DriveSolar: Terraforming the Earth

The DriveSolar vision

Contents

Introduction

We at Techogeny think the global public has been told too many doom and gloom stories about climate change.

The reality is that known technology, used intelligently, is fully capable of stabilising human-made warming without disrupting human development or spoiling anyone's fun.

We developed the DriveSolar vision to illustrate the technological possibilities. We are not trying to predict the future, we are laying out a total solution that we know will work, and challenging other technologists to improve on our vision.

Here's the gist of it:

- Fossil fuels will be phased down from 2020, with fossil fuel consumption falling to zero by 2080. This will limit human-made global warming from carbon dioxide emissions to about 1.92 degrees Celsius*. That is INSIDE the two degree target set by the UNFCCC (UNFCCC, 2011).
- We think fossil crude oil will be replaced by a smorgasbord of technologies.
- The most expensive alternative is solar crude oil. Solar crude oil facilities occupying less than 2.1% of the world's land area (excluding Antarctica) would satisfy future global demand for liquid hydrocarbon fuels (petrol or gasoline, jet fuel, and diesel), with global population of 11 billion people. Fuel production requires about 251 square metres of land per person. And, that land can also be used for other purposes such as desalination.
- Solar crude oil will be made at commercial scale from carbon dioxide sucked out of the atmosphere. It cannot affect the climate because it does not change the amount of carbon circulating in the atmosphere and oceans. It is made from atmospheric carbon. When it is burned, it goes right back where it came from.
- Everything that is currently made from fossil crude oil can be made from solar crude oil, including gasoline, jet fuel, and diesel that are drop-in replacements for existing fuels.
- Conventional cars and trucks in 2080 will need only about half as much fuel as today's vehicles.
- Economic growth between 2010 and 2080 will boost real personal income. On average, people in 2080 will earn twice as much as we do today.
- If our descendants have twice as much (inflation-adjusted) money to spend, and they need only half the amount of fuel we buy each year, they won't mind if a litre of fuel is three or four times more expensive that it is today.

Based on three independent costings, we can expect the price of solar crude oil to fall between 2.7 and 3.95 times the price of fossil crude oil (excluding taxes). That is based on known technology. Technical improvements might drive down the cost. And, there might be cheaper ways to make carbon-neutral crude oil. That's OK. Solar crude will be good enough to stabilise human-made warming. Anything better will be a bonus.

In a post-Euro 6 world the environmental impact of internal combustion engines will not be significantly worse in most areas, than the impact of battery or hydrogen drivetrains.

This does not mean climate policy should discourage new technology. Climate policy must directly target the root cause of human-made warming. Temperatures are going up because atmospheric carbon dioxide is increasing. NET emissions of carbon dioxide (and some other greenhouse gases**) emissions must be regulated.

A policy that targets NET carbon dioxide emissions, and nothing else, avoids interfering in the development of new technology vehicles and machinery. If someone invents a better car and consumers go for it, that's their business.

The DriveSolar vision clearly shows that road transport at the end of the 21st century will be at least as affordable at the end of the 21st century as it was in 2010. We say that is a good thing, because road transport is fundamental to suburban civilisation. Human-made global warming is a significant problem, but it is NOT a reason to discourage people from driving cars.

The most important point is that phasing out fossil fuels will not harm economic and technological development.

Notes

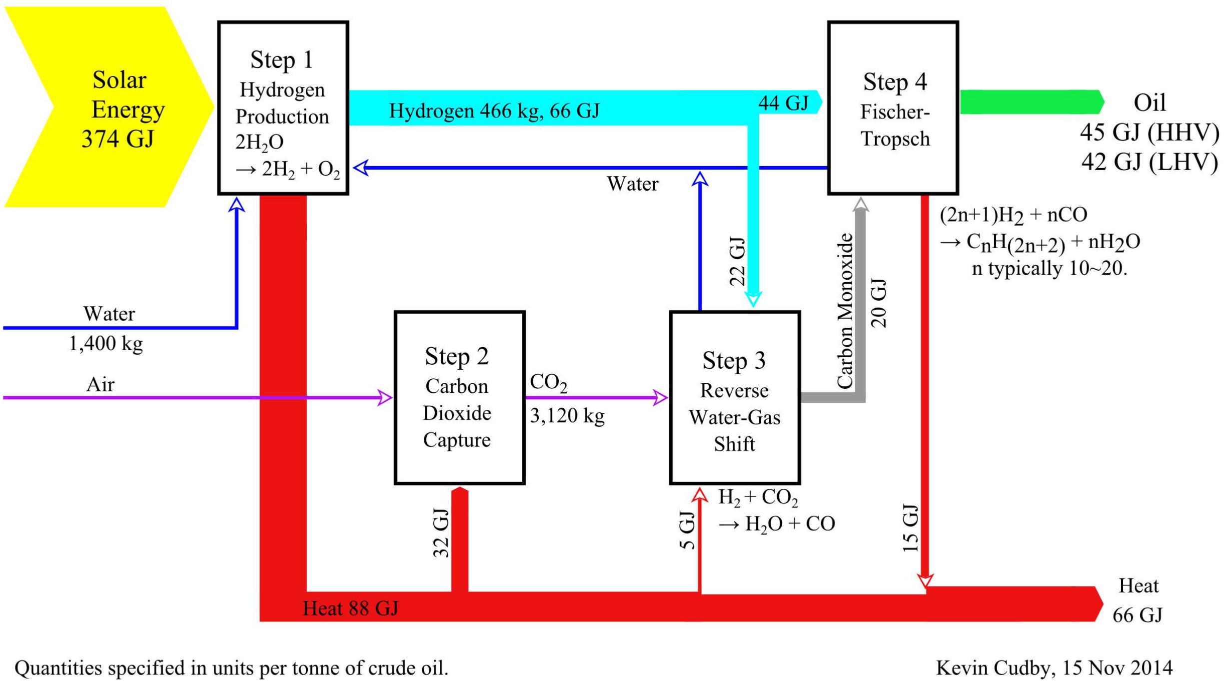
* There is considerable uncertainty in the exact amount of expected warming. The IPCC estimates cumulative emissions equivalent to one trillion tonnes of carbon would increase global average temperature between 0.8 °C and 2.5 °C (IPCC, 2013, p. 102).

** Greenhouse gas regulations should aim to stabilise long-term warming. Climate regulations need to consider each greenhouse gas according to its specific characteristics. For example, there is a case for regulating annual emissions of nitrous oxide. Atmospheric methane is pretty-much stable, and considering methane's technical characteristics we do not think methane emissions need to be regulated. On the other hand, net emissions of some long-lived synthetic greenhouse gases need to stop.

DriveSolar reference process

The DriveSolar reference process is designed to give a general idea of how solar crude oil production will work. It is based entirely on known technology. Here's a summary of the main steps:

- Electricity from a concentrating solar power station drives an electrolyser that liberates hydrogen from water (IEA, 2010; IEA, 2011).
- Energy from the solar power station also drives the atmospheric carbon dioxide capture system (Holmes, 2013; Keith, 2009; Lübbehüsen & Becker, 2013: ScienceNow, 2012).
- A reverse water-gas shift (RWGS) reactor converts captured carbon dioxide into carbon monoxide.
- In the Fischer-Tropsch (FT) Synthesiser, carbon monoxide reacts with hydrogen to form crude oil.



