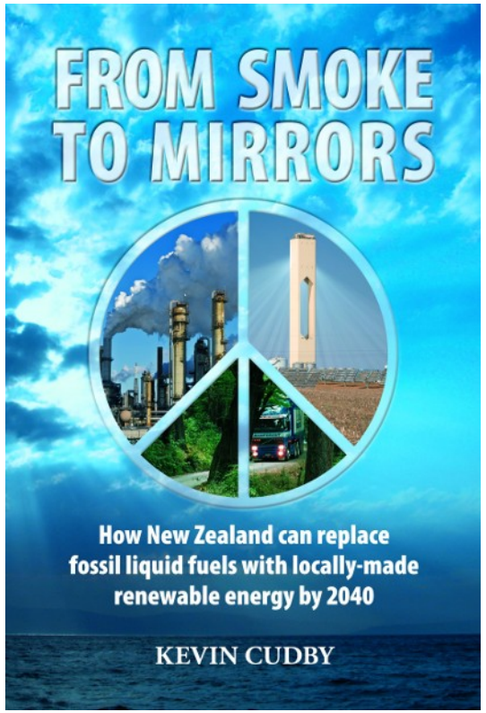
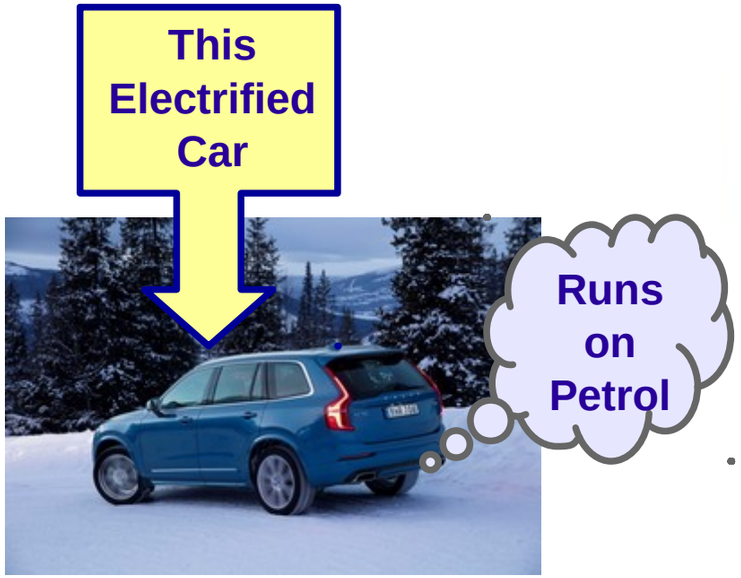
Replacing Fossil Liquid Fuels with Renewables

More Cars, Less Pollution, Stable Climate

Kevin Cudby



https://kevincudby.com
30 Nov 2017



What’s the Goal?

What do YOU want to do with human-made climate change?

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What’s the Goal?

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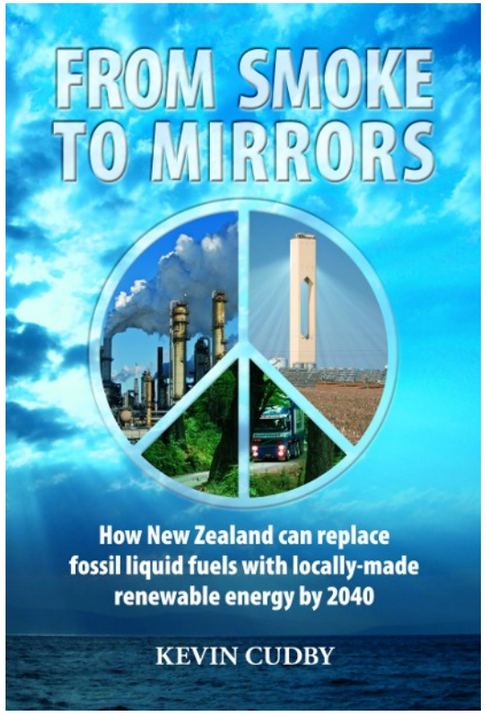
STUDY it?

FIX it?

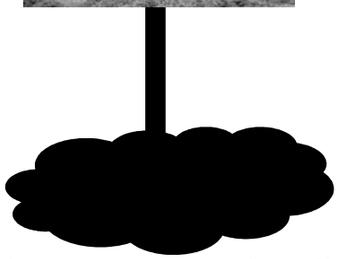
Is that what everyone else wants?


FROM SMOKE
TO MIRRORS
How New Zealand can replace
fossil liquid fuels with locally-made
renewable energy by 2040
KEVIN CUDBY

The Problem

What We **Know**

Carbon Dioxide & Water



Oil producer extracts fossil crude oil from natural underground deposit.

Oil refinery converts crude oil into marketable products, mostly hydrocarbon fuels: methane, LPG, petrol, kerosene (jet fuel), diesel, etc.

Burning **FOSSIL** hydrocarbons puts **EXTRA** carbon dioxide in the atmosphere.

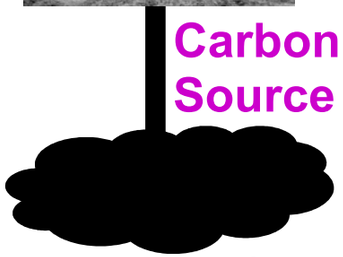
$$C_mH_{2n} + xO_2 \rightarrow mCO_2 + nH_2O$$

What We **Know**

Where is the Carbon Sink?

Carbon Dioxide & Water

Carbon Source



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When we increase atmospheric carbon dioxide (CO_2) we:

Warm the atmosphere and oceans, and

Acidify the oceans

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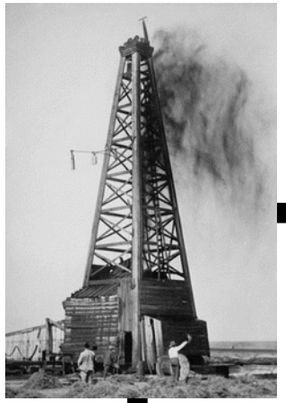

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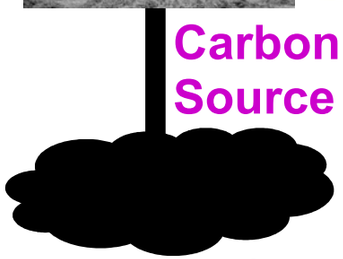
Fossil fuels are made out of things that died and were buried HUNDREDS of MILLIONS of years ago!

Carbon Source



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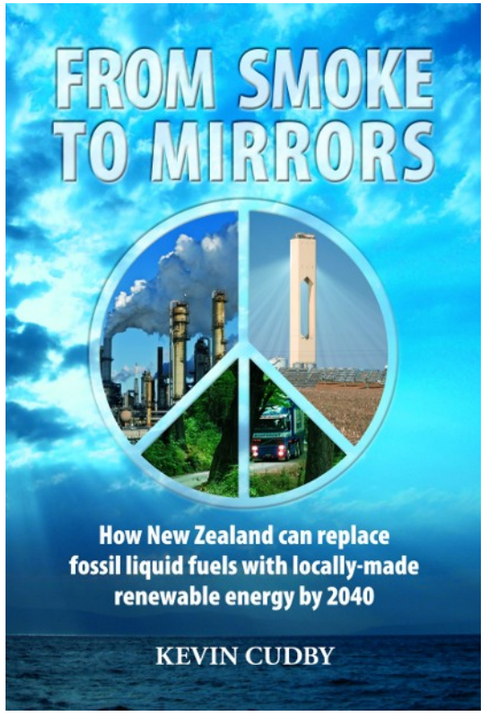


Constraints

Basic Constraints

Thermodynamically feasible

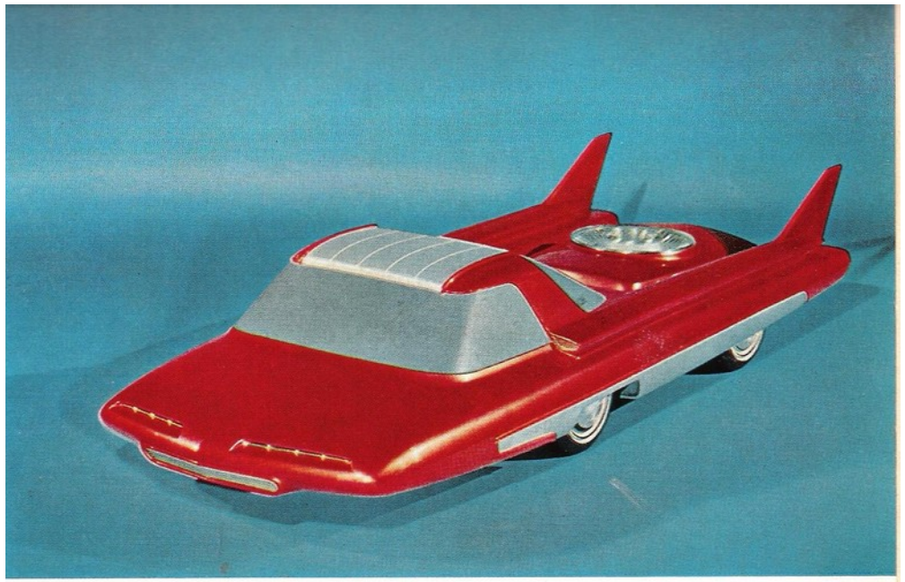
Good EROEI (Energy return on energy invested, also EROI)

Known technology

Practical

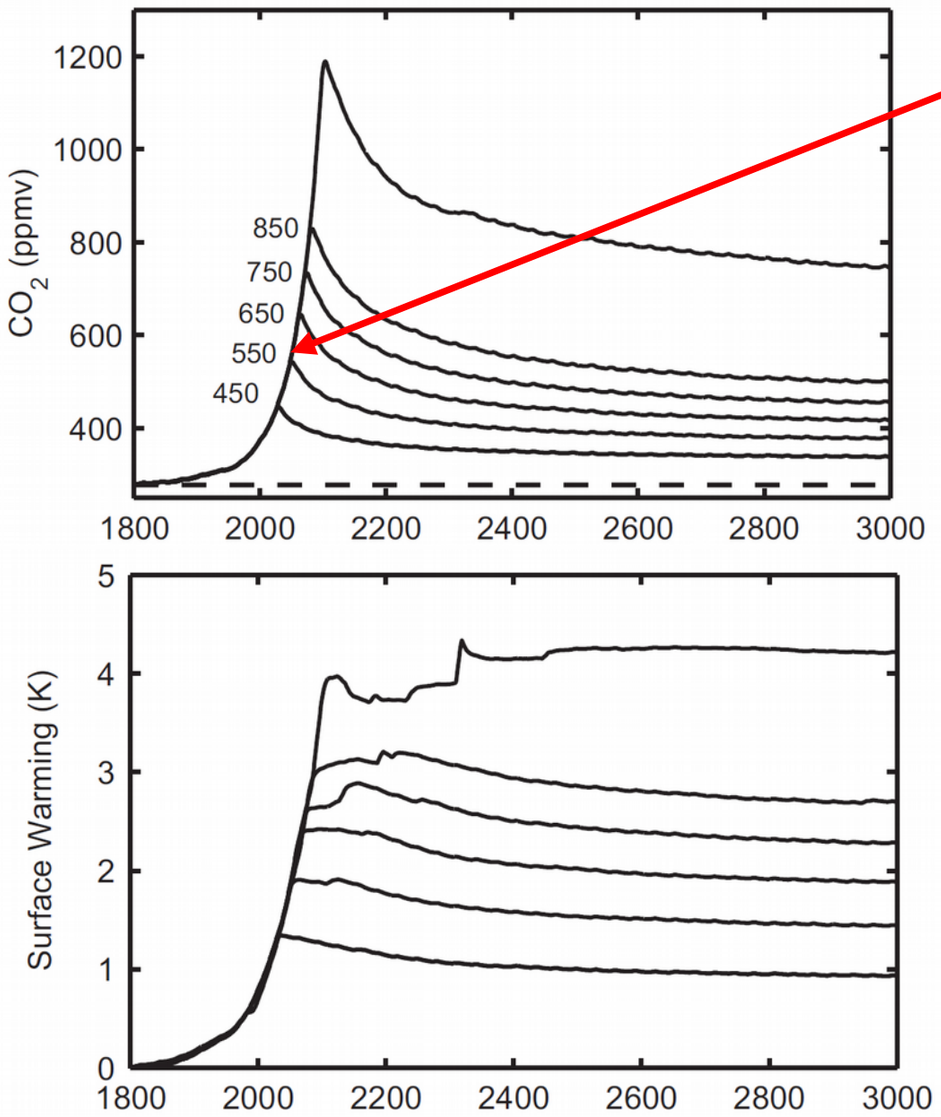
Actionable

FUN!!!



The Ford Nucleon Concept Car, 1958.

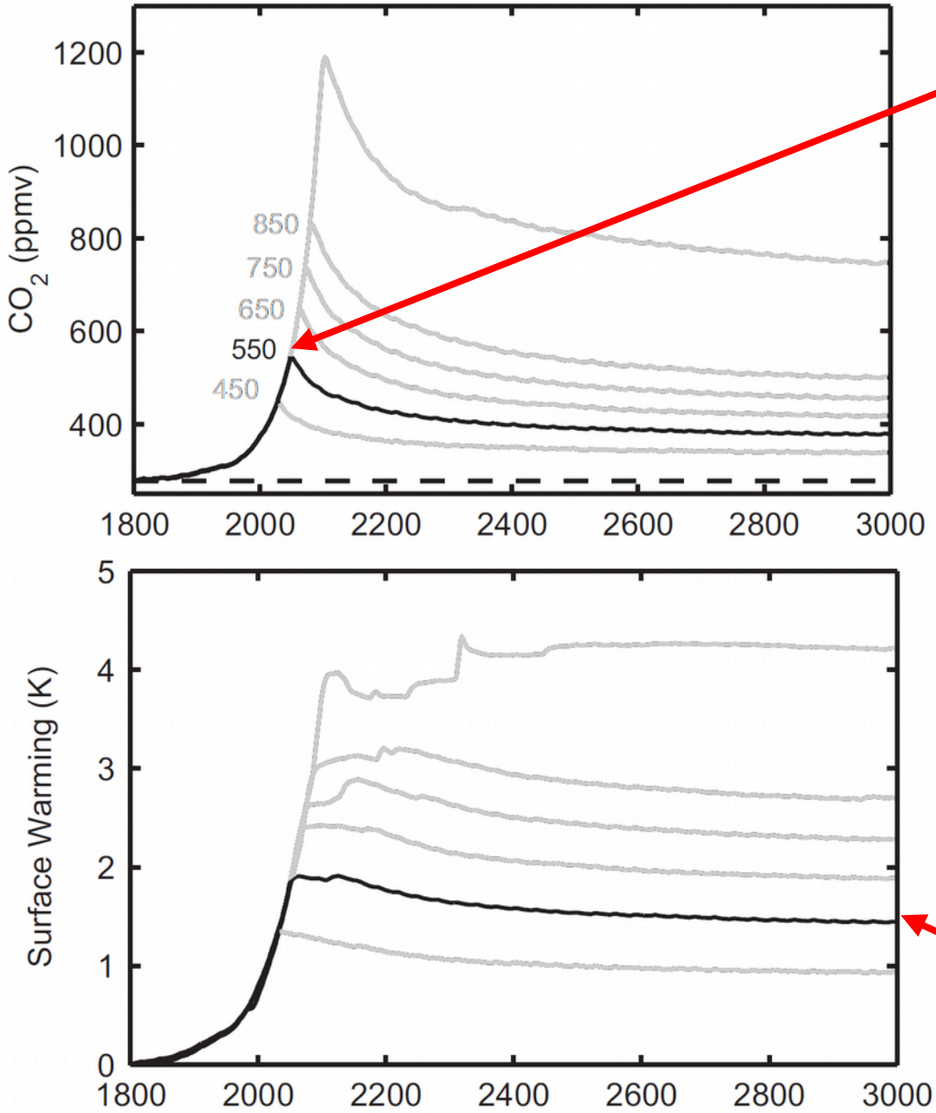
A Typical Long-Term Climate Modelling Study



Suppose fossil carbon dioxide emissions suddenly stop.

This study begins at the start of of the nineteenth century and looks almost one thousand years into the future.

A Typical Long-Term Climate Modelling Study



Suppose fossil carbon dioxide emissions suddenly stop.

Global average temperature will take thousands of years to recover.

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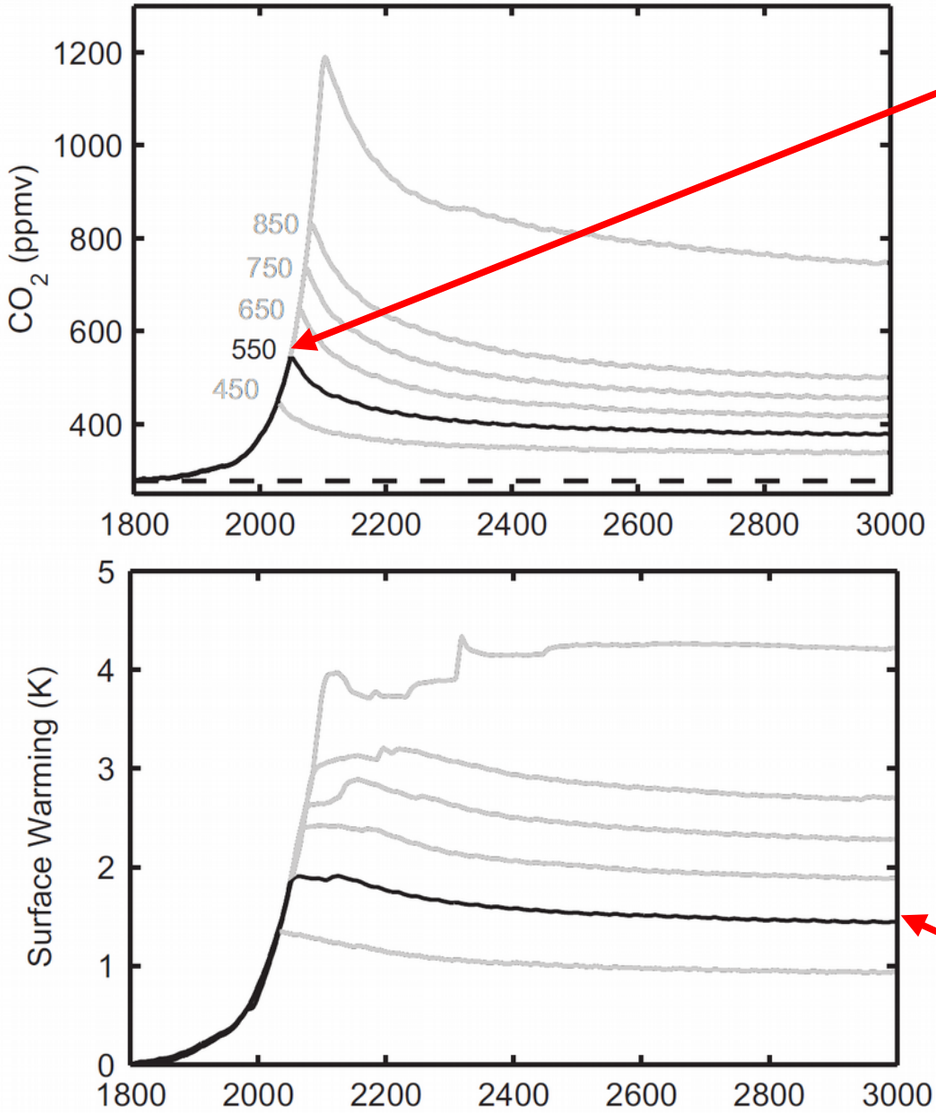


Suppose fossil carbon dioxide emissions suddenly stop.

