustainability of continuing to burn fossil fuels. Competition for the next hectare of land will force the price of fossil fuels up non-linearly to a level which will force them out of the market-place.

2. Won't it stimulate the wrong kind of forestry? What if it competes with land for agriculture?

In the context of the overriding need to control atmospheric CO_2 levels, the best kind of forestry is the one that grows fastest in each climate and terrain. This might offend the aesthetics of those who like slow-growing forests, and certainly national parks and other conservation areas should be preserved. Importantly, a price signal will be given to prevent deforestation. As for afforestation, it will normally take place on marginal lands, where it competes with neither national parks nor arable land. In the final analysis though, market competition (in the widest sense of that concept) will decide what land is used for, while proper regulation of the TAO will ensure sustainability. We can rely on the fact that food is more basic in humanity's hierarchy of needs than combustion fuel. We need to achieve sustainable combustion fuel production, closing the carbon cycle, just as we do (or rather need to, to the extent that we don't) for our food requirements.

3. What about other biofuels?

Liquid biofuels (mainly cane ethanol and vegetable oils/biodiesel) and gaseous biofuels (methane from sewage plants, landfill and agricultural sources) will have an important role in a sustainable solar future. Their market share will be determined according to abundance of local resources and the advantages of liquid and gaseous fuels. Thus when I use the term "afforestation" as a response to the TAO, it could equally be conversion of land-use to such purposes, or coppicing plantations rather than the normal type of commercial forest.

However, relative to liquid and gaseous biofuels, forestry can absorb more carbon per hectare during the transient period before fossil fuels can be phased out.

Furthermore wood-fired power is fundamentally cheaper than liquid or gaseous biofueled power. There will be growing demands for electricity world-wide (particularly with the upsurge of EVs), and wood-fired power has been developed at large scale in the last 30 years. Coal-fired power dominates generation in many countries, and wood-firing (in particular circulating fluidised bed combustion technology) is able to be directly substituted for it. It will not be as dominant as coal-firing has been, since wind power and PV power are lower-cost and will continue to gain market share rapidly world-wide. But wood provides energy storage, which complements the attributes of wind and solar power. It also suits combined heat and power systems, which are commonly built into New Zealand's many dairy factories that are presently coal or gas-fired.

4. Isn't trading carbon morally repugnant like selling indulgences?

No, this is a false equivalence. Selling indulgences involved taking money from people in exchange for a purported cancellation of guilt for moral crimes, weighing the material against the spiritual, and as immoral as a judge taking bribes. Trading carbon weighs the material against the material and (regulated properly) achieves desired outcomes of net emission. Energy, money and the carbon cycle are very closely interlinked and therefore should be traded against each other:

- One view of money is that it is the tradeable value of human energy.
- The Industrial Revolution has enabled us to harness other forms of energy than human and animal energy, and primitive biofuel, solar, wind and water devices, thus increasing productivity hugely. In the process we have become sufficiently sophisticated that sustainable solar forms can take over from fossil solar in providing the labour-saving and life-enhancing benefits of industrialisation. Modern synchronous wind turbines and foiling catamarans are hugely more efficient than 18th century windmills and schooners
- The carbon cycle is above all an energy cycle: photosynthesis takes in solar energy to remove oxygen atoms from CO_2 and H_2O to form organic compounds; respiration (or burning) releases that energy again by turning organic compounds back into CO_2 and H_2O.

Trading carbon is an economic way to address a very real problem of how to close the carbon cycle, weighing the material against the material. And what could be more moral than taking responsibility for cleaning up one's mess? "I will take a benefit by using energy which emits greenhouse gases into the atmosphere in one place, but (to the extent required by law) I will make sure I pay the cost of taking greenhouse gases out of the atmosphere somewhere else."

There is an argument that a carbon tax would be morally repugnant if the funds be not applied to absorbing the CO_2, because of the prospect of losing the funds in a government's consolidated accounts without a kilogram of CO_2 being absorbed. And there is an argument that governments are morally bankrupt while they procrastinate and prevaricate about putting laws in place to protect future generations. Governments should look after the interests of future generations, remembering that individuals all have a century at most to live, while nations should be around many centuries into the future. Certainly governments should aim for the least-cost way to absorb carbon, and thus "leave this to the market" as much as possible. If this means that the fossil-fuel companies should pay directly for afforestation, and own the future carbon credits/obligations as a result, this should be a good thing, as it would create an interest for the fossil-fuel companies to become tomorrow's biofuel providers.

5. Does the absorption obligation have to be 100%?

Logically speaking, the TAO will work at any absorption level, from 1% of emissions (99% net) to 100% (zero-net). It will also work at more than 100% to enable net absorption (which some experts say will be needed in future to lower atmospheric CO_2 levels), but in that case the costs would need also to be borne by energy users in general (not just fossil energy users), especially if by then the use of fossil fuels has been substantially phased out. In practice, governments seem likely to adopt trajectories of net emissions reductions. This suits the flexibility of the TAO. It can be also used for other greenhouse gases than CO_2 (eg agricultural methane).