DriveSolar solar crude oil reference process.

This process can be expected to achieve average solar to crude oil thermodynamic efficiency of more than 11% (LHV).

Solar power tower electricity systems are expected to yield energy return on energy invested (EROEI) of at least 40:1 (Richter et al., 2009). Allowing for the reduced process efficiency, the overall EROEI for a DriveSolar system should fall between 10:1 and 25:1.

Various research groups around the world are trying to develop practical systems similar to, or better than, DriveSolar.

A practical example

The Sunfire project in Dresden, for example, is a pilot plant that runs off the power grid. Audi reported April 21, 2015, that the pilot plant was up and running, after a four-month commissioning period. We think this reflects engineering improvements over the last decade or so on Fischer-Tropsch technology. Energy manufacturers in the twentieth century could spend a year or two getting a Fischer-Tropsch reactor tuned up. We've spoken to several engineers who reckon they've cracked that problem, which is why we're prepared to believe Audi when they say Sunfire is already producing FT crude oil.

The Sunfire pilot plant is getting its carbon dioxide from a biogas facility. That's not viable for large-scale commercial crude oil production. Sunfire plan to harvest atmospheric carbon dioxide using a process developed by Climeworks. We have no figures on that. The calculations for our DriveSolar reference process came from Carbon Engineering, which is building a pilot-scale air-capture plant in Canada.

In any case, after Sunfire have tuned up their process they could take the design to a sunnier location and hook it up to a solar power system such as PS20 near Andalusia in Spain.

DriveSolar is a benchmark

Fischer-Tropsch fuels from the DriveSolar process are identical to FT fuels from other energy sources, such as natural gas or biomass. Well-known oil refining techniques are able to convert FT crude oil into gasoline, jet fuel, diesel, and pretty-much all the other products that presently come from fossil crude oil.

Drivesolar provides an excellent benchmark for carbon-neutral liquid fuel production. We already know how to do this. The process can fully support long-term economic and technological development. If someone comes up with something better, that would be a bonus.

It doesn't matter if nothing better comes along. Drivesolar shows that engineers already know how to make road and air transport fully sustainable. But that's not all. In the following pages, we'll show how DriveSolar can help fix worrying environmental problems.

Resource requirement

We think in the future, fossil liquid fuels will be replaced with a smorgasbord of technologies, probably including liquid fuels made from biomass and nuclear energy, and hydrogen from solar photovoltaic systems and nuclear energy.

It is useful to think about the extreme case, in which all present-day uses for fossil liquid fuels are replaced with solar crude oil. If our descendants can do that with the resources available to them, then they will certainly be able to implement other possibilities. For example, nuclear crude oil production needs less land than solar. Solar hydrogen needs less land than solar crude oil.

All solar scenario

Here's a conservative estimate of the resource requirement, assuming all global production comes entirely from solar crude oil facilities.

Land use and energy

Population	11 billion
Annual oil production & consumption	18 billion tonne
Annual oil production, HHV	813.5 billion GJ/yr
Solar collectors, input energy	9.69×10^{12} GJ/yr
Average direct solar insolation	8.76 million GJ/km²/yr
Total area of production facilities	2.76 million km²
Fraction of Earth's land area (excluding Antarctica)	2.05%
Fraction of total solar resource harnessed by mirrors	0.35%
Footprint per person (mirrors)	100 m²
Footprint per person (total)	251 m²

Notes

Land coverage factor

Solar concentrating facilities usually leave gaps between the mirrors to allow some sunlight to reach the ground. We've assumed forty percent of the total area of production facilities would be covered with solar collectors (mirrors).

Solar energy

Concentrating solar energy facilities need direct sunlight. Average (mean) annual solar insolation for suitable locations is 2,434 kWh/m² (8.762 million GJ/km²). (Calculated from regional data in Breyer & Gerhard, 2009, p. 5.)

Water

We envisage most solar crude oil facilities would use desalinated water. Surplus heat from the plants' cooling systems would power the desalination plants. In fact, there is so much heat available that these facilities could export very large amounts of desalinated water, suitable for town water supply, or for irrigation. We'll post more details when we get time.

Carbon dioxide

Solar crude oil production and consumption would cycle as much as 15.5 billion tonnes of carbon (56.8 billion tonnes CO_2) per year.

The atmosphere and oceans together hold about 39,120 billion tonnes of carbon (144,340 billion tonnes of CO_2). Assuming the average turnover time from production to consumption is one year, then solar crude oil production and consumption exploits less than 0.04% of the relevant carbon resource.

Stabilising the sea level

Globally the sea level will take thousands of years to adjust to human-made warming, even if the warming stops at two or three degrees Celsius. That's one of the few sure things in climate science.

We at Techogeny think engineers will find strong demand for technology that can stabilise global sea level. That's why carbon-negative crude oil production is integral to the DriveSolar vision.

The idea is to exploit the link between global average temperature and sea level. The "equilibrium" sea level depends mathematically on the global average temperature. Let's flip the previous sentence end to end. Global average sea level depends on global average temperature. Two hundred and fifty years ago, for example, the sea level corresponded to zero human-made global warming.

In the late 22nd century, we might expect the sea level to be one or two metres higher than it was in 1870. That would be the long-term equilibrium sea level corresponding to perhaps 0.7 degrees of human-made warming. So, if we reduce atmospheric carbon dioxide to a level that corresponds to 0.7 degrees of human-made warming, we would expect the sea level to stop rising.

Right now, politicians are arguing about whether to stop the warming at two degrees, which corresponds to an average sea about 4.6 metres higher than we have today.

The sea level will rise very slowly, taking at least 2,000 years to adjust. The DriveSolar sea level stabilisation strategy removes the warming before it can push the sea level all the way up to its new equilibrium level. Without the extra heat, the water in the oceans would stop expanding, and ice sheets and glaciers would get a chance to stabilise.

We expect the sea level to move up and down for some time after the temperature has fallen to the target level. But these small fluctuations will be far easier to live with than the metre-or-more per century sea level rise that will be otherwise be pretty-much unavoidable through the 21st and early 22nd centuries.

The DriveSolar strategy centres on carbon-negative crude oil production. The oil industry would extract more carbon from the atmosphere than it puts into fuel. The extra carbon, in the form of carbon dioxide, will be pumped into permanent geologic (underground) storage in formations such as depleted natural gas fields. This is known in climate engineering circles as "carbon sequestration."

Here at Techogeny we are crunching the numbers on two carbon-negative crude oil production systems: *Solar crude oil*, and *biomass gasification and Fischer-Tropsch (BGFT)*. Both systems will be 100 percent carbon neutral in a carbon-neutral world. (Some commentators try to argue otherwise. Their calculations do not take into account the long-term effect of carbon dioxide.) Kevin Cudby's book, From Smoke to Mirrors, describes the BGFT process in detail. For solar crude, our calculations are based on the DriveSolar Reference Process. Both processes can be made carbon negative. However, the details are very different.

A typical BGFT facility produces an exhaust stream consisting of pure carbon dioxide. The process can be made carbon negative simply by pumping the CO2 into a suitable reservoir. The reservoir might be up to a couple of hundred km from the fuel factory, so we have to allow for the cost of pumping CO2 through a pipeline, and then the cost of pumping it into the ground and looking after the reservoir. The figures we have seen here at Techogeny suggest this will add only a few cents per litre to the cost of fuels like petrol (gasoline) and jet fuel. (We'll post more detail later).