Scientists are arguing about how many hundreds of thousands of years the warming will go on for.

They are arguing about whether the warming is permanent...

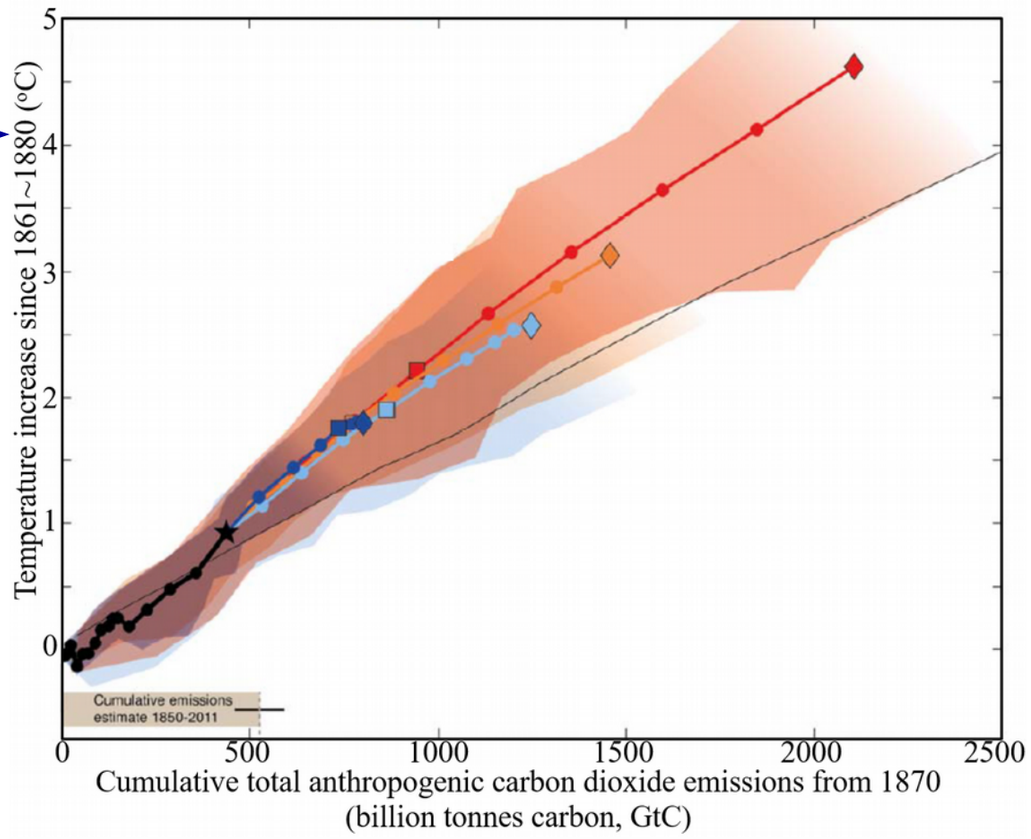
OR

... or whether it is permanent.

Global average temperature will take thousands of years to recover.

IPCC* Published This Chart in 2013

Human-made warming since 1870



* Intergovernmental Panel on Climate Change

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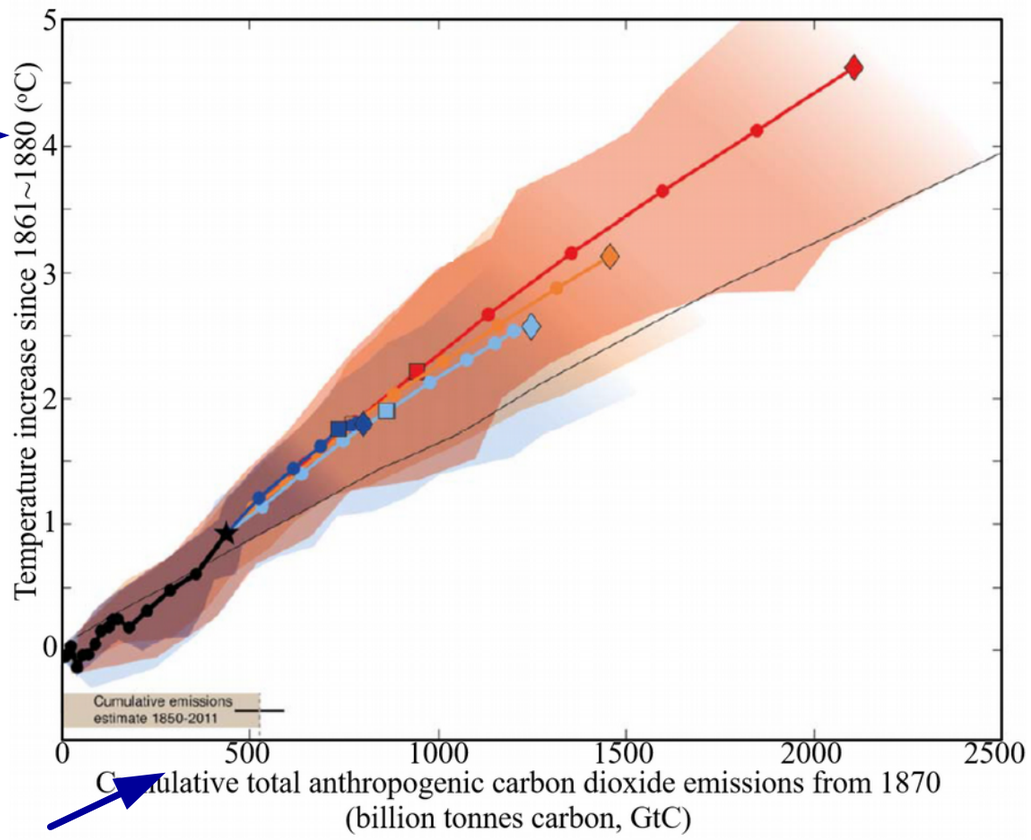
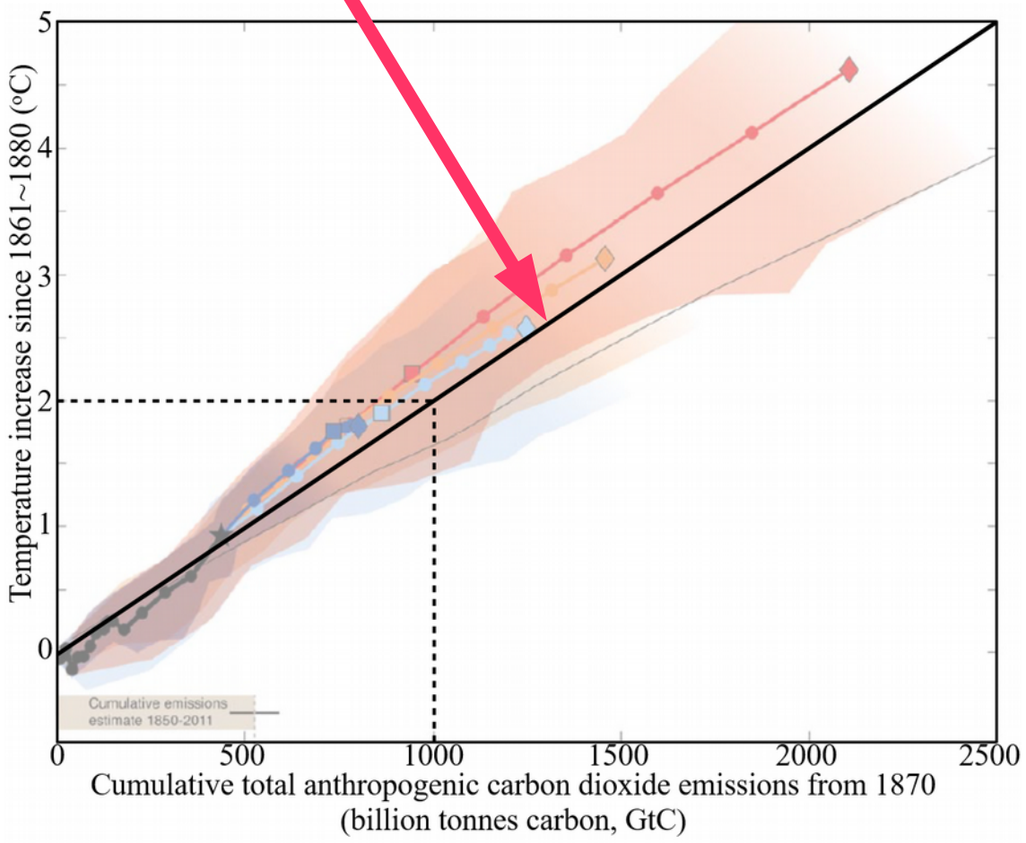


Permanent warming is a linear function of net carbon dioxide added to biosphere

* Intergovernmental Panel on Climate Change

Let's Use the Science

The solid black line shows expected warming for any amount of CARBON DIOXIDE added to atmosphere and oceans



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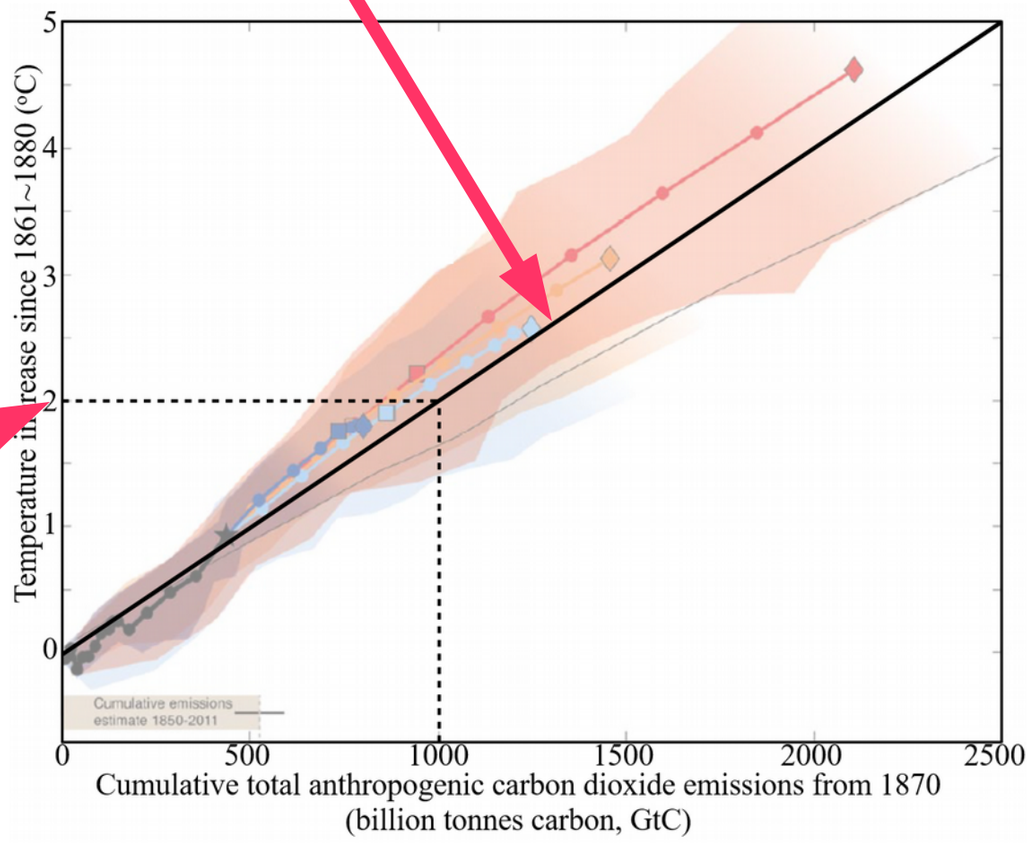
To prevent human-made warming exceeding 2 °C



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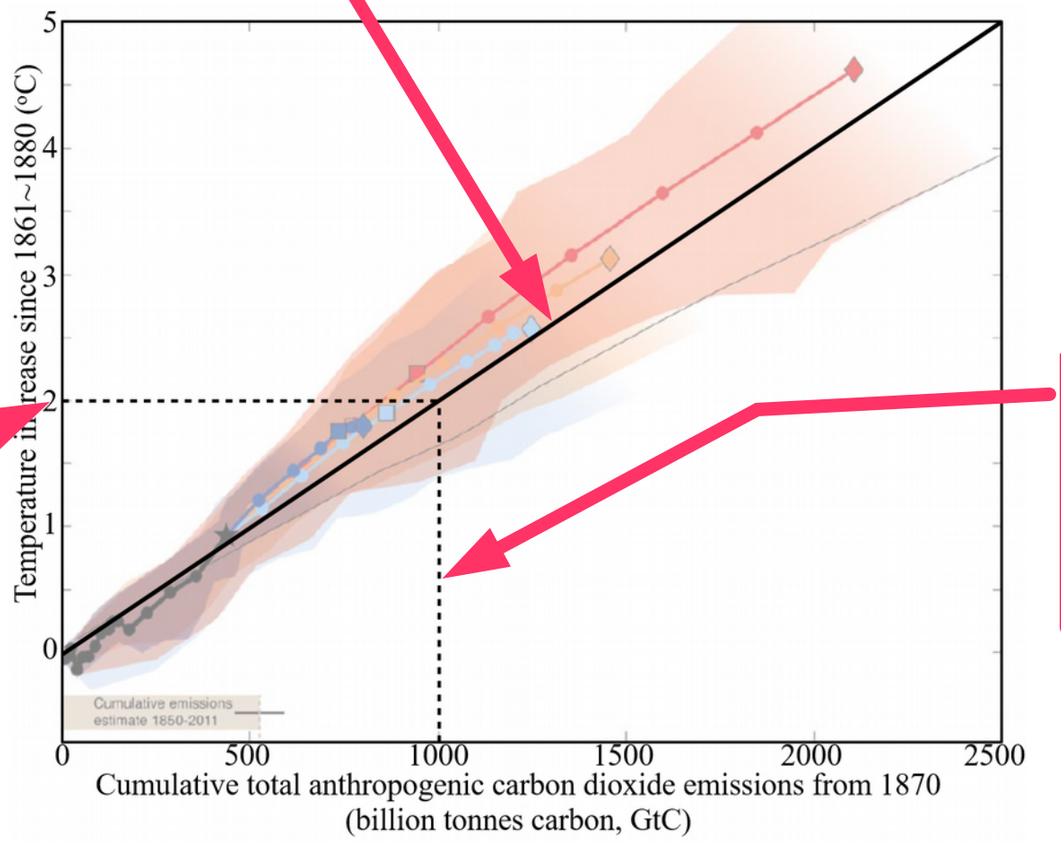

To prevent human-made warming exceeding 2 °C

Cumulative emissions of CO_2 **MUST NOT EXCEED** one trillion tonnes of **CARBON** (= 3.67 trillion tonnes CO_2)

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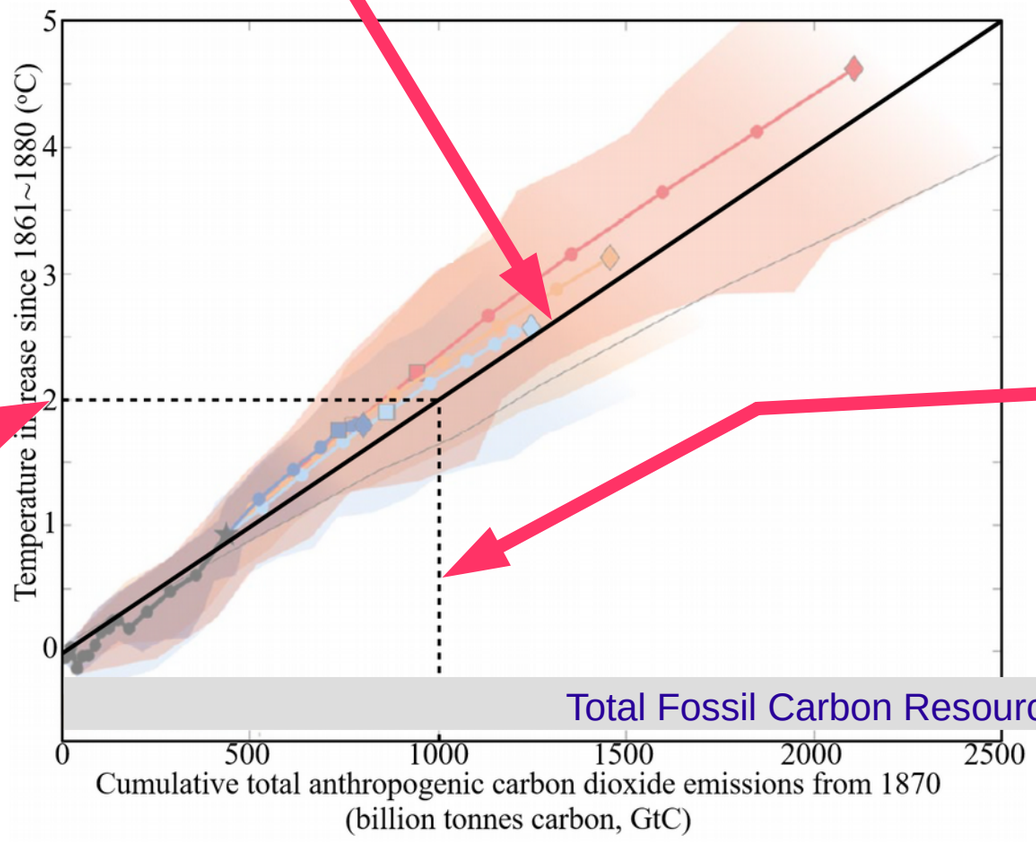

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Total Fossil Carbon Resource ~12 trillion tonnes