6. Which is better, the TAO or a carbon tax?

The TAO (properly implemented) will provide certainty of the net emission quantity (tonnes of CO_2 and other GHGs) achieved, whereas a carbon tax will provide certainty of the price ($/tonne). In practice "certainty" is somewhat illusory as governments have been anything but constant in their policy settings and can change in 3 years or less. My strong view is that the "certainty" of the emissions quantity is the decisive factor in favour of the TAO, and I believe its political durability will be better than a carbon tax. This is because of its logical and moral foundation, which society will "buy into" more than another tax. People will understand the argument that we need to clean up our mess. A carbon tax, by contrast, requires people to trust government's ability to set the correct price of carbon (it can't, any more than it can set the correct price of a loaf of bread), as well as to understand that, over time, the government will adjust the price of carbon to obtain the desired emissions trajectory in order to clean up our mess (why have an indirect role in controlling the emissions trajectory when government can simply regulate the emissions trajectory directly?).

The only benefit of a carbon tax is to put a ceiling on the price of carbon so that fossil-reliant business has some certainty as to the forward cost. Even so, given the long timescales of energy-related investments, this is illusory at best, because the political cycle is so much shorter. In practice, governments seem likely to adopt a "hybrid" approach which will combine trading with a carbon tax acting as a price ceiling. This will work with a trajectory approach since the TAO will be cheaper than the tax predicts, and thus we will overperform relative to any trajectory, provided we enable the TAO in any regulations.

7. Isn't a fiscally neutral carbon tax easier because it provides tax cuts elsewhere to ease the political pain?

It's easier but less effective as a result. A fiscally neutral carbon tax, in theory, could result in no net emissions reductions. Imagine a consumer at a petrol pump. Last year it cost him $80 to fill his tank, which emits 140 kg of CO_2 every time he empties it by driving however many kilometres. This year a $100/tonne tax is introduced so it now costs him an extra $14 to fill his tank. But he knows he will get that back through the tax system, as surely as if the forecourt attendant simply handed him the $14 back. What incentive does he have to buy a hybrid car or an electric car? Not much. Does anyone have an incentive to invest in wind farms, or plant trees? Not as far as I can see.

In practice, the psychology of a fiscally neutral carbon tax could be slightly better than that, and it seems a good way to introduce a carbon tax to get people used to the idea. Back in the 1990s, that was not unreasonable. Nowadays the world has moved beyond the need for this, especially since fiscal recycling (without a penny going to the forestry sector for the absorption work of tree-planting!) will necessitate a very high nominal level (perhaps $1000/tonne?) for the psychological effects to be measurable in terms of emission changes. In turn, those very high levels will create political opposition of the usual "big government vs small government" kind.

8. Can you have both the TAO and a carbon tax?

Yes, as set out under question 6, a hybrid solution is quite possible. However it is expected that the TAO is the one that will drive net emission results, with the tax being there as a ceiling to enable political buy-in.

9. Won't carbon credits of dubious merit be mixed with respectable ones as happened with the Kyoto Protocol?

When Kyoto was being negotiated the principle of differentiated responsibility was predicted to create "carbon leakage". I remember being naïve enough to discount this, as I thought the developed "Annex 1" nations would not want to shut down whole industries to exploit the "carbon havens" that were being created by the others having no obligations. However the effect has been massive and has thwarted real progress in controlling atmospheric GHGs. An important benefit however has been the accelerated development of the developing nations as they (particularly China and India) have become the "factory of the world". In spite of all the air pollution and other ills of industrialisation, it is overall a good thing for the developing world to have significantly developed, with hundreds of millions being lifted out of poverty. And nowadays China leads the world in renewable energy (by a long way). The post-Paris settings are much more comprehensive, and the global challenge is at the same time more urgent but also more achievable, so the degree to which international trading can bring the price of carbon down will be much reduced. Thus Kyoto will prove to be a one-off product of its times.

At the end of the day, the Kyoto Protocol achieved its targets under its rules. The post-Paris rules will be tighter. Without an agreed international process, this issue cannot be addressed.

Ultimately a jurisdictional issue will come into play. Governments will be held to account by a combination of the UN process and political pressure from its citizens, local governments and corporate sector. What can a government control? It can only control what happens in its own country with any great certainty. The TAO lends itself well to government administrative processes through the land registry system. Absorption credits are tied to a piece of land through afforestation. While they can be separately traded from actual ownership of the land, the land registry processes can prevent double-dipping etc. By contrast, international trading will carry a greater risk and should only be undertaken with reliable counter-parties and under UNFCCC rules.

10. What about other government programmes like subsidies and targets for renewables (i.e. sustainable solar energy)?

These can supplement a TAO especially when the absorption obligation is less than 100%. Until zero-net emissions are regulated and achieved, there is no "level playing-field" for renewables and thus other complementary measures (like Australia's mandatory renewable energy target, MRET, scheme) should be continued.

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