The amount of CO_2 that can be permanently sequestered by a BGFT facility depends on the type of gasifier. A facility with an "oxygen-blown" gasifier might sequester up to 225 grams of carbon (825 grams of CO_2) for every litre of fuel produced. The carbon can't be made into fuel because there is not enough hydrogen being fed into the Fischer-Tropsch reactor. This puts an upper limit on the amount of carbon that can be sequestered using the BGFT process: About one tonne of carbon for every 3.6 tonnes of crude oil produced. Optimistically, using BGFT, the oil industry might sequester a billion tonnes of carbon per year. Not enough to make a significant dent in sea level rise.

Solar crude oil facilities can do way better. However, carbon dioxide is not a byproduct of normal business operations. Process equipment at a solar crude oil facility extracts carbon dioxide direct from the atmosphere (or the ocean, but we don't have all the numbers on that yet.) Carbon dioxide in a solar fuel oil facility is a valuable raw material. To make carbon-negative crude oil, the capacity of the carbon dioxide capture process has to be increased.

Our figures indicate that this adds a tolerably small extra cost. For example, doubling the rate of carbon dioxide extraction would increase fuel cost by as little as 15%. Our calculations shows that even with this small extra cost, carbon-negative petrol in 2080 will be more affordable than today's petrol. After that, ongoing economic growth will keep making petrol ever more affordable. That won't stop people grumbling about the cost, but (as in the USA today) demand for petrol will be practically independent of the price.

On these figures, we think that by 2080 the oil industry could, in a suitable commercial environment, permanently sequester one tonne of carbon for every tonne of carbon it puts into crude oil. Solar petrol, in itself, cannot warm the climate because it is made from carbon extracted directly from the atmosphere. But then, on top of that, when our great-grandchildren buy a litre of fuel, they would also pay the oil company to remove from circulation the amount of carbon added to the atmosphere when my grandfather drove about seven kilometres in his 1958 Ford V8.

Starting by 2080 (possibly earlier), carbon negative crude oil production could remove at least five billion tonnes of carbon per year from the atmosphere. Continuing economic growth would continue to improve the affordability of solar fuels as time goes on. We think that in the early 22nd century it would be economically feasible to require the oil industry to increase the rate of sequestration. In principle, if cumulative carbon dioxide emissions do not exceed one trillion tonnes of carbon, then it is feasible to drive cumulative man-made emissions back down to zero well before the end of the 22nd century.

Sea level stabilisation probably requires something of that nature. Sea level between now and the mid 22nd century can be expected to rise by perhaps 1.5 metres or so, though of course the numbers are highly uncertain. If equilibrium sea level rise for two degrees anthropogenic warming is roughly 4.6 metres (IPCC, 2013, ch 13, p. 1190), then stabilising the sea level at 1.5 metres above today's level, requires total anthropogenic warming to fall to perhaps 0.6 ~ 1.0 degrees.

If you think this means cumulative carbon dioxide emissions need to be reduced to about 330 billion tonnes, you're not allowing for hamburgers. Short-lived warming agents like methane (which comes from cows) warm the atmosphere by an amount that depends on the annual rate of emissions. More people: more short-lived warming agents like methane: more warming.

This warming can be offset by removing additional carbon dioxide from the atmosphere. That's why we think there may be a case for driving cumulative carbon dioxide emissions practically to zero.

Here at Techogeny we think it's vital to crunch the numbers on this, which is why we're looking for folks who can help. Most importantly, we want to run a series of hypothetical scenarios to get a first estimate of when the sea level might be expected to stabilise.

How to cap global warming at one degree

DriveSolar’s vision of carbon-negative crude oil production eliminates anthropogenic global warming by the mid to late 22nd century.

This leaves a period of almost two hundred years during which global temperatures would change very quickly. Warming would reach 2 degrees by about 2080 and then fall to zero within about a hundred years. Such rapid warming and cooling appears to be unprecedented in geological history. Bad things might happen.

Solar radiation management (SRM) can eliminate this rapid heating and cooling. A few kilos of small particles scattered in the upper atmosphere would reduce the amount of solar energy reaching the earth’s surface, cancelling out the effect of increased carbon dioxide. The effect is relatively short-lived, which means it can be adjusted quickly. In the near term, the amount of particles being scattered would gradually increase as atmospheric carbon dioxide increases. When atmospheric carbon dioxide begins to fall, less material would be sprinkled in the upper atmosphere. SRM would finish when atmospheric carbon dioxide reaches the target concentration, probably about 300ppm or less.

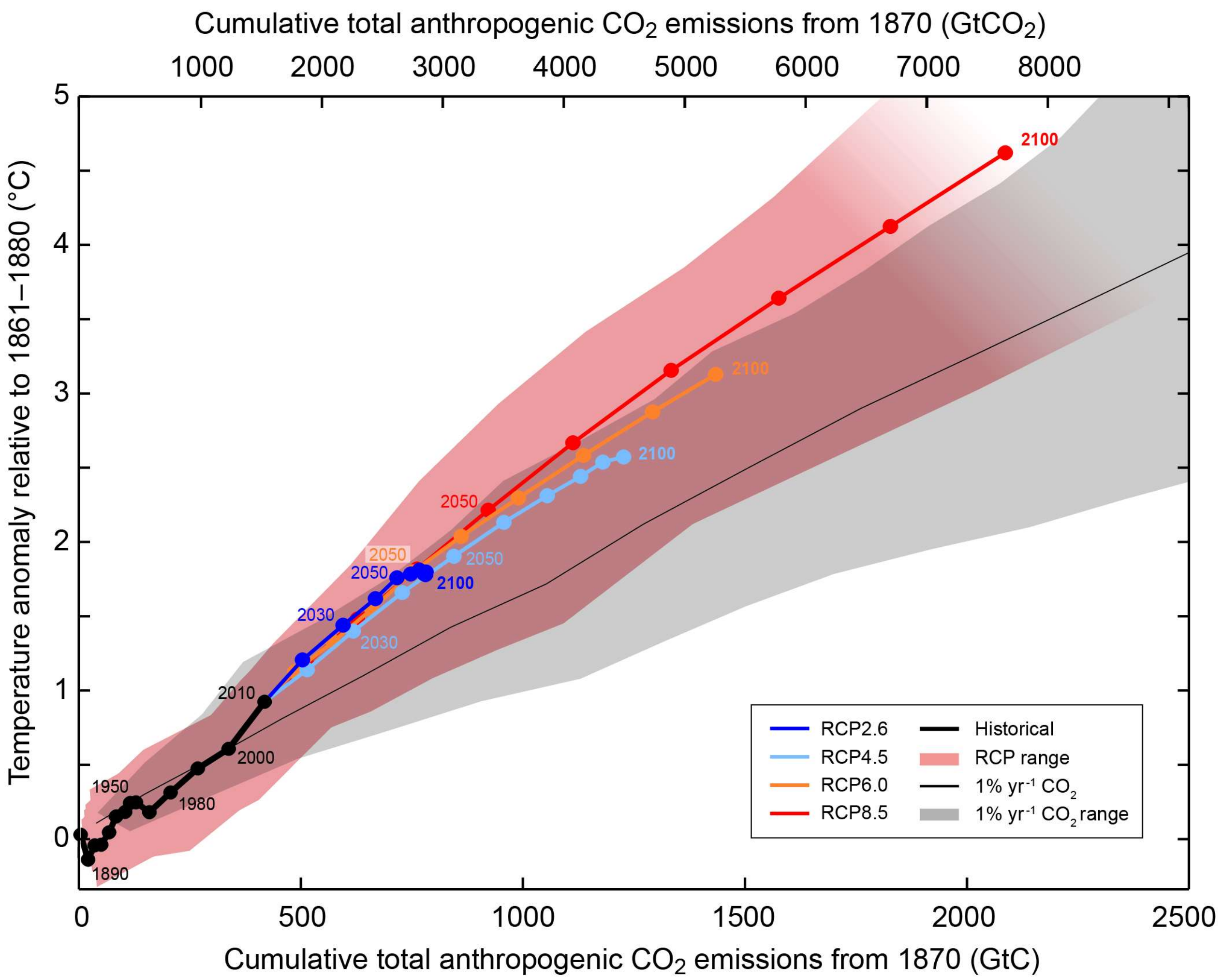
The DriveSolar + SRM combination requires good planning. Most importantly, the particles need to be kept away from the locations of solar concentrating energy plants, which suggests they should be sprinkled in higher latitudes. We know that the amount of material is quite small compared with natural concentrations. There are no concerns about large-scale environmental contamination. This form of SRM appears to be easily affordable. Questions about local effects need to be factored in to SRM engineering models, which is why Techogeny supports the proposal by Long et al for increased research into climate engineering.