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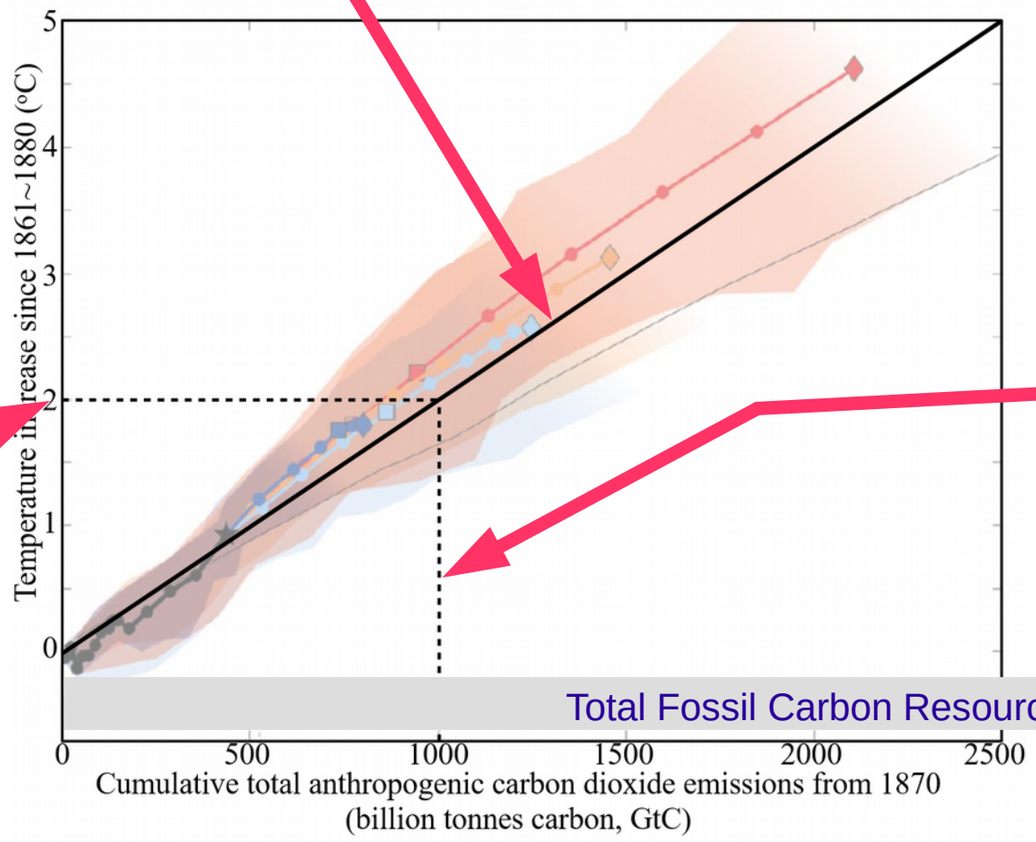

Cumulative emissions of CO_2 **MUST NOT EXCEED** one trillion tonnes of **CARBON** (= 3.67 trillion tonnes CO_2)

Total Fossil Carbon Resource ~12 trillion tonnes

This model does not apply to "FLOW" gases!

Methane (CH_4) & nitrous oxide (N_2O) do not cause CUMULATIVE warming

The Science has Established a Constraint

The sustainable level of net carbon dioxide emissions is

ZERO!!!

The Kyoto Protocol did not acknowledge the need for net-zero CO2 emissions.

The Paris Agreement DOES

The Paris Agreement requires NEW THINKING

The CO_2 Constraint Comes with an Agreed Deadline

The Timescale

"Parties aim to reach global peaking of greenhouse gas emissions as soon as possible... so as to achieve a **BALANCE** between anthropogenic... **SOURCES** and... **SINKS** of greenhouse gases in the second half of this century..."

(UNFCCC, Paris Agreement)

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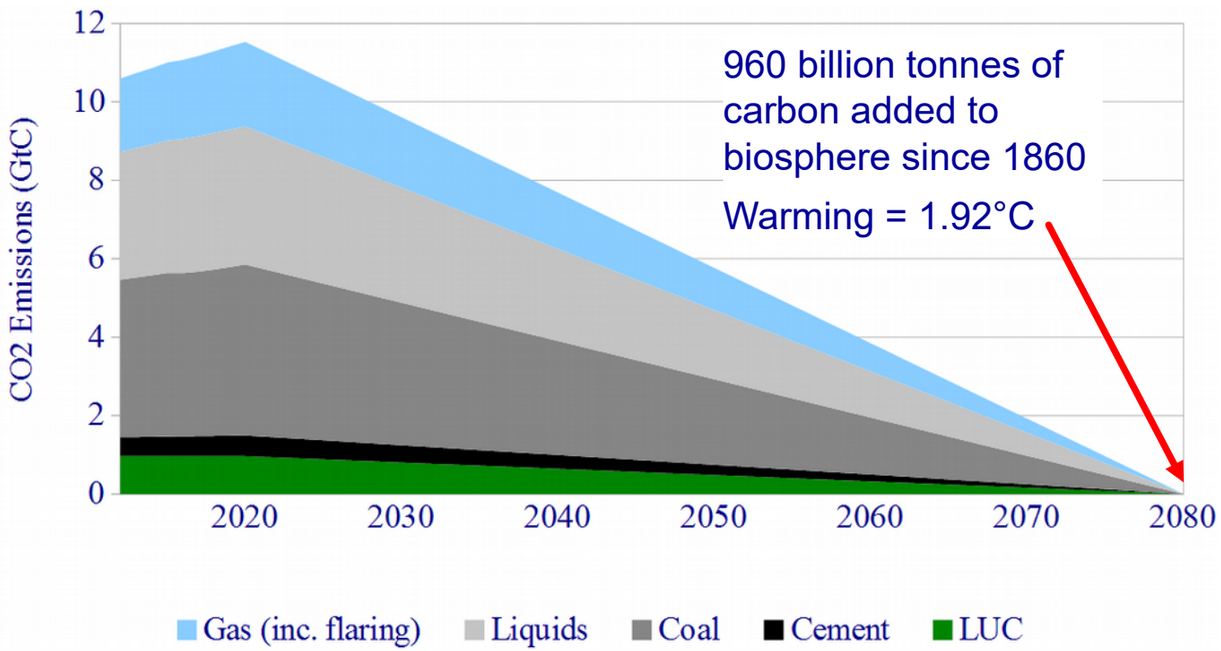

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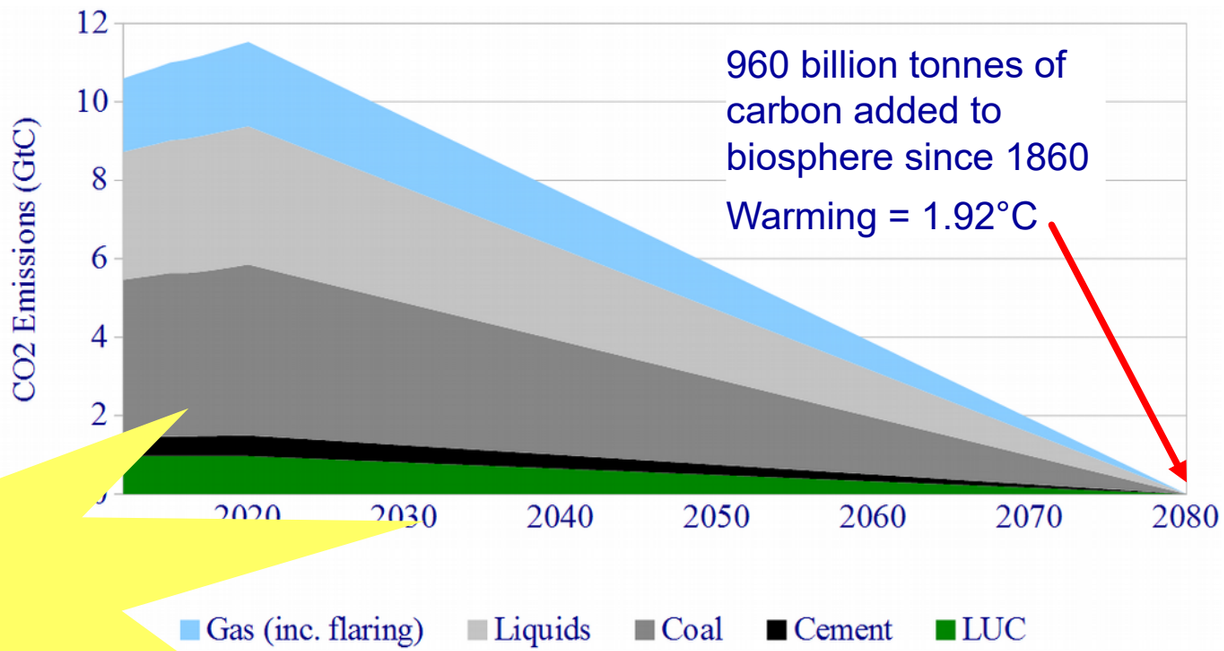
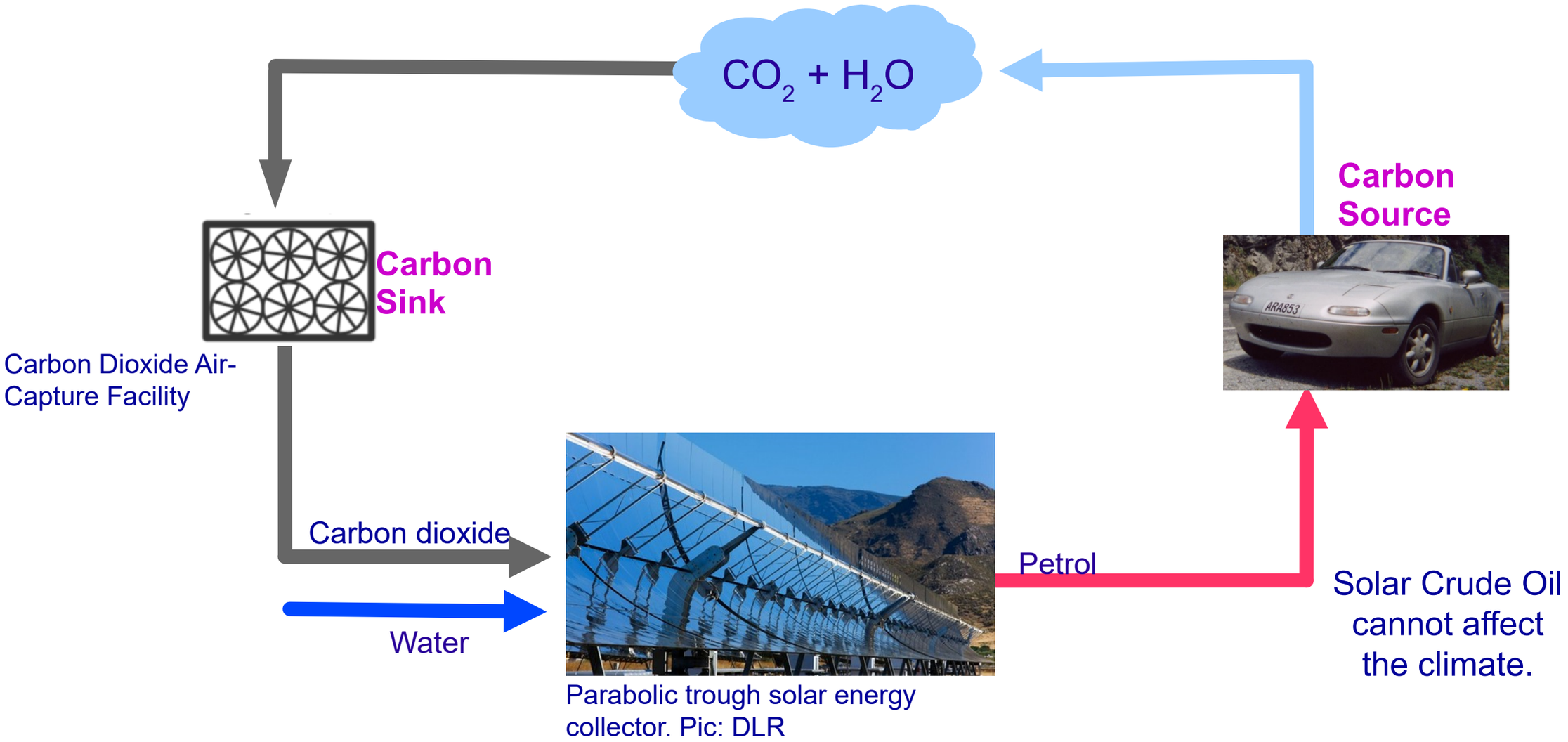


Did YOU know that if we want to stop the warming, we have to TOTALLY STOP putting EXTRA carbon in the biosphere?

The Paris Agreement Sets an Engineering Goal

What	“Hold... the increase in the global average temperature to well below 2 °C above pre-industrial levels...” (Art. 2)
How	“achieve a BALANCE between anthropogenic... SOURCES and... SINKS of greenhouse gases” (Art. 4)
When	“in the second half of this century...” (Art. 4)

Is Energy a Constraint?



Energy Will Never Impose a Constraint

Solar hydrocarbons are drop-in replacements for today's fuels

No new inventions are needed – We already know how to do this!

Every continent has suitable locations.

EROEI >12

If solar fuel production reached 18 billion tonnes/ year (4.**5x** current global consumption)

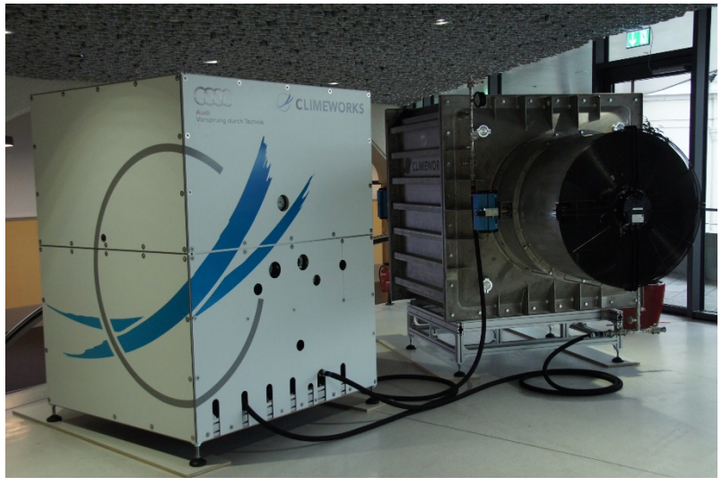
Production facilities (mirrors &c.) would cover < 2.3 % global land area

NEW (Paris Agreement) THINKING:
The supply of carbon-neutral energy **WILL NOT CONSTRAIN** human civilisation.

BUT! New Zealand does not get enough sun.

Needs >2,000 kWh/m²/yr

Sunfire experimental solar crude oil facility in Dresden entered full production late 2015. Photo: Audi.



Clime-works direct carbon dioxide capture system. Photo: Virgin Earth Challenge.

Constraints: Local Air Quality?

Until the mid-late 20th century, if you wanted transportation, you had to accept pollution.

New York, 1852:

It is difficult for those reared after the automobile ousted the horse to realize how [horse] excrement... pervaded the outdoors of the nineteenth-century city, making it a sort of equine latrine.

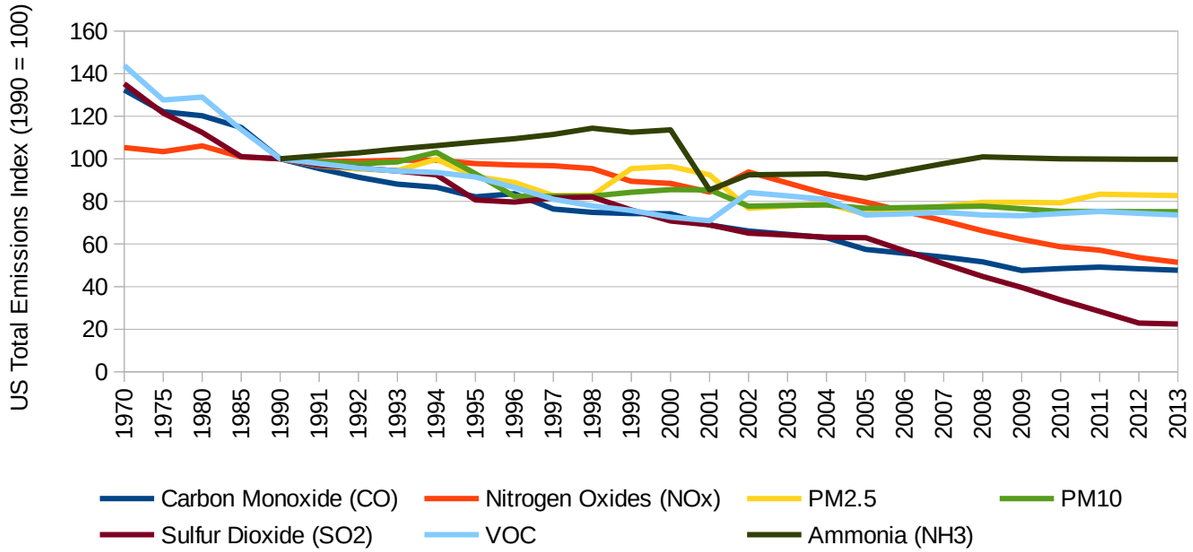
J. C. Furnas, 1970

Tokyo, 1962:

The pollution from exhaust fumes from the thousands upon thousands of cars... was so noxious that traffic policeman carried small oxygen cylinders, while Tokyoites wore face masks and bought oxygen from vending machines.

Robert Whiting (Apr 2014)

Constraints: Local Air Quality?



USA, 1970s:

Air quality regulations in the 1970s triggered a **downward trend in air pollution**

EVEN THOUGH

The US **road vehicle fleet more than doubled** from 111 million in 1970, to 254 million in 2013

New Zealand, today:

Outside of Auckland, most air pollution in NZ is caused by domestic fires

Globally, today:

Most air-quality-related health problems are caused by SOOT from fires, especially solid-fuel cooking – **not vehicle exhaust**!

Diesel-powered Peugeot 908 with Euro 5 anti-smog gear in the 2008 Le Mans 24 hours

Tetra-Ethyl Lead

Carbon Monoxide

Tetra Ethyl Lead

Teched!

Carbon Monoxide

Teched!

Sulphur Oxides (SOx)

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DODGY SOFTWARE

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DODGY SOFTWARE

Portable Emissions Measurement System

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DODGY SOFTWARE
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Portable Emissions Measurement System

Exhaust Treatment & NOx Emissions

NOx is the main focus of new air quality rules in **DEVELOPED COUNTRIES**

NOx is a precursor to photochemical smog

NOx is a mixture of two gases:

Nitric Oxide (chemical symbol “NO”), and
Nitrogen Dioxide (“NO_2”)

... but **NOT** Nitrous Oxide (N_2O)

“Real-World” testing shows that exhaust treatment technology on **HEAVY-DUTY VEHICLES** built after 2010 works better than expected, for both particles and NOx

BUT:..