Previously, the main objection to SRM was that the world would have to do it for tens of thousands of years. if, for any reason, SRM suddenly stopped, global temperatures would rise very quickly. DriveSolar eliminates this concern. SRM will operate for a limited time only. If it stops, the worst that can happen is that global warming could reach two degrees Celsius. By the early 22nd century, with falling levels of atmospheric carbon dioxide, the risk gradually lessens.

Assuming fossil carbon dioxide emissions start falling by the early 2020s, we think it is entirely feasible to cap human-made global warming at one degree Celsius. Perhaps less.

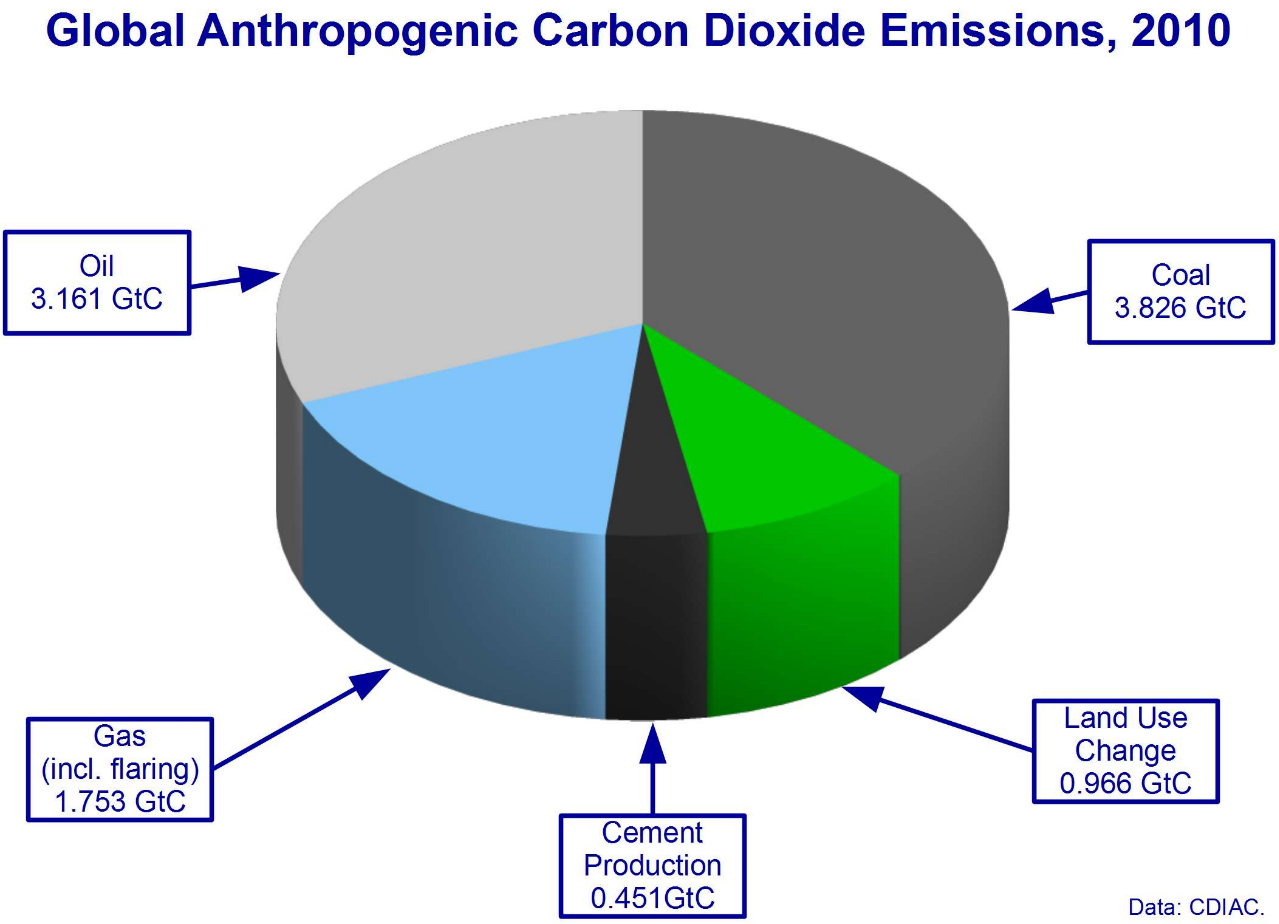
Why 100%?

The IPCC's 2013 fifth assessment report (IPCC, 2013, Figure SPM.10, p. 28) unequivocally shows that the only way to stabilise human-made warming is to completely stop net carbon dioxide emissions. There is no uncertainty in that. Scientists can't say exactly how much extra carbon dioxide can be added to the atmosphere and oceans before human-made global warming hits two degrees. But they can say with almost total certainty that human-made warming can be stopped only by completely stopping net carbon dioxide emissions from burning fossil fuels.



Global mean surface temperature increase as a function of cumulative total global CO2 emissions. Chart: IPCC (2013): Climate Change 2013: The Physical Science Basis, Figure SPM.10, p. 28.

Some scientists think perhaps some small annual flow of mineral carbon dioxide might be tolerable. From the practical perspective, we at Techogeny think that is irrelevant. Even if it is true, it makes no practical difference. That is because three to five percent of emissions come from cement production. So far, we have not seen any really practical alternative to ordinary concrete, which suggests it might be difficult to find a climate-stable substitute. We think any small allowable flow of carbon dioxide into the atmosphere and oceans should be allocated to cement production.



Net anthropogenic carbon dioxide emissions in 2010, from the "Full Global Carbon Budget (1959-2011)," CDIAC, 2011.

That's why the DriveSolar vision is based on total cessation of carbon dioxide emissions from burning fossil fuels.

What about nitrous oxide?

If we have to completely phase out fossil fuels, shouldn't we also phase out other "long-lived" greenhouse gases?

Depends

We've been told by climate scientists, several times, that certain other climate scientists think human-made nitrous oxide (N2O) emissions have to stop. Completely. Nitrous oxide has a mean atmospheric lifetime of about 121 years. In plain English: If you add some extra nitrous oxide to the earth's atmosphere today, then, 121 years from now, about 63% of that extra nitrous oxide will have dropped out of the atmosphere.

"So," said the unnamed climate scientists, "nitrous oxide builds up in the atmosphere, just like carbon dioxide. Therefore, just like carbon dioxide, human-made N2O emissions must stop." ... ! ... ! ....!

Shoulda done the 'rithmetic

The numbers tell a different story.

Suppose, for example, that habitat engineers decide to stabilise nitrous-oxide-induced warming at the present-day amount: 0.063 °C. What should they do?

The math says our hypothetical habitat engineers would need to reduce human-made nitrous oxide emissions by about 43%.

Last time we checked, forty-three was not the same as a hundred. Especially not when you're talking about percentages.

Where did the "scientists" go wrong?

Each gas is different

Our mendacious "scientists" implied atmospheric lifetime was the only thing that mattered. Carbon dioxide stays in the atmosphere for tens of thousands of years. Myles Allen, Dave Frame, and their collaborators demonstrated conclusively that net carbon dioxide emissions must stop. (We, at Techogeny, think they should be knighted for this remarkable achievement. They're not the ones saying N2O emissions have to stop.)

Nitrous oxide also stays in the atmosphere for a long time. Therefore, claimed our misleading pseudo-boffins, nitrous oxide must be like carbon dioxide. Whatever we have to do about carbon dioxide, we also have to do about nitrous oxide.

It sounded reasonable. But as time went on, techogenist Kevin Cudby started feeling uneasy.

So, he decided to crunch the numbers. He used a fairly simple mathematical model, and data from the IPCC report, to check the scientists' guesswork. It's their equation, and their data. How come it proves them wrong?

The answer lies, as you'd expect, in the math. To get a result, we had to put numbers on several quantities. The most important parameters were: Natural emissions, Human-made emissions, Atmospheric lifetime, Total amount in the atmosphere in 1870, Total amount in the atmosphere today.

The big difference between carbon dioxide (CO_2) and nitrous oxide(N20)?

With CO_2, natural emissions, averaged over hundreds of years, are negligible compared with human-made emissions. Natural emissions of N_2O (10.1 million tonnes per year), by contrast, are greater than human-made emissions (6.3 million tonnes per year).

Human activity has increased atmospheric N_2O by about 20%. Mainstream climate scientists think this has increased average global surface temperatures by about 0.063 °C.

To prevent further warming, we could reduce human-made emissions to about 3.7 million tonnes per year. We don’t know if that’s feasible. We do think it’s a lot more realistic than demanding human-made N_2O emissions must stop.

We are almost certain, now, that carbon-negative crude oil production can be used to reduce atmospheric carbon dioxide, offsetting warming caused by other gases such as nitrous oxide. (Provided N_2O emissions don’t increase out of hand).

In any case, the math clearly shows that atmospheric N_2O will not build up indefinitely, which is the big worry with fossil carbon dioxide.

Always crunch the numbers

We have very little time for “scientists” who are too lazy to crunch the numbers. Climate science is not a joke. We need practical engineering tools we can trust, not wild guesses and unrealistic goals.

It’s becoming clear that greenhouse gases must be treated on a case by case basis. Nitrous oxide, for example, is not merely a warming agent. Scientists have found evidence that in the stratosphere, nitrous oxide boosts production of the OH radical. The OH radical helps clean pollutants out of the atmosphere. It is possible that future habitat engineers will want to increase atmospheric N_2O. Right now, we don’t have enough information to put numbers on this. More research is needed.

Meantime, we think there’s a case for reducing global nitrous oxide emissions, to make sure N_2O doesn’t get out of control. The figures are highly sensitive to uncertainties, but they clearly show that some anthropogenic emissions of N_2O will be acceptable.

It is premature to call for a total cessation of anthropogenic N_2O emissions.

In the last few years we have discussed nitrous oxide with several climate scientists. It’s not unusual to hear: “It builds up in the atmosphere. Anthropogenic emissions have to stop.”

Our analysis has reminded us of something every technologist must keep in mind: Always do your math before shooting your mouth off.

Links & References

Crude oil production

Air Fuel Synthesis	http://www.airfuelsynthesis.com/home.html
Sunfire	http://www.sunfire.de/en/

Direct capture of atmospheric carbon dioxide

Air Fuel Synthesis	http://www.airfuelsynthesis.com/home.html
Carbon Engineering	http://carbonengineering.com/
Climeworks	http://www.climeworks.com/

* Techogeny cannot vouch for any of these organisations. The only thing we can say is that our analysis shows they are pursuing an achievable goal.

References

Audi(2014): “New Audi E-Fuels Project: E-Diesel from Air, Water and Green Electricity.” Ingolstadt, Audi AG, 2014. https://www.audi-mediaservices.com/publish/ms/content/en/public/pressemitteilungen/2014/11/14/new_audi_e-fuels_project.html, visited 14 Nov 2014. An end-to-end pilot plant demonstrating crude oil production from electricity. At full scale, driven by concentrated solar power, this would closely resemble the DriveSolar Vision. This project uses the Climeworks CO2 air-capture system.

Christian Breyer & Gerhard Knies (2009): “Global Energy Supply Potential of Concentrating Solar Power.” Proceedings SolarPACES, pp. 15 – 18. A general survey of the global resource.

CDIAC (2011): “Full Global Carbon Budget (1959-2011).” Oak Ridge, TN: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

F.D. Doty, G.N. Doty, J.P. Staab, & L.L. Holte (2010): “Toward Efficient Reduction of CO2 to CO For Renewable Fuels.” Proceedings of ASME 4th International Conference on Energy Sustainability, 1, pp. 775 – 784.

Geoffrey Holmes, Kevin Nold, Tylor Walsh, Kenton Heidel, Matthew A. Henderson, Jane Ritchie, Paul Klavins, Arvinder Singh, & David W. Keith (2013): “Outdoor Prototype Results For Direct Atmospheric Capture Of Carbon Dioxide.” Energy Procedia, 37, pp. 6079 – 6095.

IPCC (2013): T.F. Stocker et al. (eds), “Climate Change 2013: The Physical Science Basis.” Cambridge & New York: Cambridge University Press. http://www.ipcc.ch/report/ar5/wg1/, visited 27 Mar 2014.

Jane C. S. Long, Frank Loy, & M. Granger Morgan (2015) “Start Research On Climate Engineering.” Nature, 2015, 518/7537, pp. 29 – 31. http://www.nature.com/news/policy-start-research-on-climate-engineering-1.16826

IEA (2010): “Technology Roadmap: Concentrating Solar Power.” Paris: International Energy Agency. http://www.iea.org/papers/2010/csp_roadmap.pdf, visited 19 Jul 2010.

IEA (2011): “Task 25 Process Sheet Synopsis - Screening Analysis Solar Thermochemical Hydrogen Concepts.” Paris: International Energy Agency. http://ieahia.org/page.php?s=publications&p=technical, visited 13 Jan 2014.