Real-world NOx emissions from diesel **CARS** in **EUROPE** need to improve

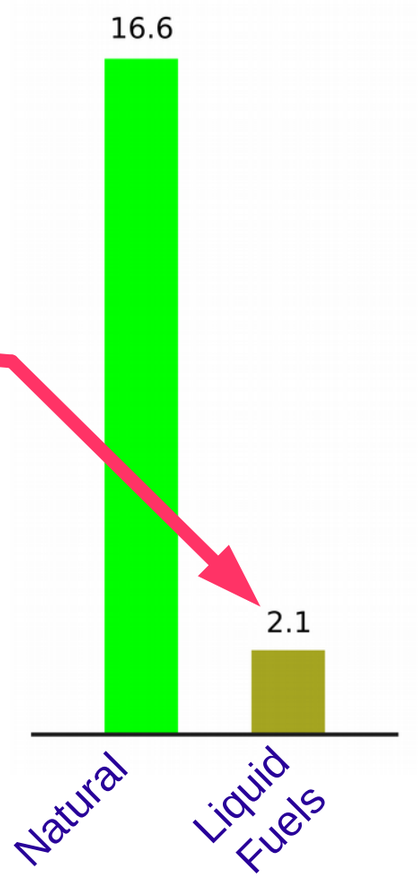
SO:..

New RDE (real driving emissions) testing protocols are being phased in between Sept 2017 and January 2021 for new cars sold in Europe

2012 Euro V Freightliner makes 95%-99% less soot than 2004 model

Air Quality will not be a Constraint

Global NOx emissions (Mt-N/yr)
(Hypothetical present-day)



What if
Everything that burns liquid fuels today complied with current USA EPA regulations for **TRUCKS (**0.2 g/bhp-hr)?

Actual present-day anthropogenic NOx emissions ~28 Mt-N/yr

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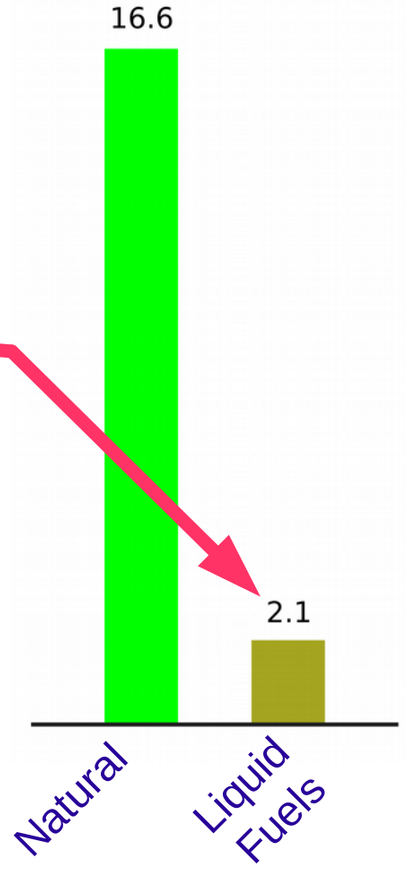

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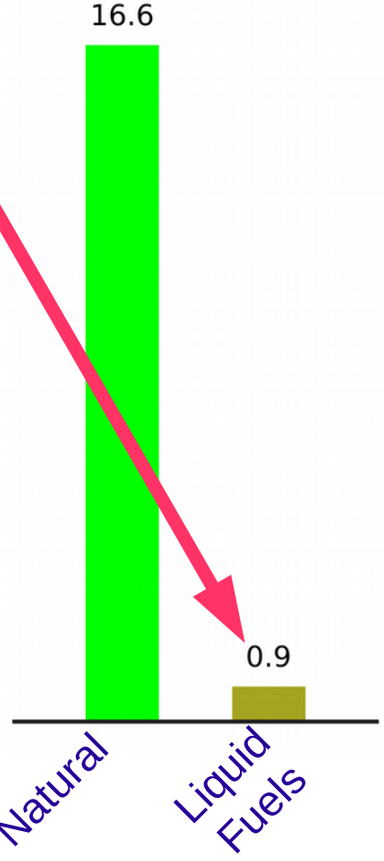

What if
Population = 11 billion,
Annual fuel use grows 450% to >18 bn tonnes,
And everything that burns liquid fuels complies with proposed USA EPA regulations for **TRUCKS** (0.02 g/bhp-hr)

Actual present-day anthropogenic NOx emissions ~28 Mt-N/yr

Air Quality will not be a Constraint

Global NOx emissions (Mt-N/yr)
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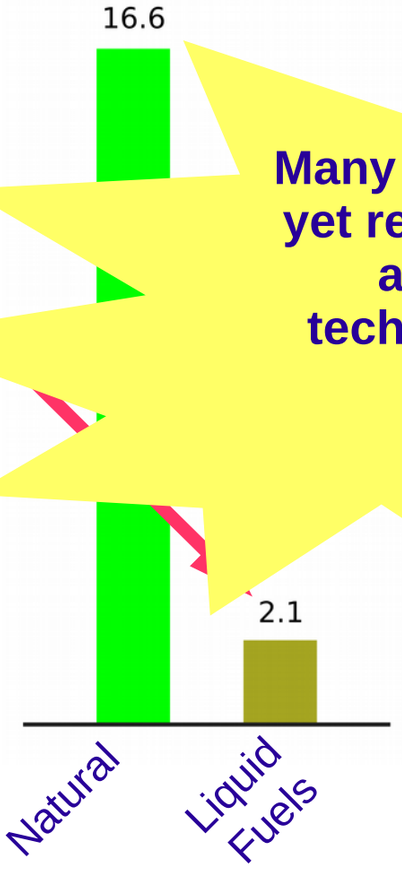

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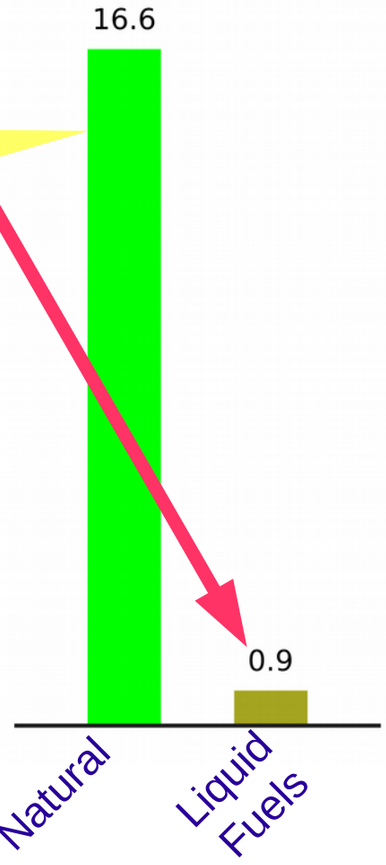

What if
Everything that burns liquid fuels today complied with current USA EPA regulations for **TRUCKS (**0.2 g/bhp-hr)?

Many countries do not yet require up-to-date anti-pollution technology on road vehicles!!!

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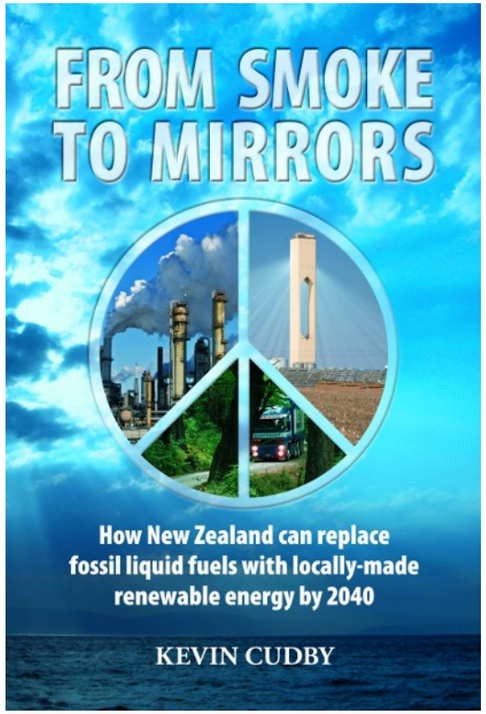
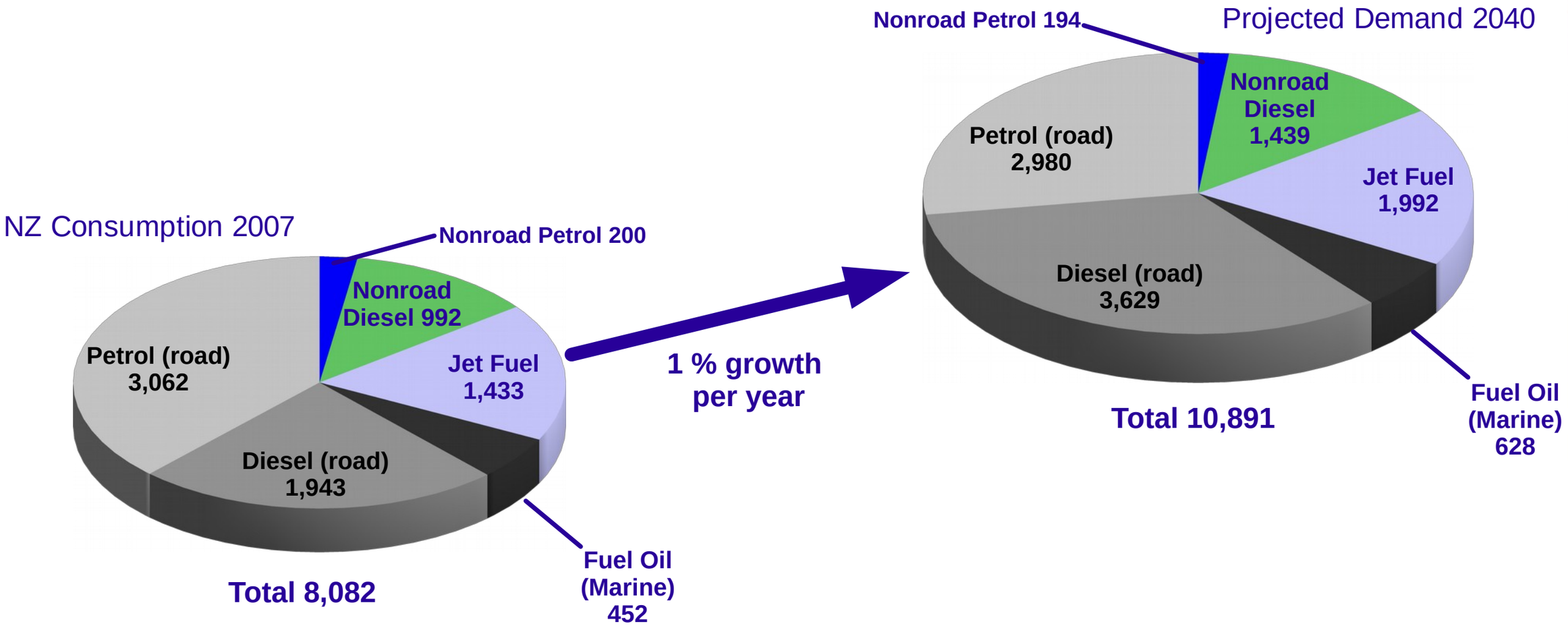


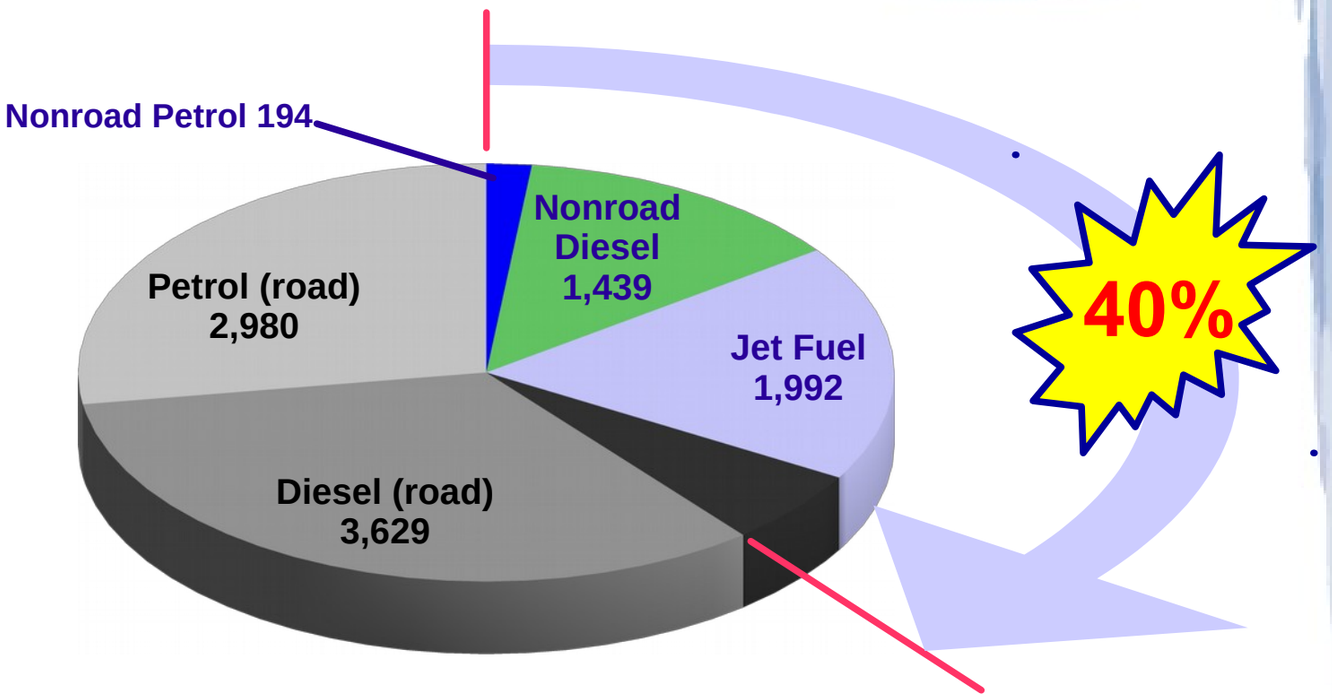
NZ Requirements

Projected NZ Demand for Liquid Hydrocarbons

(or Substitutes) (millions of litres per year)



Non-Road Fuel is Vital

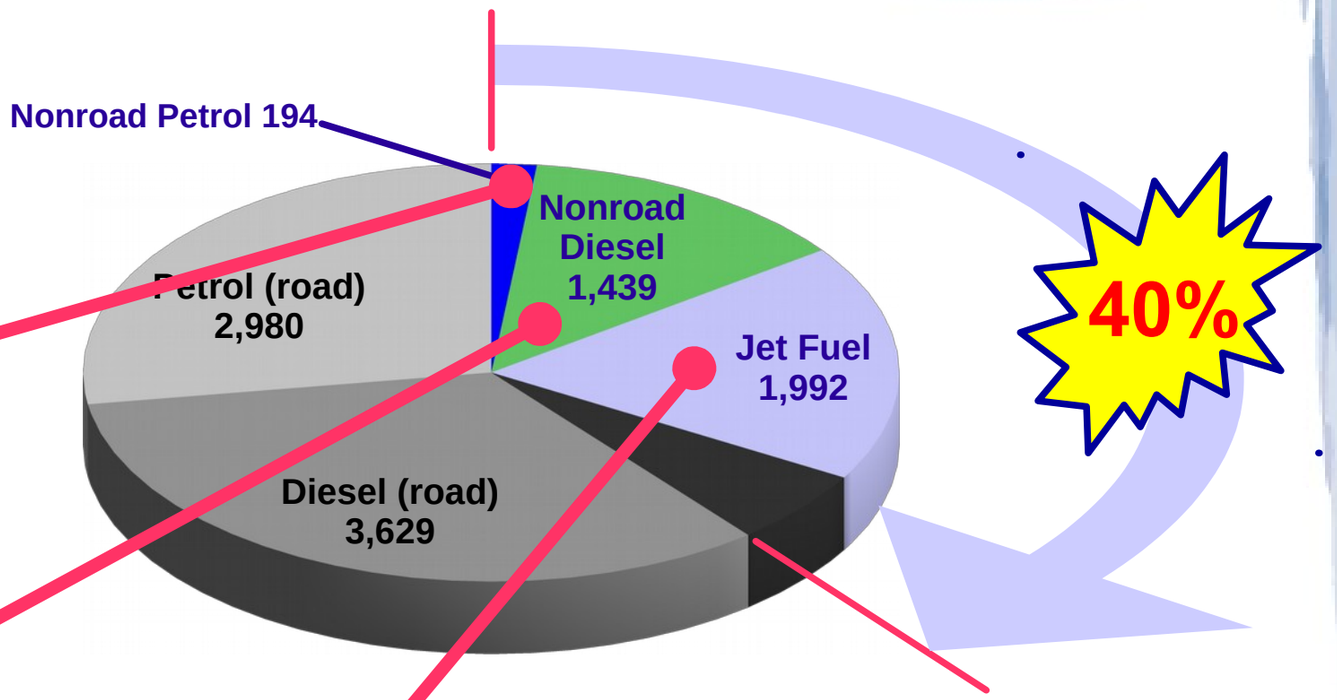


Non-Road Fuel is Vital

Petrol drums stowed on deck of anti-whaling protest ship “Bob Barker”, Taranaki Street Terminal, Wgtn.

An agricultural contractor in Wairoa uses this diesel tank and a tanker trailer to support a fleet of tractors.

Jet fuel tanker, Queen’s Wharf, Wellington.



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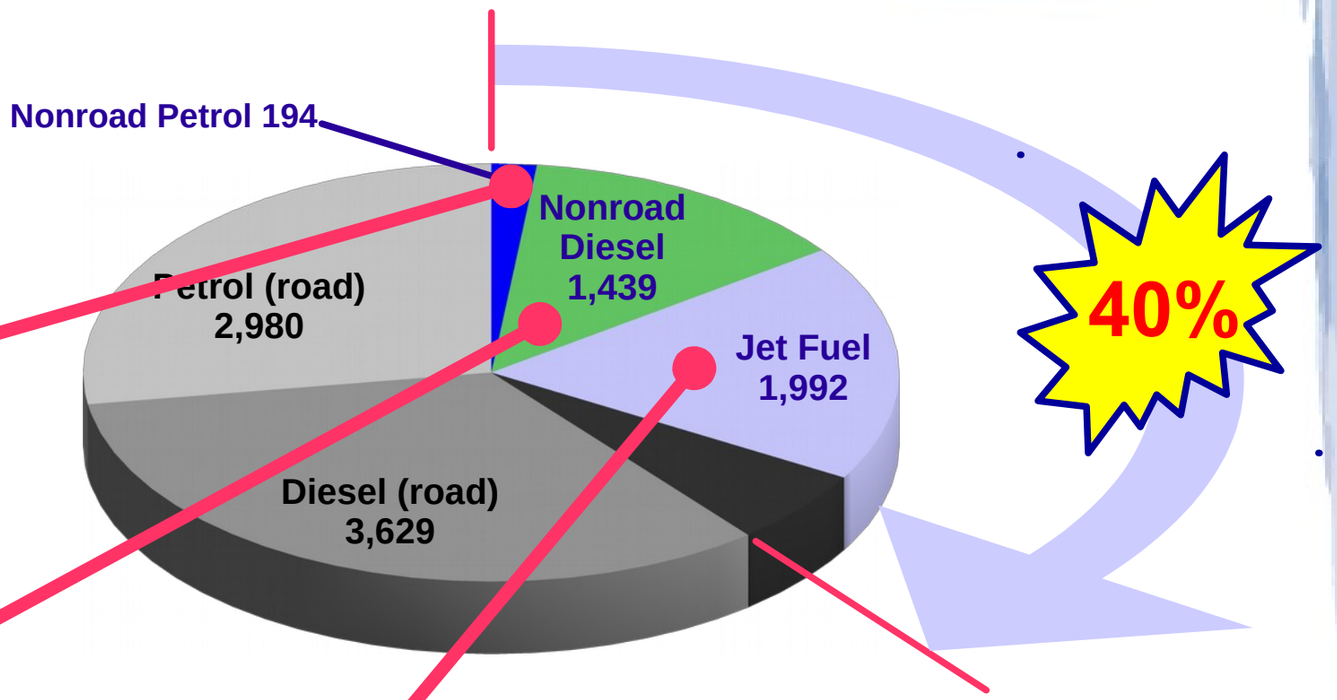
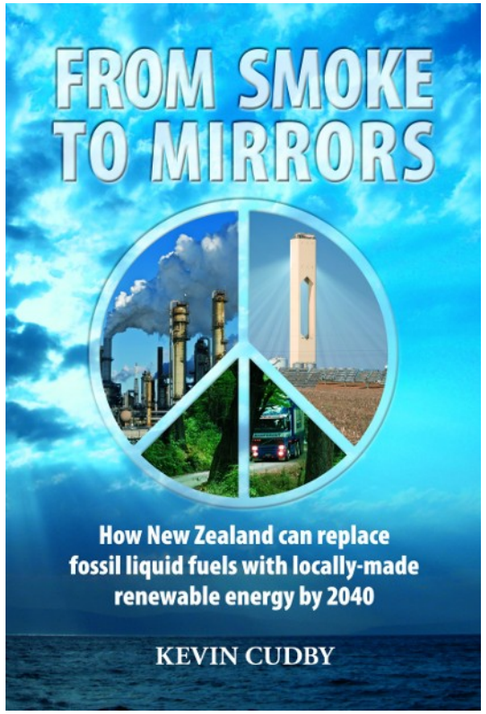
An agricultural contractor in Wairoa uses this diesel tank and a tanker trailer to support a fleet of tractors.

Jet fuel tanker, Queen’s Wharf, Wellington.



Globally

Non-road applications account for **at least one-third** of total liquid fuel consumption



Carbon-Free Vehicles

Carbon-Free (“Electric”) Vehicles

Two major candidates:

- Hydrogen Fuel Cell Vehicles (HFCV)
- Battery-Powered Vehicles (BEV)

No carbon dioxide (CO_2) tailpipe emissions

... Theoretically: Reduce the **SOURCE** of CO_2

Hydrogen or Electricity must be carbon-neutral

“Electric” vehicles don’t make soot!

But all road vehicles create tyre emissions

Hydrogen Fuel Cell Vehicles

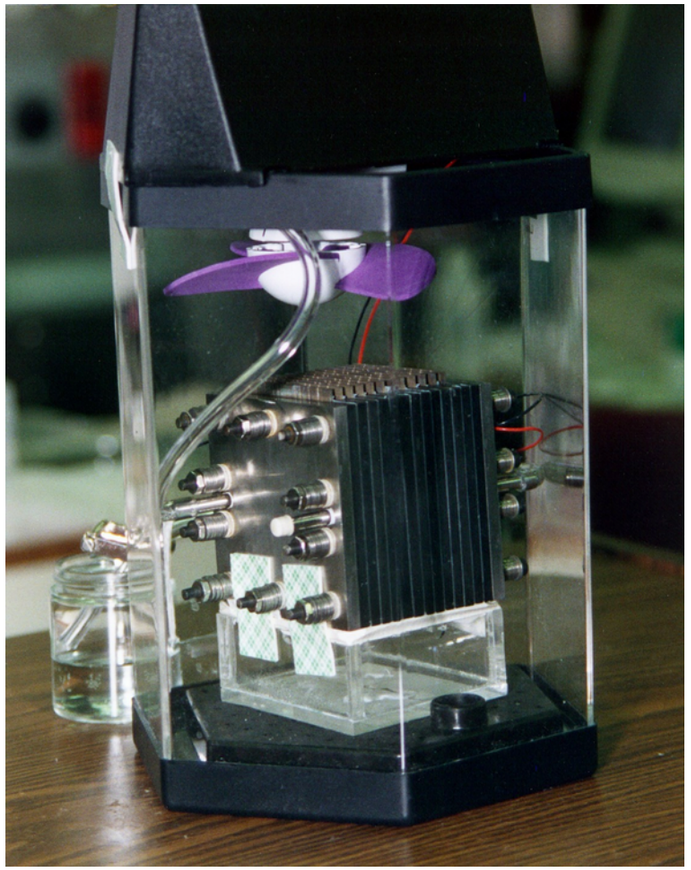
First hydrogen fuel cell demonstrated in 1839 by Sir William Grove

Hydrogen Fuel Cell is like a “refuelable battery”

Hydrogen + Air → Electricity + Water

The fuel cell generates electricity which drives an electric motor

Hydrogen fuel-cell vehicle drivetrain often has the same parts as a battery-powered vehicle from the same manufacturer



A small experimental fuel cell. Instead of an exhaust pipe, it has a drain pipe. Note the jam jar to catch the water.

Hydrogen Vehicles: Operating Cost

How much will it cost to buy enough renewable hydrogen to drive **the same distance** as you can drive on one litre of petrol or diesel?

	Price per kilogram.	Cost to drive same distance as one litre of diesel.	Cost to drive same distance as one litre of petrol.
Biomass Gasification*	$7.21	$1.35	$1.06
Solar Photovoltaic (PV)*	~~$35.20~~ $20.00	~~$5.63~~ $3.07	~~$4.20~~ $2.25

Solar panel prices have fallen since my book came out

Hydrogen can also be produced by using grid electricity to split water. To do this for all road transport in New Zealand would increase total electricity demand by about **82 % - 120% ! !!**

These costs include worst-case distribution cost estimates by hydrogen critics.

Solar photovoltaic panels at Rarotonga International Airport

* 2008 dollars, excluding inflation, GST and taxes. Excluding tax, diesel in 2008 was about $1.012 per litre.

Battery Vehicles

Before Petroleum...

1859: First rechargeable battery (Gaston Planté, lead-acid)

Some cars in the mid-late 19th century had rechargeable batteries driving electric motors.

Renewed interest spurred by **lithium-ion** rechargeable batteries (as in cellphones, tablets, laptops, etc.)

Lithium-ion batteries can store more energy per tonne than older rechargeable batteries.

Morris & Salom Electric Cab, New York, 1890s. World's first horseless hansom cab.

1901 Columbia Electric Victoria Phaeton..

Battery Vehicles: Operating Cost

Estimated cost* in 2040 to buy enough battery (depreciation) and electricity, to **drive the same distance** as you can drive on one litre of petrol or diesel:

	Cost to drive same distance as one litre diesel	Cost to drive same distance as one litre petrol
Family car	$5.79~$23.28	$4.21~$16.92
Commercial vehicle or shared/rental car	$1.68~$5.73	—

Lucid Air: 1000 horsepower battery-powered luxury car.
Price? I have no idea but it will be **HEAPS**

Batteries have to be replaced several times during the life of a family car

Battery component (especially cathode) manufacturing has very high scrap rate, typically >60%

It takes a lot of coal to make a lithium-ion battery!

That's why battery depreciation is so expensive

* 2008 dollars, excluding inflation, GST and taxes.

Battery Vehicles: Resources

To run NZ's road transport system exclusively on batteries we would have to increase total generating capacity by 40%–56%

New Zealand would need to develop untapped resources such as biomass or tidal power

Most or all of NZ's power grid would need significant upgrading.

Power prices would go up

This substation near Pauatahanui can supply up to ten Megawatts of electric power.
That's enough to simultaneously fast-charge (8~10 minutes) three trucks or sixteen cars. Photo: Kevin Cudby.

Carbon-Free Vehicles: Range/Payload

I compared the range and payload of trucks.

Trucks are in the middle of the technical spectrum between cars and aircraft.

	Diesel	Battery*	Hydrogen
Operating Range	660 km	320 km	320 km
Total loaded weight	44 tonne	44 tonne	44 tonne
Payload	25+ tonne	~18.8 tonne	25+ tonne

If battery and hydrogen trucks can be refueled halfway through a shift:

One hydrogen-powered truck can do the same work as one diesel truck

BUT

It takes four battery-powered trucks to do the same work as three diesel trucks.

Fonterrra truck-and-trailer milk tanker near the Manawatu Gorge

Toyota 670 hp hydrogen fuel cell tractor-trailer. Rated up to 36 tonne gross combined mass. Range >320 km per fill.

Fuso eCanter: 7.5 tonnes gross, with 83 kWh battery. Range 100 km per fill

* The battery-powered truck needs a 7.6 tonne battery.

Carbon-Free Vehicles: Life Expectancy

Hydrogen

No hint of calendar life issues

Satisfactory life expectancy:
... 25,000 operating hours,
... >300,000 km (Daimler B-Class)

Toyota Mirai:
Hydrogen fuel cell
with NiMH battery.
$US 57,500 in USA
(2015)

Battery

Calendar life expectancy of lithium-ion batteries is 7 – 8 years from date of manufacture, whether the battery is used or not
... Important for family cars

Cycle life ~1,000 – 4,000 charge-discharge cycles.
... Important for commercial vehicles, shared cars, etc.
... A truck-driver can wear out a battery before it goes rotten

2011 Nissan Leaf at Lower Hutt Pak ‘n Save, July 2017
Range per charge:
2011 = 200+ km
2017 = 130 km

Carbon-Free Vehicles: Summary

Battery and hydrogen vehicles are **more dependent on infrastructure** than conventional road vehicles. You can carry a useful amount of petrol or diesel in jerry can.

TERRIBLE substitutes for conventional vehicles.

USELESS for most non-road applications.

Battery vehicles will become common in niche applications such as buses and small delivery vehicles long before battery cars are economic

CHANGING OUR CARS WILL NOT COMPLETELY BALANCE ANTHROPOGENIC CARBON DIOXIDE SOURCES AND SINKS!!!

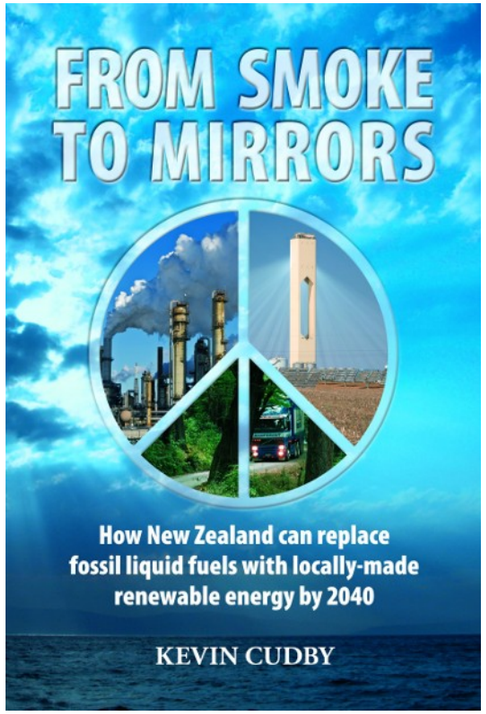
Top: Proterra Hydrogen Fuel Cell Bus.
Bottom: Proterra Battery-Powered Bus.

“Electrified” cars need hydrocarbon fuels...

The Mitsubishi Outlander P-HEV and the Toyota Prius are hybrids. They **NEED** petrol!

Exhaust Pipe

Most hybrid cars run on petrol (gasoline)...
... and most of the rest are diesel-electric hybrids.


FROM SMOKE
TO MIRRORS
How New Zealand can replace
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KEVIN CUDBY

Biofuels

Biofuels

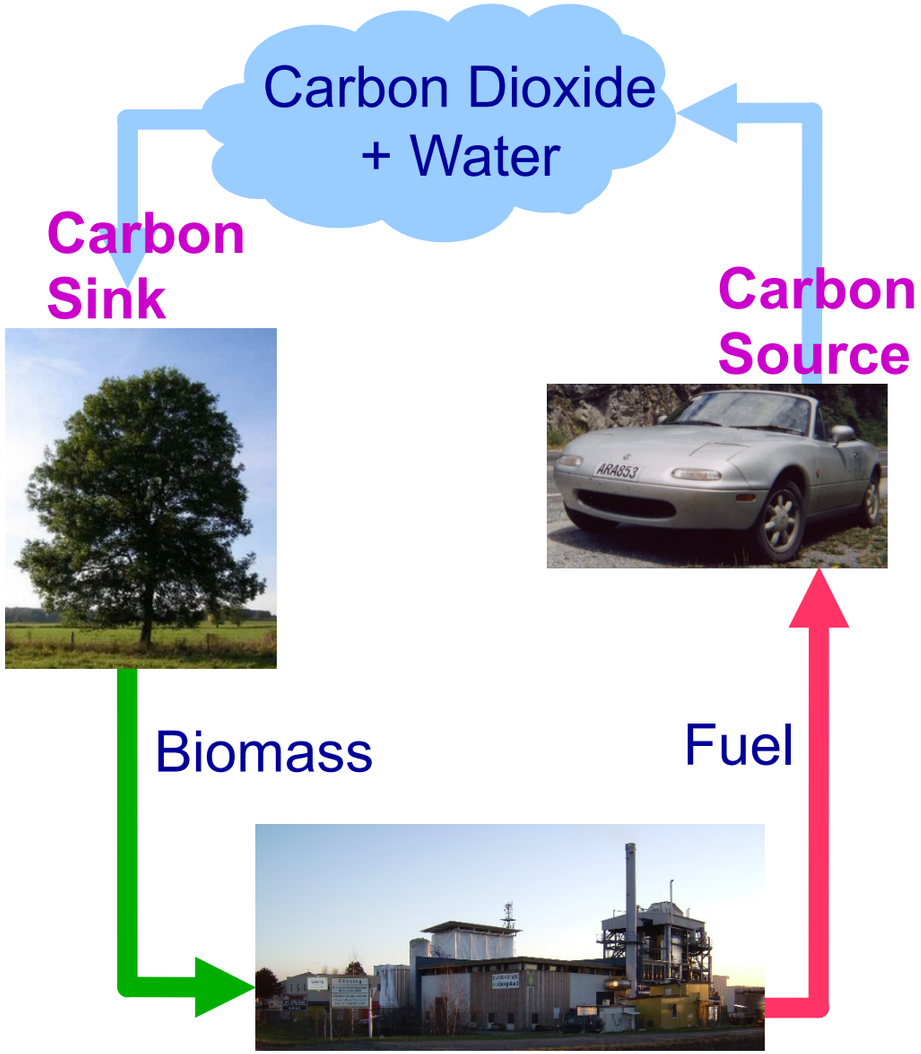
Carbon dioxide tailpipe emissions (**SOURCE**) balanced by carbon dioxide absorbed by growing biomass (**SINK**)

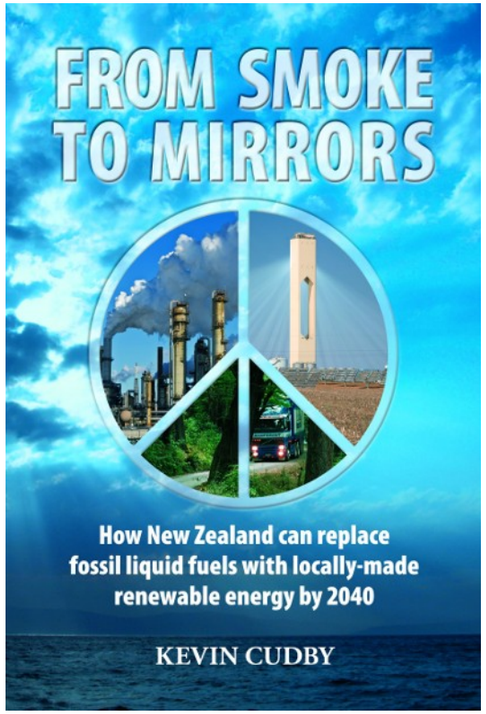
In a fully carbon-neutral economy, biofuels will be 100% carbon-neutral

In Plain English:
If we FIX the Climate, all biofuels will be 100% carbon-neutral

There are two Major Groups

- Alternative Fuels (Ethanol, Biodiesel...)
- Renewable Crude Oil





Alternative Fuels/ Agricultural Biofuels

Photo: World Elite Spirits.

Ethanol

Ethanol has been used in spark-ignition engines since they were invented (1854).

Can be used as an additive, or blended with petrol as E85 (up to 85% ethanol). (requires special engine)

Can be made from a wide range of raw materials. Any raw material that can be made into grog, can be made into fuel.

Almost all of today's fuel ethanol is made from agricultural products such as corn, sugar-cane, wheat, sugar-beet, etc.

NIWA/Scion research indicates large-scale production of agricultural ethanol would significantly reduce NZ's exports.

Top: Henry Ford was a strong advocate of running cars on ethanol
Bottom: Alcohol fuels (methanol, ethanol) have been popular in motor-racing

Cellulosic Ethanol

Numerous “cellulosic” (second generation) ethanol facilities are now starting production.

These facilities convert cellulose from straw and other agricultural waste into fermentable sugar, which is then made into ethanol using standard brewing, fermentation, and distillation processes.

BUT... Farmers like to return agricultural “waste” to the soil.

Short-rotation hardwood forestry (SRF) has been proposed as a source of raw material for cellulosic ethanol.

Short-rotation forestry as usually described in the literature is a form of agriculture.

Short Rotation Forestry.

Photo: CHOREN

Biodiesel

Biodiesel is not a fuel, it is a group of man-made chemicals, some of which can be used as fuel in some diesel engines.