David W. Keith (2009): “Why Capture Co2 From The Atmosphere?” Science, 2009, 325, pp. 1654 – 1655.

David W. Keith (2013): “A Case for Climate Engineering,” Cambridge, MA, The MIT Press.

Stephan Lübbehüsen, & Sebastian Becker (2013): “Bilfinger Industrial Technologies Power-to-Liquids: Fuels from Solar Energy, CO2 and Water.” Cloppenburg, Germany: BIS E.M.S. GmbH. http://www.sunfire.de/wp-content/uploads/BILit_FactSheet_POWER-TO-LIQUIDS_EMS_en.pdf, visited 15 Nov 2014.

Paul Marks (2012): “The Big Question Mark over Gasoline From Air.” New Scientist, 22 Oct 2012. http://www.newscientist.com/article/dn22407-the-big-question-mark-over-gasoline-from-air.html

Tom Meyer (2001): “The Reverse Water Gas Shift,” http://spot.colorado.edu/~meyertr/rwgs/rwgs.html, visited 3 Mar 2010. Robert Zubrin credits Tom Meyer with showing how RWGS can be used for making hydrocarbons.

Christoph Richter, Sven Teske, & Rebecca Short (2009): “Concentrating Solar Power Global Outlook 09.” Amsterdam, Brussels, & Tabernas: Greenpeace International, European Solar Thermal Electricity Association, & SolarPACES Secretariate.

ScienceNow (2012): “Can Geoengineering Save the World?” Washington, DC: American Association for the Advancement of Science., http://news.sciencemag.org/sciencenow/2012/05/live-chat-can-geoengineering-sav.html, visited 3 Jun 2012.

Robert F. Service (2015): “Tailpipe To Tank.” Science, 2015, 349/6253, pp. 1158 – 1160, http://www.sciencemag.org/content/349/6253/1158.full, visited 12 Sep 2015. Survey of direct cycle crude oil development projects.

UNFCCC (2011): “Report of the Conference of the Parties on its Sixteenth Session, held in Cancun from 29 November to 10 December 2010. Addendum Part Two: Action Taken by the Conference of the Parties at its Sixteenth Session.” Geneva: United Nations. http://unfccc.int/meetings/cancun_nov_2010/session/6254/php/view/decisions.php, visited 15 May 2014.

Jan Wurzbacher (2013): “Capturing CO2 from Air.” Zurich, Switzerland: Climeworks AG. http://www.empa.ch/plugin/template/empa/355/*/---/dat_id=133210/l=2, visited 23 Jul 2015. An operational CO2 air-capture pilot plant.

Robert M. Zubrin, David A. Baker, & Owen Gwynne (1991): "Mars Direct: A Simple, Robust, And Cost Effective Architecture For The Space Exploration Initiative". American Institute of Aeronautics and Astronautics. http://www.marssociety.org/home/about/mars-direct, visited 6 Jun 2015. Two processes for making hydrocarbons from carbon dioxide, water, and nuclear or solar energy: Sabatier, and Fischer-Tropsch (like DriveSolar).

Robert Zubrin, Brian Frankie, & Tomoko Kito (1997): “Mars In-Situ Resource Utilization Based On The Reverse Water Gas Shift: Experiments And Mission Applications.” American Institute of

Aeronautics and Astronautics. http://pioneerastro.com/Team/RZubrin/Mars_In-Situ_Resource_Utilization_Based_on_the_Reverse_Water_Gas_Shift_Experiments_and_Mission_Applications.pdf, visited 19 May 2014

About

Sometimes tongue-in-cheek, always accurate, seldom apologetic*, Techogeny is unashamedly positive about the future of humanity.

Humans are technology

Our ancestors shaped our evolution with fundamental inventions such as tool-making, cooking, and language. To understand this we need only look at our teeth. We are predators: But where are our killing teeth? Our ancestors invented spears and clubs with which to collect food. According to at least one anthropologist, our ability to transfer new technology from person to person, for example, by inventing a better hammer and teaching others how to make it, is what sets us apart from all other animals. Market-led innovation is the essence of humanity.

Archaeologists have found evidence that hominins were making stone tools at least 3.5 million years ago. They don't know how these tools were used, but they have evidence that hominins were regularly using tools by 3.1 million years ago. It seems fairly clear that these early technologies shaped human evolution. Our genus, *Homo*, was probably shaped from the outset by the technology of its ancestors: Our species, *Homo sapiens*, most certainly was. We at Techogeny are good with that. We like technology because we like shaping the world around us. We especially like the idea that our ancestor's technology shaped our evolutionary history. Homo sapiens is NOT a natural animal: It is part biology, but it is all technology. We are technological organisms.

Humanity's future

The best scientific knowledge suggests human civilisation has billions of years ahead of it. We have trouble visualising such an enormous timescale. We cannot know what our descendants will discover or invent. We cannot know how the long-distant future will unfold. The only way anyone will ever find out is to go there. To do that, future generations will need to deploy technology that has not yet been imagined. History has shown that successful technological deployment and economic growth advance, hand-in-hand. That is why humanity has a moral obligation to continue, and if possible, accelerate, the technological and economic momentum of the last few centuries. It also means we must actively discourage the attitudes and behaviours that stalled technological and economic development between the Dark Ages and the late eighteenth century.

Looking after the home-world

Techogeny unashamedly steals a basic principle of human sustainability from tech writer Annalee Newitz. Newitz wrote that humanity should aim to thrive and prosper for at least the next million years. To do that, we must look after our habitat. That's why this blog is guided by the principles of constraints-based environmentalism:

- The purpose of environmental action is to provide for the full range of human needs (including biodiversity and wilderness areas);
- Activity aimed at fixing an environmental problem must not inhibit economic development any more than necessary to prevent the environmental problem becoming a constraint on human development;
- Technological solutions are preferable to social or behavioural "solutions"; and

- Environmental action should strive to eliminate constraints.

For example, Techogeny acknowledges that human activity is increasing the amount of carbon dioxide in the earth's atmosphere and oceans. To the best of our knowledge, this would raise global temperatures for tens of thousands of years, unless someone does something practical to reverse the warming. That's why Techogeny seeks out and documents technological methods by which human-made global warming can be stabilised. The IPCC has clearly stated that this can be achieved only if humanity stops putting extra carbon into the atmosphere and oceans. Fossil carbon is the constraint. Scientists and engineers have already identified more than enough options to overcome this constraint.

Techogeny rejects the defeatist negativity of "green" ideology. We also reject the fake optimism of climate denialists.

Habitat Engineering

We consider large-scale habitat engineering to be crucially important to human sustainability. We can't say exactly how humans in the future will use engineered habitats. We do know that science fiction writers have imagined more than enough good reasons to get stuck in and develop the necessary technology. Engineering the earth's climate is an important step on the road to practical deep-space human habitats. We can do that in parallel with other aspects of the space programme. This is the most important, and in our view, the most exciting aspect of habitat engineering.

The planet we live on is blue.

Not green.

Blue.

Innovation

Per-capita economic growth is an important goal of human activity. Given a fair go, people naturally create more than they consume or destroy. As economic historian Deirdre McCloskey says, growth "is about what we make with our hands, our brains, and our machines." Market-led innovation and exploration over past few centuries has dramatically increased the wealth of everyone alive today. The poorest contemporary humans have access to goods and services that were unimaginable only a hundred years ago. Until someone invents a better economic system, humanity's best option is market-led innovation (which non-technologists erroneously call "market-led capitalism").