Biodiesel is made from certain types of vegetable oils and animal fats: rapeseed (canola) oil, soybean oil, castor oil, sunflower oil, safflower oil, mustard oil, beef tallow...

Each raw material yields a different kind of biodiesel.

Biodiesel can be made in the suburban garage, but... the traditional process involves cooking a mix of vege oil and methanol, which is flammable. Be very careful. Some biodiesel enthusiasts blow up their garages.

Biodiesel

Large-scale biodiesel production in New Zealand would require purpose-grown agricultural raw materials such as rapeseed (canola) oil.

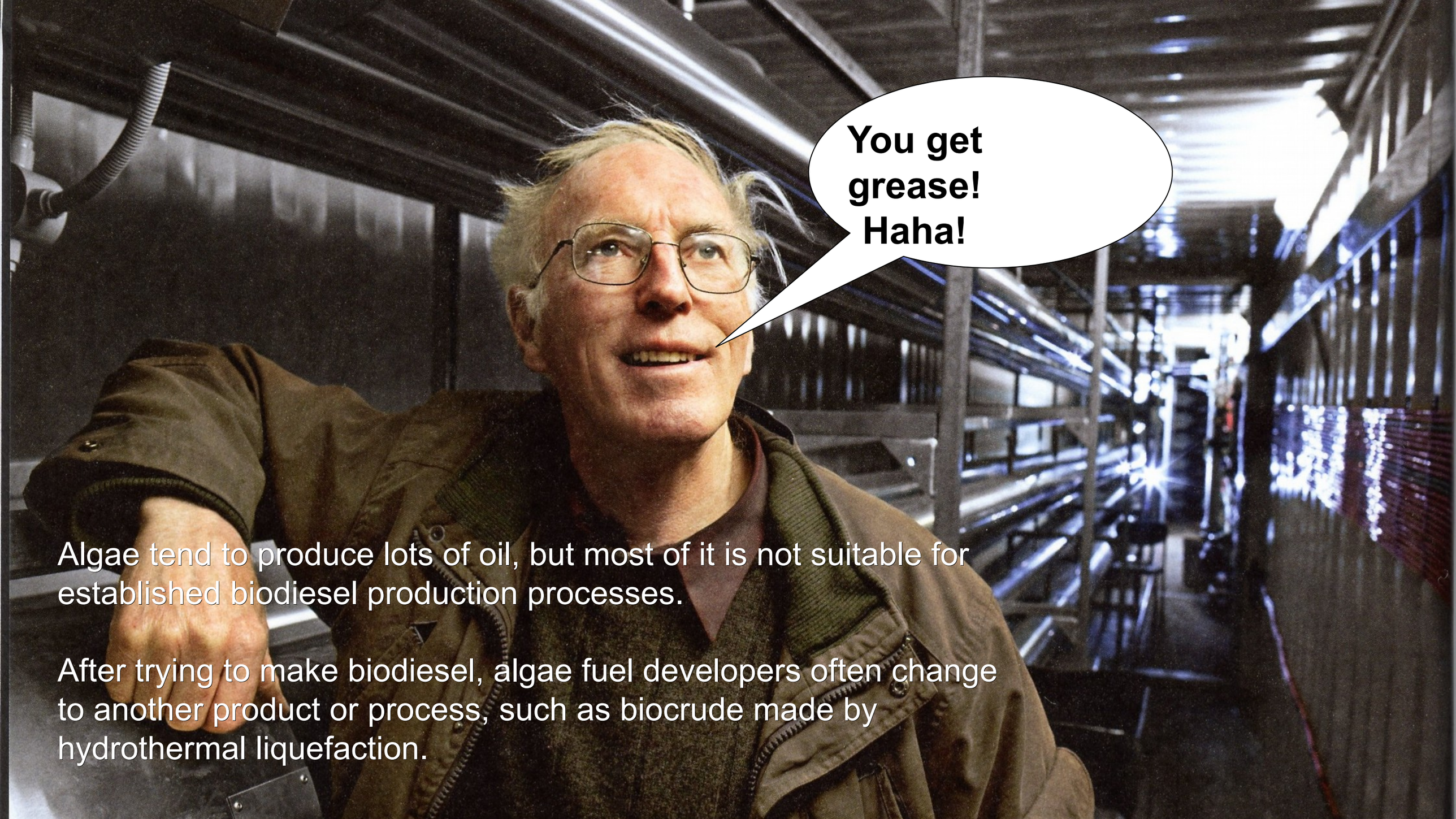
New Zealand does not have enough arable (flat, fertile) land to replace conventional diesel with biodiesel. Exports would be severely curtailed.

Biodiesel can be used as a lubricity additive in diesel and jet fuel.

Fuel systems depend on the fuel for lubrication.

~2% biodiesel usually solves the problem.

New Zealand can make enough biodiesel to satisfy this requirement from byproducts (esp. tallow), used cooking oil, and a small amount of purpose-grown canola.



Algae tend to produce lots of oil, but most of it is not suitable for established biodiesel production processes.

After trying to make biodiesel, algae fuel developers often change to another product or process, such as biocrude made by hydrothermal liquefaction.

Algae

Algae are interesting as a raw material for biofuel, because of their high photosynthetic efficiency

BUT... This is usually wildly over-hyped.
In New Zealand, algae might optimistically produce three times as much biomass per hectare as energy forests.

HOWEVER...
Algae production requires flat land, which, in New Zealand, would otherwise be used for food production.

After many decades of research, we have learned...
... Production cost is ~10–100 times greater than other renewable fuels.
... EROEI is very poor, ~0.5:1
... Algae biofuels require “real scientific breakthroughs.” J. Craig Venter.

The primary objective of NIWA’s Christchurch algae experiment was to remove nutrients (nitrates, phosphates) from effluent.

FUEL WAS A BYPRODUCT!

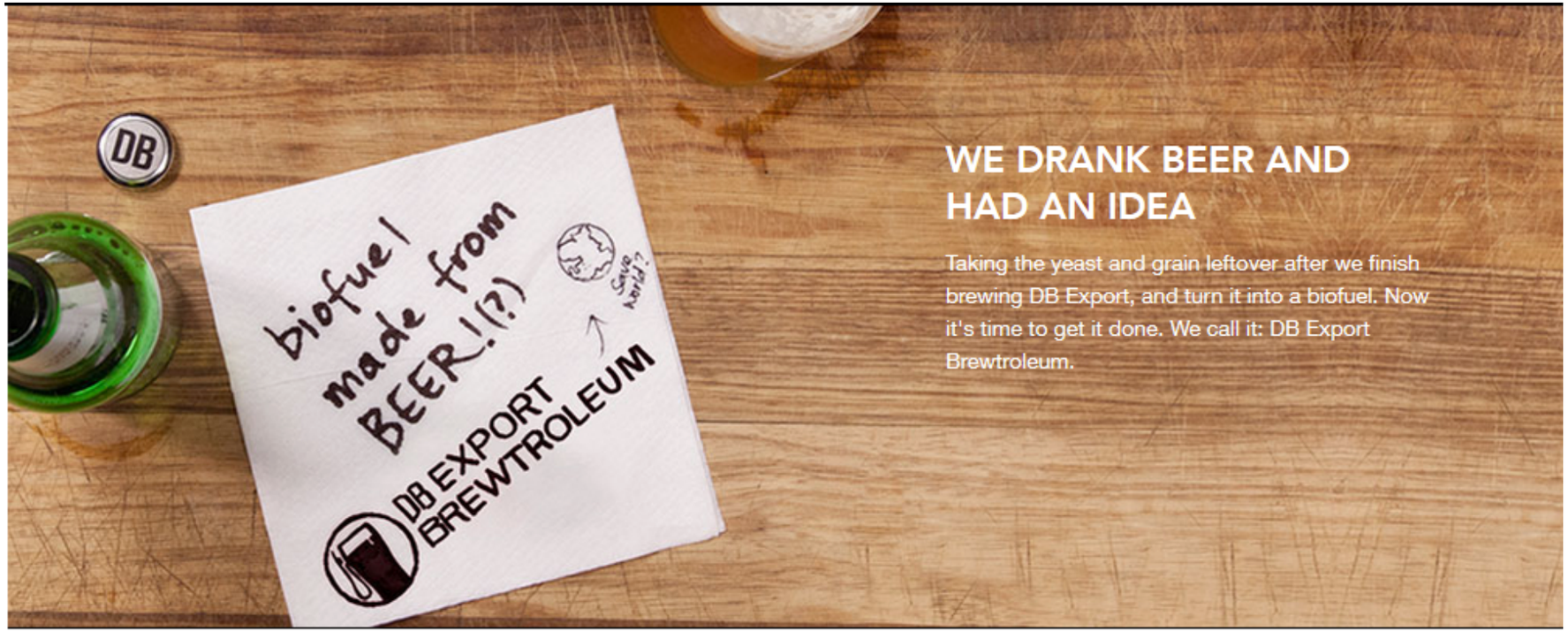
High-rate algae pond at the Christchurch sewage treatment plant.
Photo: Rupert Craggs.

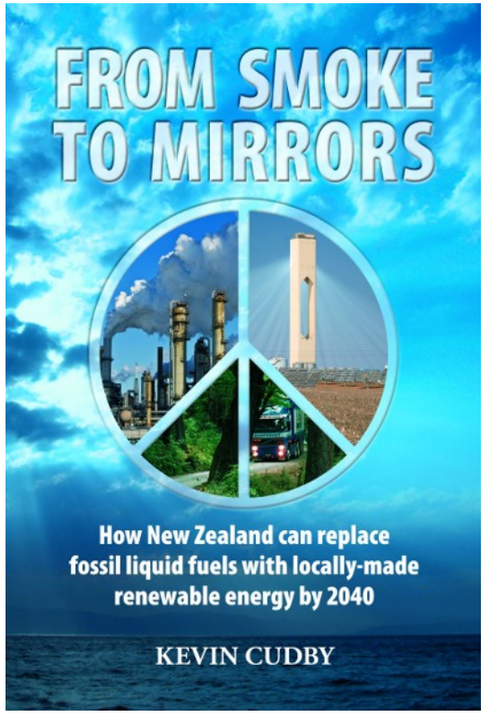
Waste-to-Energy

Waste-to-energy systems are usually very good at displacing fossil carbon dioxide emissions.

Some waste to energy projects are economic in their own right.

BUT : We **do not throw away enough** stuff to run all our cars, aeroplanes, boats, etc..
EXAMPLE: 96% of Sweden's rubbish is recycled or converted into energy. But, energy from rubbish supplies only 3.5% of Sweden's total energy demand. Very little room to increase market share.





Synthetic Hydrocarbons

Synthetic Hydrocarbons

Sometimes called “second-generation”, or “advanced” biofuels.

Drop-in replacements for methane, LPG, petrol, kerosene, diesel, & fuel oil.

There are several proven methods of making hydrocarbon fuels out of biomass

This “Electric” (Hybrid) Car Runs On Petrol!

Hydrotreated Renewable Fuel

Hydrotreatment: A chemical reaction between raw material and hydrogen

HR fuels can be made from vegetable oils and animal fats, and also waste oils from industrial processes such as paper-making

HR fuels (sometimes called “HEFA”) are mostly paraffins (alkanes):

- **Clean Burning (low soot production)**
- **Low Toxicity**

Hydrotreated renewable (HR) diesel and jet fuel are commercially available now

No country can produce enough raw materials to replace conventional fuels with hydrotreated fuels

Neste Oil’s 940 million litre per year Hydrotreated Renewable Fuel Plant in Rotterdam converts vegetable oil or waste fat into diesel

Biomass Gasification + Fischer-Tropsch (BGFT)

Biomass such as wood is first converted into syngas (hydrogen + carbon monoxide) by Gasification.

Gasification was developed in 19th century.

FT process converts syngas into synthetic crude oil.

Invented in the 1920s by Franz Fischer and Hans Tropsch

There are two versions. Most present-day projects use low-temperature FT (LTFT).

Like Hydrotreated Renewable Fuels, LTFT synthetic crude oil is a mixture of paraffins (alkanes).

- Because of their very low toxicity, paraffins are used for pharmaceutical and food industry products such as white mineral oil, paraffin oil, Vaseline, ointments, etc.
- LTFT fuels are inherently clean-burning

EROEI for FT fuels from energy forestry in NZ significantly greater than 5.5: 1, that is, **better than fossil fuels** in NZ!

(Fossil Petrol and Diesel in NZ, EROEI = 5.18:1)

Güssing (Austria) wood gasifier, near Vienna. Photo: Dr. Reinhard Rauch.

FT products made at Güssing. Photo: Oxford Catalysts.

Hydrothermal Fuels (HTL)

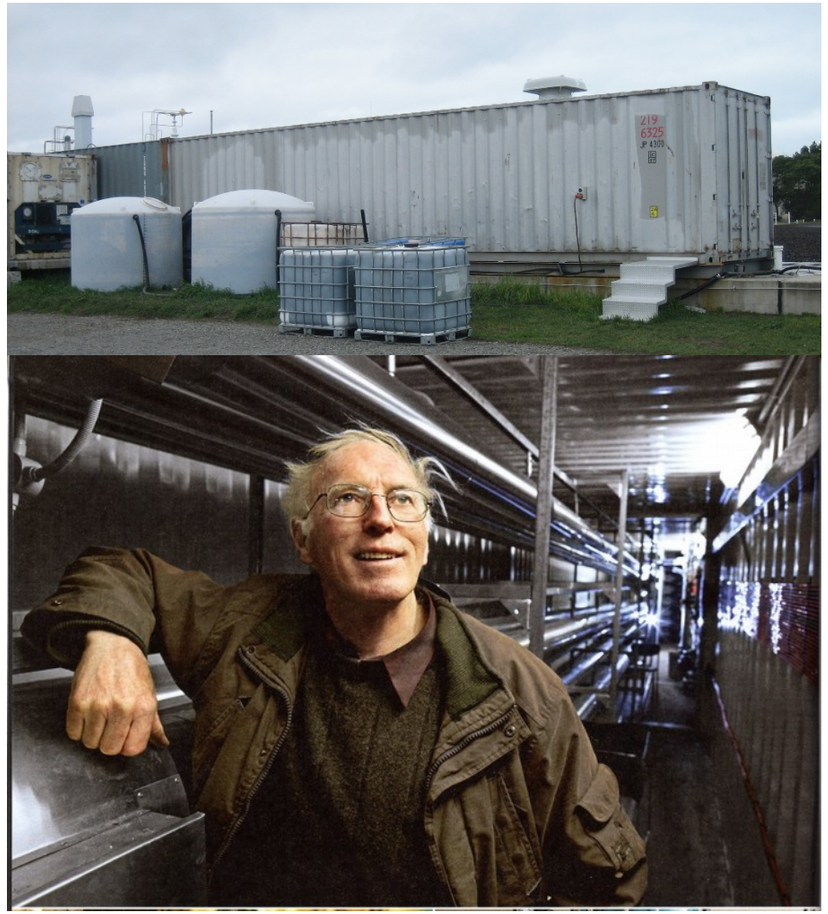
This process was known as early as the 1970s.

A slurry of raw material (biomass) and water is subjected to high-ish temperature and extreme pressure, which converts it into crude oil.

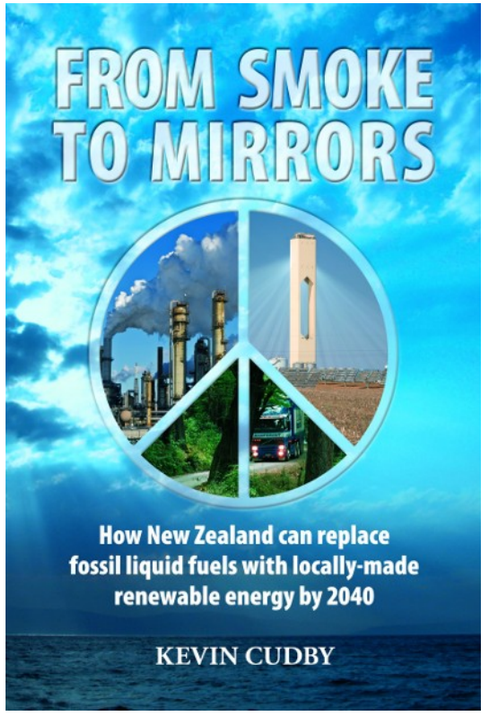
HTL works on wet or dry biomass: wood chips, straw, sewage sludge, grass clippings, algae...

Fuel properties depend on the raw material and the detailed process design.

HTL fuels are practically free of sulphur, but may contain aromatic hydrocarbons.



Dr. Chris Bathurst's HTL pilot-plant at Christchurch. Photos: Rupert Craggs (exterior); Reicofil Pure (interior)



Energy
Forestry

Energy Forestry

Energy forestry in NZ was identified as a potential source of renewable fuels during the 1970s. This was confirmed by Scion researchers in the early 21st century.

The idea is to convert STEEP GRASS AND SCRUBLAND into sustainably-managed forests.

Wood from these forests would be converted into synthetic crude oil or hydrogen.

This land is currently used for sheep farming. It is subject to heavy soil erosion and the economic yields are poor.