We have not yet seen any economic analysis that goes back more than a couple of thousand years. It is clear, however, that the ancient Greeks of the Iliad and the Odyssey were a great deal more wealthy than people who lived hundreds of thousands of years ago. We at Techogeny consider that economic growth started with the first people who learned to teach each other how to manufacture and use new inventions. We hypothesise that per-capita economic growth is what humans naturally do. In fact, because our evolution has been shaped (inadvertently) by technology, our propensity to make more than we destroy may be one of the few truly natural aspects of the human character. We know, for example, that chimps can grieve. We don't see then trotting off to the bank to open savings accounts.

Urbanisation

We like the way cities have evolved. Auckland, for example, combines wonderful sprawling suburbs with lots of green space, more boating opportunities than you can wave an outboard at, and dispersed industrial areas scattered all over the place. In the last decade or so it has outgrown its transport system and it really needs to fix that problem. We don't think it needs to change its fundamental character to do that. We have nothing against skyscrapers. In fact, from the technological perspective we think they're great. But we do not think everyone has to live in one.

Auckland's growing pains are partly due to the disconnect between what new arrivals want and what the local bureaucracy think they should have. People move to New Zealand to get the Kiwi dream: A quarter-acre section with a detached house. The bureaucrats want them to live in ten-story apartment blocks, like so many Parisiens.

Auckland, including all its urban parks and gardens and carefully manicured offshore islands, has 1200 people to the square kilometre. If everyone in the world lived in settlements with the same population density as Auckland, and if world population never went over 11 billion, only 6.8% of the world's land area would be urbanised. Our DriveSolar vision shows that solar crude oil production would require only another 2.2% of the world's land area (excluding Antarctica). We do not have comparable calculations on the amount of land needed for electricity production, but we reckon it would be less than half what's needed for crude oil production. Water? Surplus heat from solar crude oil production could desalinate enough water to satisfy a big chunk of world demand for freshwater. We are working on better figures for that, but it's not our biggest priority. The point is that there's nothing wrong with sprawling settlements. Greenies hate them because greenies hate cars.

Which is why we normally avoid arguments about urban population density. We are quite happy with sprawling car-friendly suburbs, if that's what people want.

We are technorg

Market-led innovation and the drive to explore and shape our environment made us what we are. These fundamental human characteristics will take our descendants beyond the stars. Along the way, as Poul Anderson has so richly imagined, we might intentionally engineer our own evolution. We can't say where this might lead, but we can be pretty sure it will eventually happen. We're OK with that. This is the real reason we say *We are Technorg*. Technology is the result of intentional design. We are not Technorg because we are born of technology: We are Technorg because we think that is a good thing.

Technogeny might occasionally sling mud at the biggest baddest enemies of market-led innovation: Monopolies and Marxists. Take our word for it: Those M&Ms really are bad for you.

Life should be fun. Technology is meant to be fun. Techogeny is about having fun with technology.

Appendix 2: Mark 1 Techogeny Posts

NOTE: Since publishing these posts I have revised some calculations. The posts are reprinted here verbatim, which means some of the numbers are out of date.

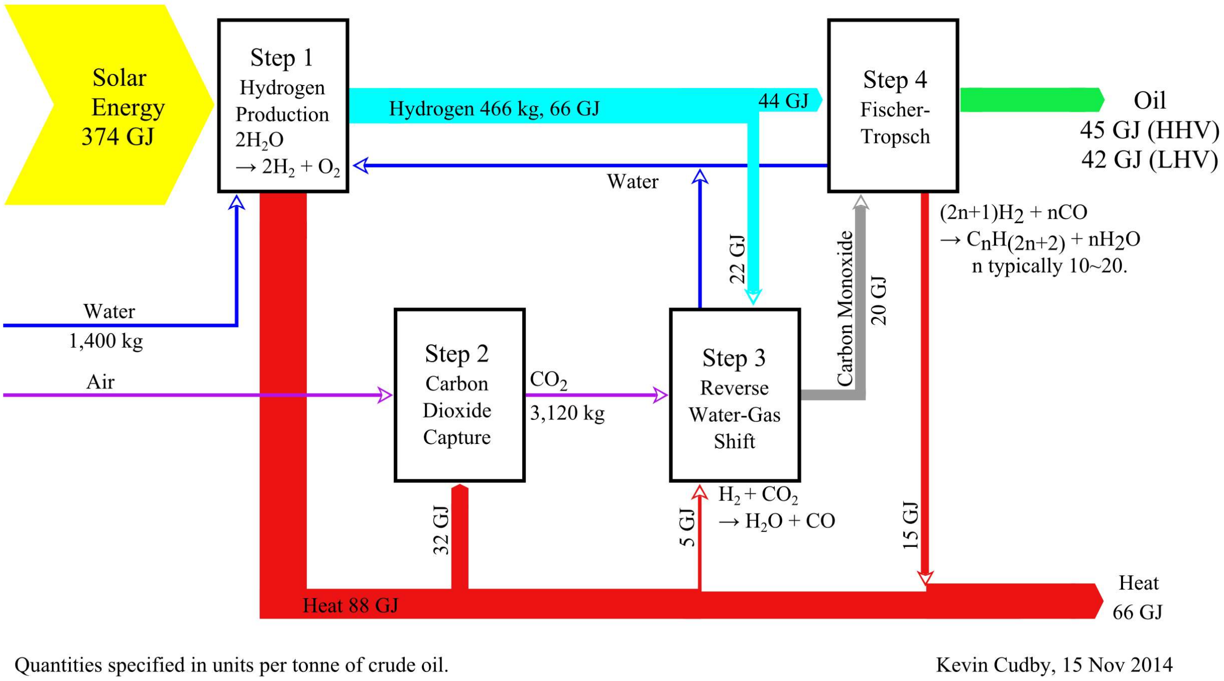
Why there'll never be a shortage of climate-neutral petrol, diesel, and jet fuel

Posted: Sun, 02 Nov 2014

Researching my book, From Smoke to Mirrors, I discovered that engineers already know how to make more than enough carbon-neutral petrol (gasoline), diesel, and jet fuel to fully satisfy future demand. Recently I've been able to get hold of more information on the potential for making crude oil with solar energy.

The basic process works like this:

1. Solar energy is used to produce hydrogen from water;
2. Carbon dioxide is extracted from the atmosphere, using solar energy and a process adapted from air filters used on submarines;
3. Some of the hydrogen from step 1 converts the carbon dioxide into carbon monoxide;
4. The carbon monoxide from step 3 reacts with the rest of the hydrogen from step 1 to produce synthetic crude oil.



DriveSolar solar crude oil reference process.

Solar crude oil is fully renewable. To work out if the world can produce enough of the stuff to fully satisfy demand, I assumed global population would ultimately reach 11 billion people. I also assumed that people in developing countries will eventually be able to afford their own cars. When everyone who wants or needs a car, has one, there'll be about 8.25 billion road vehicles, compared with about 1.25 billion today. This includes all the cars, trucks, buses, and other road vehicles.