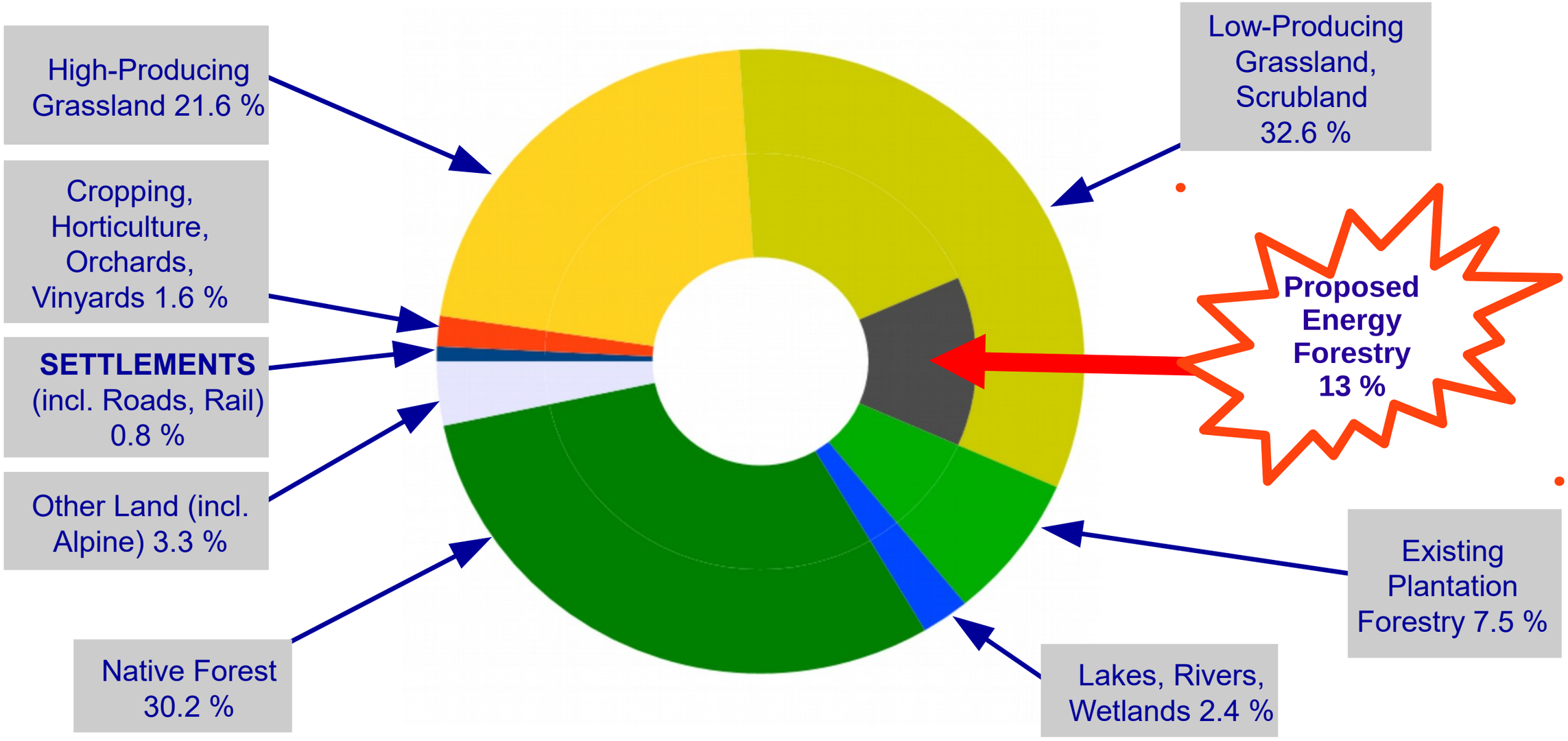
Energy forestry is not expected to trigger the kind of undesirable side-effects associated with agricultural biofuels like ethanol and biodiesel.

Natural processes and good management ensure adequate nutrient supply, especially via the mutually symbiotic relationship between forest trees and fungi.

- Foresters generally do not use fertiliser.
- Forests lose less nutrients into waterways than grazing land.

Some established central North Island exotic forests are now up to their third crop and if anything, the trees are doing better than the original plantings.

Land Use in New Zealand



Data from: Land Use Environmental Snapshot: January 2010. Ministry for the Environment.

Energy Forestry: What Kind of Tree?

Conifers such as radiata pine like the same type of soil as native podocarps (totara, rimu, matai, miro).

Radiata pine (P. radiata) has been bred to grow in the open. It should not establish itself in mature native forest and cannot out-compete native trees.

HOWEVER... !.

> Some exotic trees can invade native ecosystems. For example, Pinus contorta (lodgepole pine) and P. uncinata/mugo (mountain/dwarf pine will establish and cone above the native treeline, and farm animals won't eat them

Some foresters are experimenting with kanuka. I suspect our native flora includes lots of other good candidates.

KEY POINT: We can **BALANCE ANTHROPOGENIC CO2 SOURCES & SINKS** just by **PLANTING THE TREES!!**

Energy Forestry: What Kind of Car?

We can use existing technology to convert wood from energy forests into

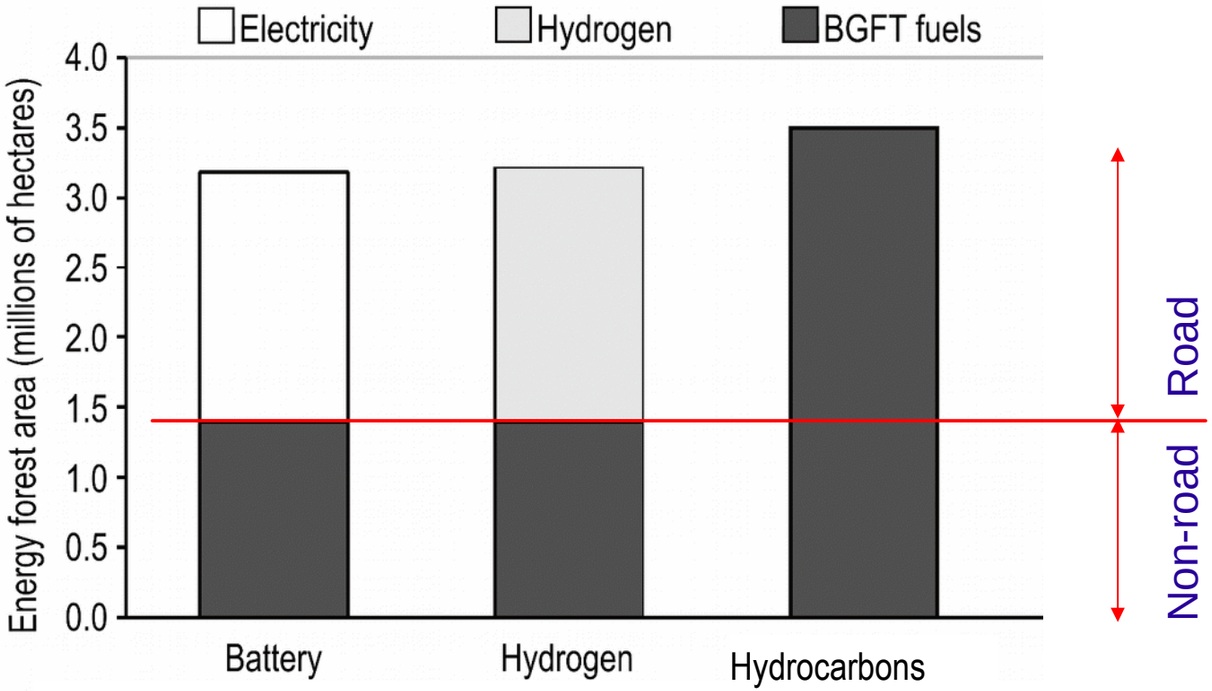
ELECTRICITY

HYDROGEN, or

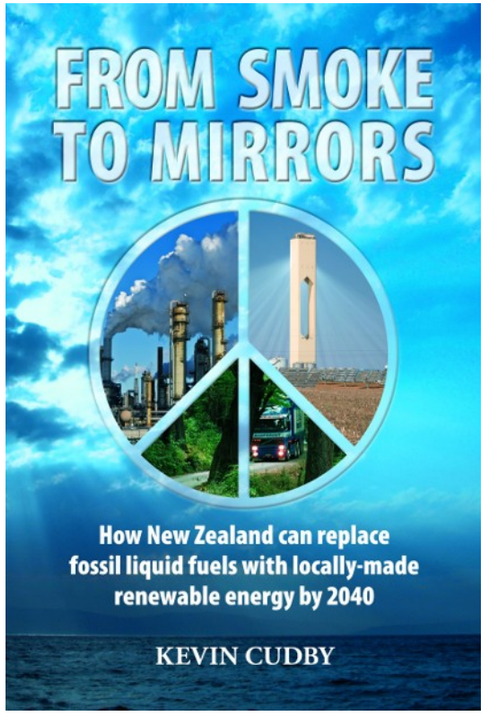
HYDROCARBONS (petrol, diesel, etc.)

3.5 million hectares of energy forest is enough to completely replace fossil liquid fuel consumption in New Zealand

No matter what kind of cars and trucks we buy!



Options for Replacing Fossil Liquid Fuels



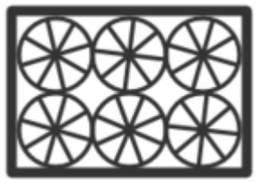
Air-Capture & Sequestration

Air-Capture & Sequestration

Carbon Source

Vehicles use ordinary fossil liquid fuels.

Carbon Dioxide & Water



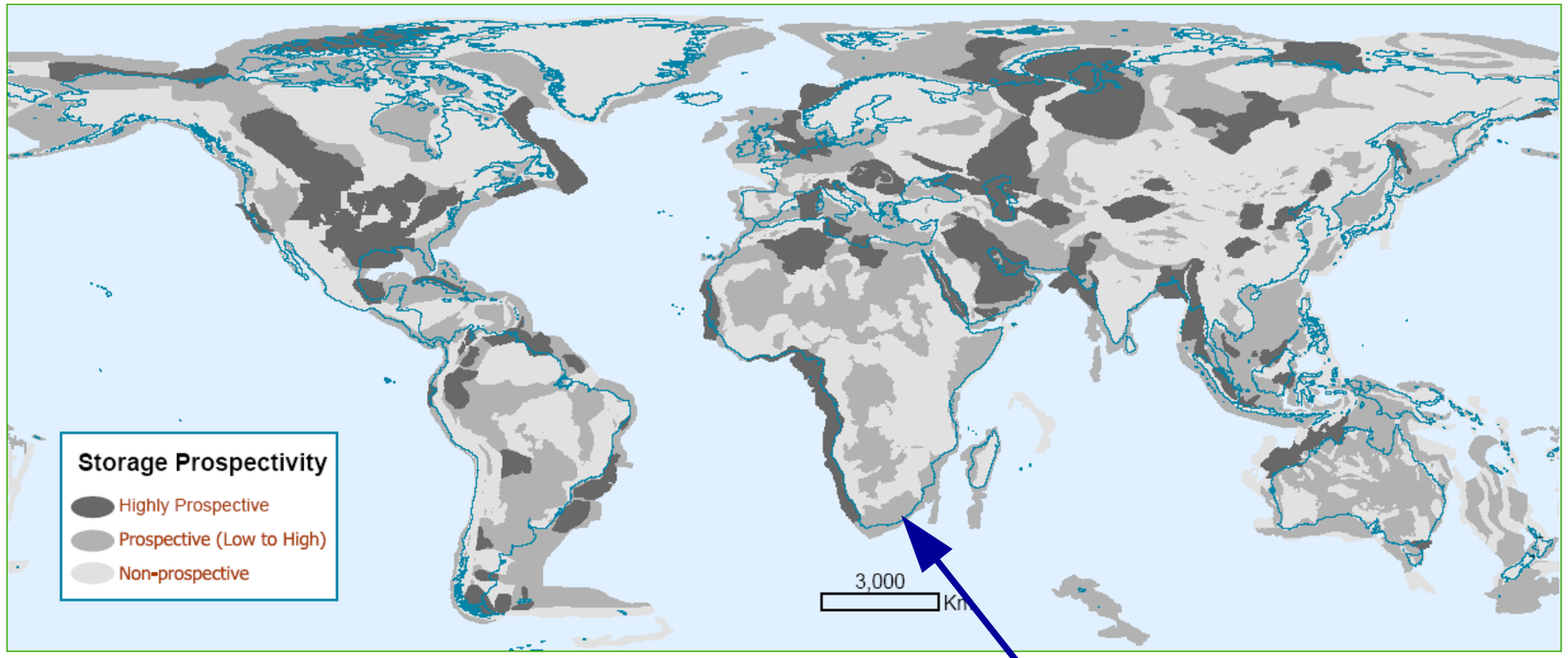
Carbon Sink

Carbon dioxide is captured directly from the air and pumped into permanent underground storage.

Air-Capture & Sequestration

Using fossil liquid fuels **IN COMBINATION WITH** air-capture & sequestration would balance anthropogenic CO2 sources & sinks, as required by the Paris Agreement.

The necessary technology has already been invented.



The world has plenty of potential storage reservoirs for carbon dioxide

Air-Capture & Sequestration

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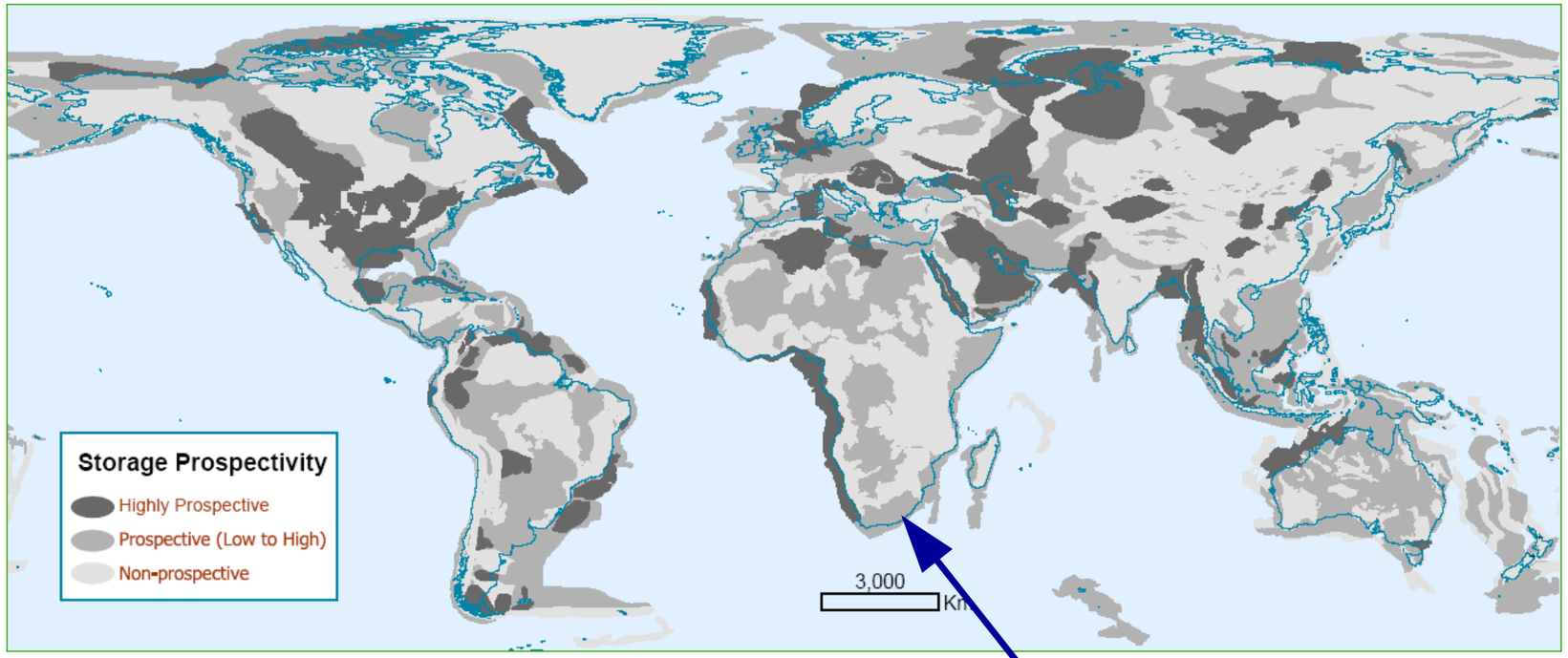


BUT:
This resource could be used in the 22nd century to reduce anthropogenic warming and stabilise sea level!


FROM SMOKE
TO MIRRORS
How New Zealand can replace
fossil liquid fuels with locally-made
renewable energy by 2040
KEVIN CUDBY

Transition

Combustion Vehicles Will Need 50% Less Fuel

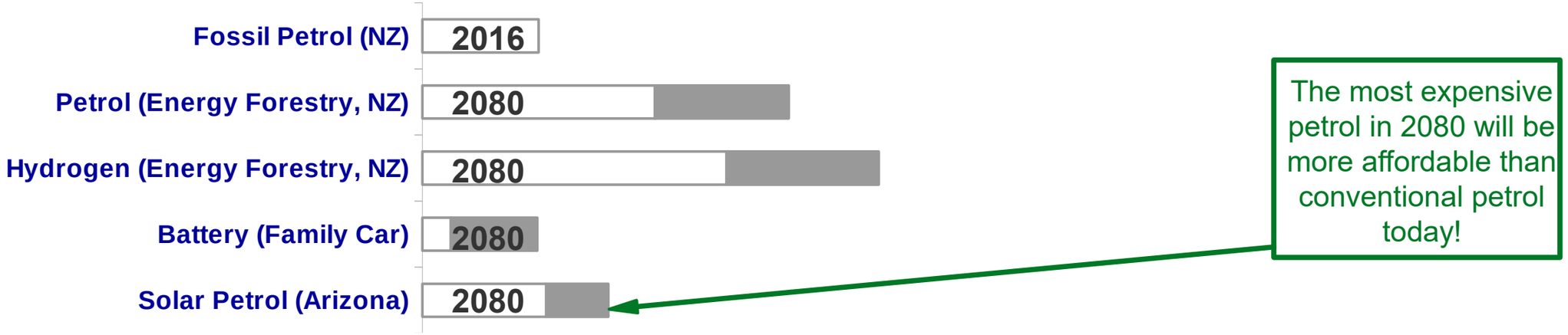
Some technologies that reduce fuel consumption:

- High compression (Mazda SPCCI).
- Cylinder deactivation (Corvette, Dynamic Skip Fire).
- Atkinson Cycle (Toyota, Lexus V8)
- Low temperature combustion (Mazda SPCCI/SkyActiv-X).
- Advanced fuel injection.
- Multi-speed transmission (8-speed Chrysler Torqueflite, Corvette).
- Flywheel Kinetic Energy Recovery (KERS) (Ricardo, Williams, Torotrack, Ford, NASA).
- Hydraulic hybrid (Chrysler, Citroën...).
- Lightweight materials.
- Aerodynamics (Trucks, Corvette).
- 48-Volt micro-hybrid (Every car maker)
- Grid-free battery hybrid (Toyota Prius).

How Far Can I Drive On The Money I Get?

Expect: Per-capita income to more than double by 2080 (average compound annual growth rate = 1.1 %)

Expect: Cars in 2080 to go twice as far on a litre of petrol, as cars in 2016 can manage.



Distance if **Fuel Budget** is a fixed % of income

If your grandchildren have twice as much money, and they only need half as much fuel, they won't mind if petrol & diesel cost almost four times as much as today's fuel!

Their (inflation adjusted) dollar will drive them further than our dollar drives us.