More vehicles means more demand for petrol and diesel. But manufacturers keep reducing the fuel consumption of cars and trucks. Taking all this into account, I reckon global crude oil demand will increase from four billion tonnes in 2013, to about 18 billion tonnes per year by the mid to late 22nd century.

Solar energy facilities need land. Here's what would be needed to make 18 billion tonnes of solar crude oil per year, using technology that has already been invented:

- Amount of global land area (excluding Antarctica) occupied by solar crude oil production facilities: 2.08%;
- Fraction of total global solar energy at the earth's surface harnessed to make solar crude oil: 0.88%.

Researchers around the world are working on potential improvements. As far as I can tell, no-one has documented the basic process. So I decided to do it myself.

Known technology can fully satisfy demand. Solar fuel cannot affect the global climate because it does not increase the amount of carbon dioxide in the atmosphere and oceans. It simply recycles what is already there. If no-one ever invents a better car, solar fuel will do the job. If something better comes along, that would be a bonus.

One thing is for sure. Everyone who wants a car can have a car. There is no technical constraint on the global fuel supply.

IPCC report confirms New Zealand will be petrolhead heaven.

Mon, 03 Nov 2014

The BBC reports that the Intergovernmental Panel on Climate Change (IPCC) is calling for a total phase out of unmitigated fossil carbon dioxide emissions by 2100.

That's fantastic news for petrolheads.

We've known for more than a decade that man-made global warming can be stabilised only if oil companies change how they make petrol and diesel. They can do that with renewable crude oil. The carbon in renewable crude oil comes from the atmosphere. Burning renewable fuels doesn't increase atmospheric carbon dioxide, it simply recycles what's already there.

The good news is that the IPCC is giving us twenty years longer than I thought we'd need to make the transition. A couple of years ago I calculated we'd have to completely change over by 2080. Based on what I knew then, carbon-neutral fuel for cars and trucks in 2080 would have been slightly more affordable than conventional fossil fuels are today (excluding taxes). The extra twenty years gives more time for economic growth to reduce the impact of higher fuel prices.

Even better for petrolheads, I've been revising my calculations. The figures on my 2013 poster overestimated the price of solar crude oil by about 50%. Basically it works out like this:

- The average car in 2100 will need about half as much fuel as an equivalent 2010 model to do the same amount of driving, assuming that only some of the technology working its way through the R&D pipeline makes it into standard production cars. (I'm not talking about downsizing. Cars actually need to get bigger.)
- Economic growth between now and 2100 will put more cash in everyone's pockets. Average per-capita growth of 0.875% per year will double average incomes between 2020 and 2100.
- If you have twice as much money, and your car needs only half as much fuel, you won't mind if the price of fuel is four times higher than it is right now.
- I estimate solar fuels will be between 2.6 and 3 times more expensive than today's fuels.
- Fuel for the average person in 2100 will be thirty to fifty percent more affordable than fuel is for me.

If you think I'm jealous of my great-grandchildren, well, yeah, I kinda am. As I wrote in F*rom Smoke to Mirrors*, New Zealand can make renewable petrol and diesel for about half the cost of solar crude oil.

This latest report shows that trying to fix climate change by investing in public transport is pretty-much equivalent to trying to lose weight by eating only fish and chips, beer, and ice-cream.

The best news, though, is that the BBC is reporting the news accurately. At last!

Warming caused by carbon dioxide can be stabilised only by totally phasing out fossil fuels. Warming caused by short-lived greenhouse gases such as methane can be stabilised by stabilising annual emissions. There is no need to phase out hamburgers.

On the other hand, our grandchildren will need carbon-neutral fuel.

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Appendix 3: Sustainable Emission Rate—Nitrous Oxide

Emission rates for constant atmospheric burden

The following table illustrates the annual rate of anthropogenic nitrous oxide emissions corresponding to stable atmospheric N_2O concentration.

Each "Scenario" represents a globally agreed atmospheric concentration relative to the estimated pre-industrial atmospheric concentration (Prather et al, 2012, p. 2, and supplement.)

Anthropogenic emission rates are tabulated for the low, mean, and high estimates for atmospheric lifetime, $\tau = 121 \pm 10$ years (IPCC, 2013, p. 675).

Natural N_2O emissions have been estimated at 9.1 Tg ± 1 Tg. The table shows anthropogenic emission rates corresponding to the mean and high estimates for natural emissions.

Anthropogenic emissions in 2010 were estimated at 6.3 Tg-N (Prather et al, 2012, p. 2). The table shows the percent emission reduction necessary to stabilise atmospheric concentration at various agreed limits.

Agreed Atmospheric Limit			**Anthropogenic Emissions (Tg-N/yr)**			**Emission Reduction with respect to 2010**		
Scenario	**Conc-entration (ppb)**	**Burden (Tg-N)**	**τ = 111 yr**	**τ = 121 yr**	**τ = 131 yr**	**τ = 111 yr**	**τ = 121 yr**	**τ = 131 yr**
			Natural emissions = 7.8 Tg					
Pre-industrial + 20%	324	1553	6.19	5.03	4.05	5%	23%	38%
Pre-industrial + 25%	338	1620	6.79	5.59	4.57	-5%	14%	30%
Pre-industrial + 33%	360	1725	7.74	6.46	5.37	-19%	1%	17%
			Natural emissions = 9.1 Tg					
Pre-industrial + 20%	324	1553	4.89	3.73	2.75	25%	43%	58%
Pre-industrial + 25%	338	1620	5.49	4.29	3.27	15%	34%	50%
Pre-industrial + 33%	360	1725	6.44	5.16	4.07	1%	21%	37%
			Natural emissions = 10.4 Tg					
Pre-industrial + 20%	324	1553	3.59	2.43	1.45	45%	63%	78%
Pre-industrial + 25%	338	1620	4.19	2.99	1.97	35%	54%	70%
Pre-industrial + 33%	360	1725	5.14	3.86	2.77	21%	41%	57%

Method

1. The atmospheric concentration of a gas will remain constant over time if the overall rate of decay is equal to the total emission rate (Jacob, 1999, p. 26).
2. Nitrous oxide (N_2O) atmospheric concentration decays exponentially: *The main sink for N_2O is through photolysis and oxidation reactions in the stratosphere.* (IPCC, 2013, p. 675; Jacob, 1999, pp. 23-27),
3. The rate of decay is given by $dm/dt = -k_d m$, where m is the atmospheric burden (mass) of N_2O and k_d is the exponential decay constant.
4. The lifetime $\tau = -1/ k_d$. For N_2O, $\tau = 121 \pm 10$ years (IPCC, 2013, p. 675).
5. The total steady-state emission rate, $S_t = m/\tau$ (Jacob, 1999, p. 26).

6. The sustainable rate of anthropogenic emissions S_a is the total emission rate, S_t minus natural emissions, 6.3 Tg-N (Prather et al, 2012, p. 2).

References

IPCC, 2013 — T.F. Stocker et al. (eds.): *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Jacob, 1999 — Daniel J. Jacob: *Introduction to Atmospheric Chemistry.* Princeton, NJ: Princeton University Press, 1999.

Prather et al, 2012 — Michael J. Prather; Christopher D. Holmes; & Juno Hsu: *Reactive Greenhouse Gas Scenarios: Systematic Exploration Of Uncertainties And The Role Of Atmospheric Chemistry.* Geophysical Research Letters, 2012, 39, L09803.

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