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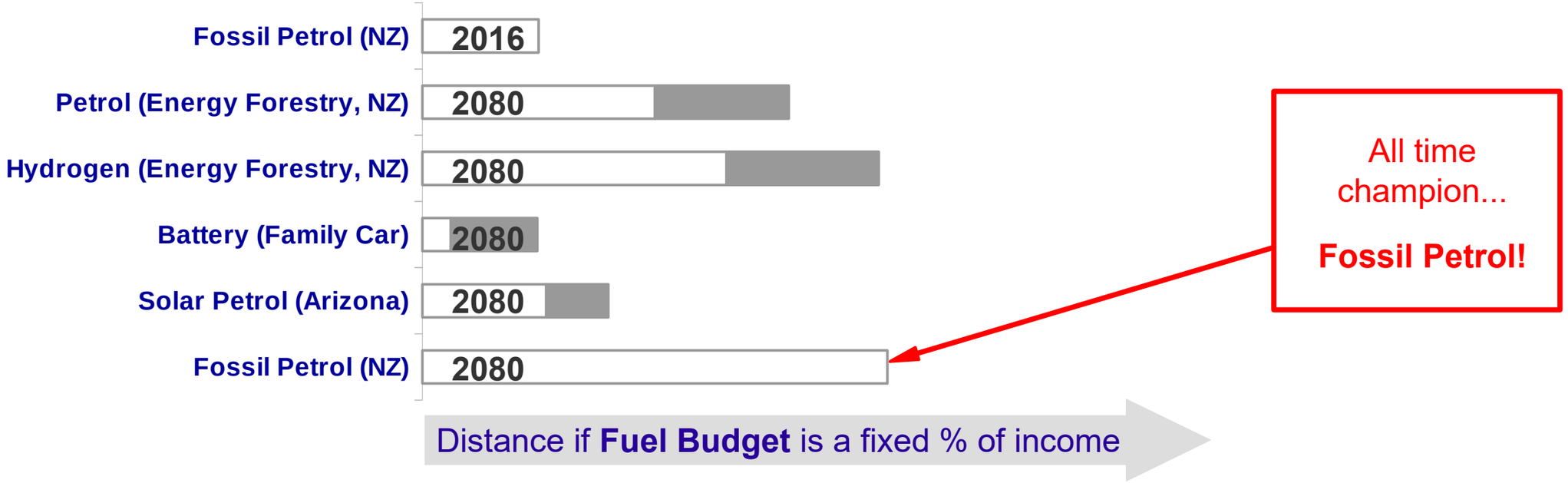

If Fossil Petrol was likely to run out, we would not be worried about climate change...

Would we?

Why Not Tax Carbon Dioxide?

The cost of harnessing renewable energy depends on commodity prices: steel, concrete, etc.

Commodity prices tend to move in unison because of technological links between commodities (example, steel is made by burning a mixture of coal and dirt.)

A **global carbon price** will drive up commodity prices, increasing the cost of renewable energy.

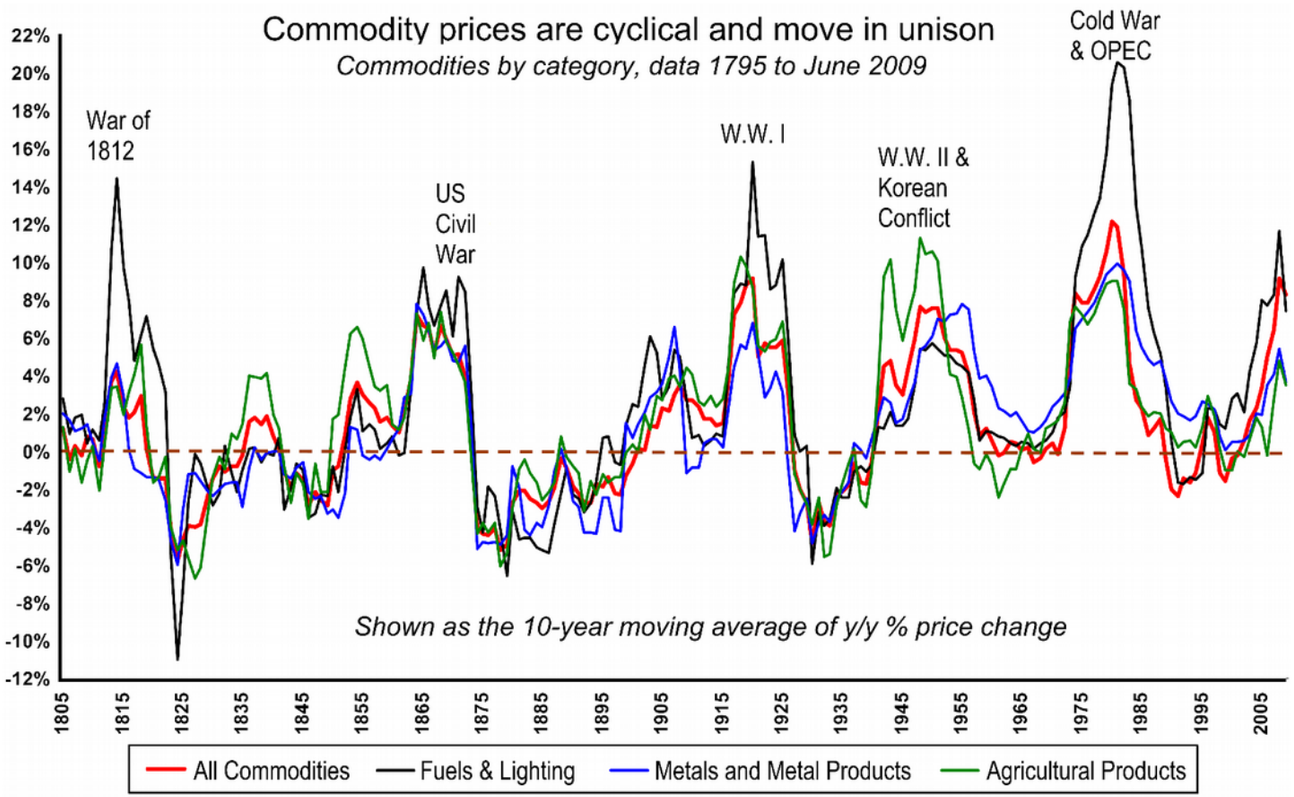

Chart: Barry Bannister, Stifel Nicolaus & Co.

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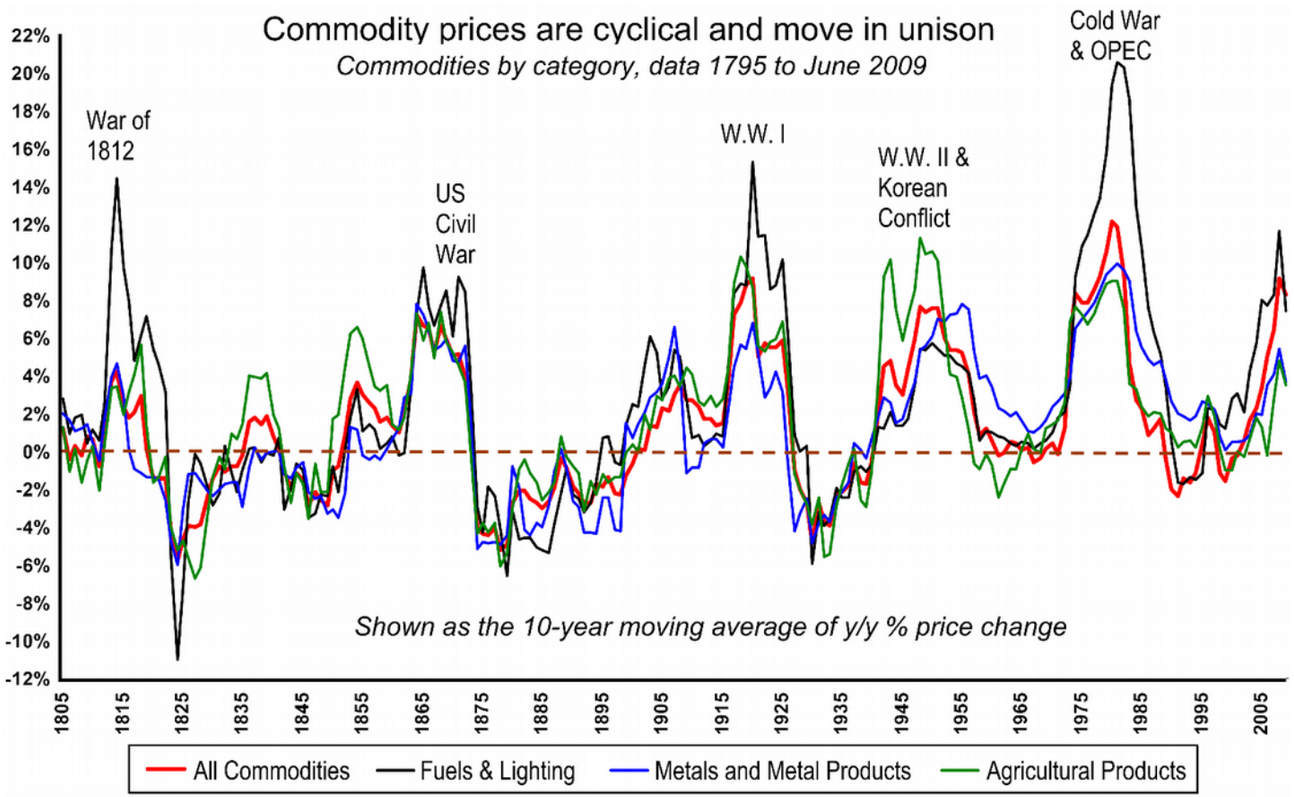

Chart: Barry Bannister, Stifel Nicolaus & Co.

The IPCC has presented
NO EVIDENCE
that a **GLOBAL CARBON PRICE**
can encourage a
BALANCE OF ANTHROPOGENIC CO2 SOURCES & SINKS.

The Policy Options

For Balancing CO_2 Sources & Sinks*, per the Paris Agreement

Phase Out by 2080	Fossil Fuels	NET CO2 Emissions
Fossil fuel extraction ends	2080	late 22nd century (approx)

* Excluding Solar Radiation Management (SRM)

The Policy Options

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Direct-capture & sequestration begins	2080	approximately 2040

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The Policy Options

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Phase Out by 2080	**Fossil Fuels**	**NET CO2 Emissions**
Fossil fuel extraction ends	2080	late 22nd century (approx)
Direct-capture & sequestration begins	2080	approximately 2040
Fuel price trend (with no carbon price)	Increases at ~ 1 % per year	Unpredictable price escalation driven by increasing technical difficulty of fossil fuel projects

* Excluding Solar Radiation Management (SRM)

The Policy Options

For Balancing CO_2 Sources & Sinks*, per the Paris Agreement

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Fossil fuel extraction ends	2080	late 22nd century (approx)
Direct-capture & sequestration begins	2080	approximately 2040
Fuel price trend (with no carbon price)	Increases at ~ 1 % per year	Unpredictable price escalation driven by increasing technical difficulty of fossil fuel projects
Fuel affordability	Stable or gradual improvement	Unpredictable fluctuations

* Excluding Solar Radiation Management (SRM)

The Policy Options

For Balancing CO_2 Sources & Sinks*, per the Paris Agreement

Phase Out by 2080	Fossil Fuels	NET CO2 Emissions
Fossil fuel extraction ends	2080	late 22nd century (approx)
Direct-capture & sequestration begins	2080	approximately 2040
Fuel price trend (with no carbon price)	Increases at ~ 1 % per year	Unpredictable price escalation driven by increasing technical difficulty of fossil fuel projects
Fuel affordability	Stable or gradual improvement	Unpredictable fluctuations
Amount of Sequestered Carbon to Restore Pre-Industrial Global Average Temperature	~ 1,000 GtC (billion tonnes of carbon)	~ 12,000 GtC

* Excluding Solar Radiation Management (SRM)

Key Points from My Research

Non-road liquid fuels account for ~33% of global consumption

So-called “electric” vehicles usually run on petrol or diesel

Unmitigated Fossil Liquid Fuels will ALWAYS beat carbon-neutral alternatives

Climate policy only needs to BALANCE anthropogenic ghg SOURCES & SINKS!

If the Goal is to FIX the climate:

We **DO NOT NEED** carbon tax or a carbon price

We **DO NOT NEED** more public transport (typ. <3.5 % of total NZ pass/km)

While We Are Waiting … … …

Let’s Plant Trees: Year One

Suppose that New Zealand establishes large-scale energy forestry over a period of 27 years.

In the first year, 1/27 of the total area is planted.

In real life we plant about 90~110 million trees.

Let’s Plant Trees: Year Two

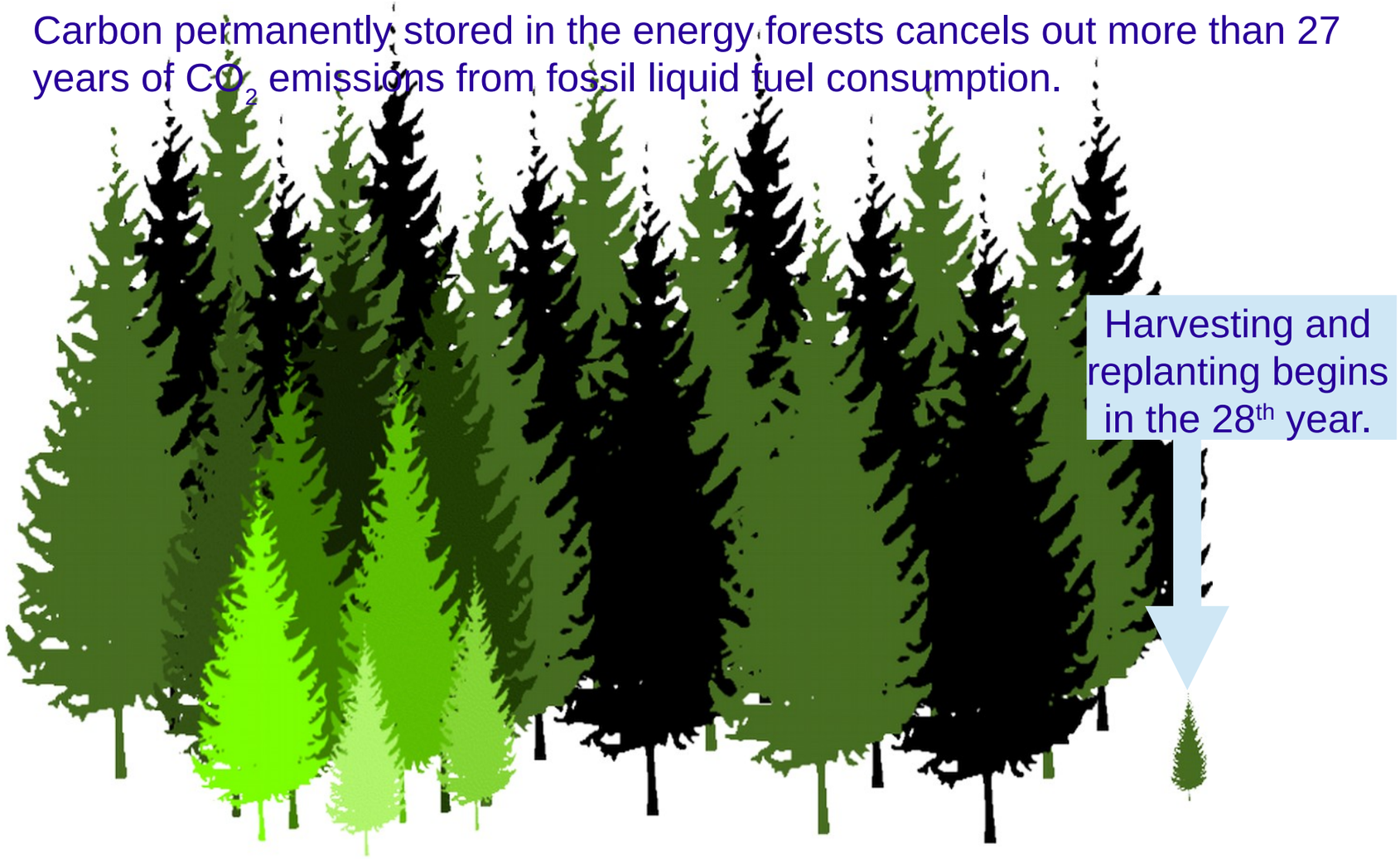
In the second year, another 1/27 of the total area is planted.

Let’s Plant Trees: Year 27

After 27 years of planting, our energy forests are fully established.

Let’s Plant Trees: Year 28

Carbon permanently stored in the energy forests cancels out more than 27 years of CO_2 emissions from fossil liquid fuel consumption.



NZ Can Be 100 % Carbon-Neutral By Tomorrow

The moment we start reforesting 3 million hectares of low-grade grazing land

AND

Commit to eliminating fossil liquid fuels by the time the trees are ready to harvest (i.e. 2044)

Everything in New Zealand that runs on liquid hydrocarbons will be 100% carbon neutral

By 2044, perhaps world leaders will have accepted the need to phase out fossil fuels.

What shall we do?

What do YOU want to do with human-made climate change?

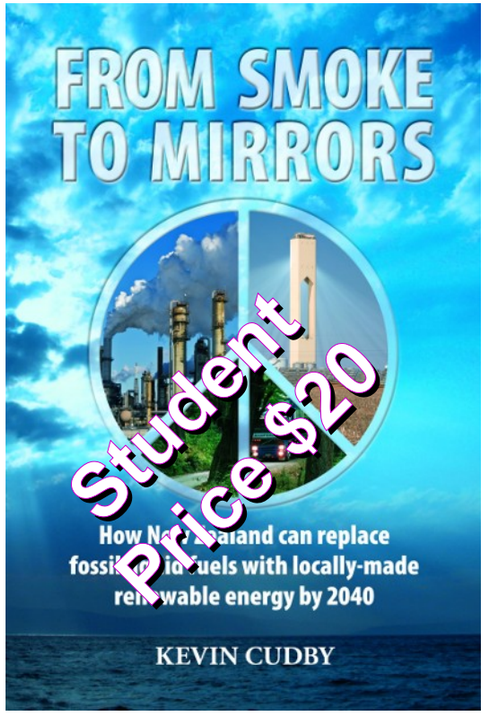
Do you want to TAX it?

Do you want to STUDY it?

Do you want to FIX it?

I want to FIX it!

Thank You!!

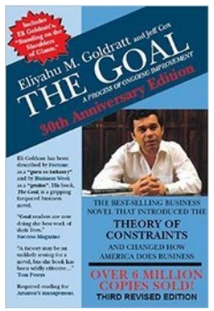


"If we want things to stay as they are,
things will have to change."
Giuseppe Tomasi di Lampedusa, The Leopard.

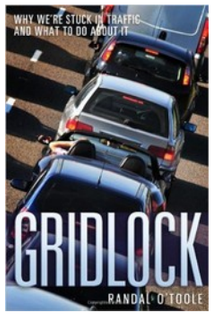
Course notes: https://kevincudby.com/esci201.html

Ian Mason, Shannon Page, & Arthur Williamson: "Transitioning to a 100% renewable electricity generation system for New Zealand."
https://kevincudby.com/Mason2013RenewableElectricityNZ.pdf

Solving complex problems



Land transport policy



Making stuff with CO2