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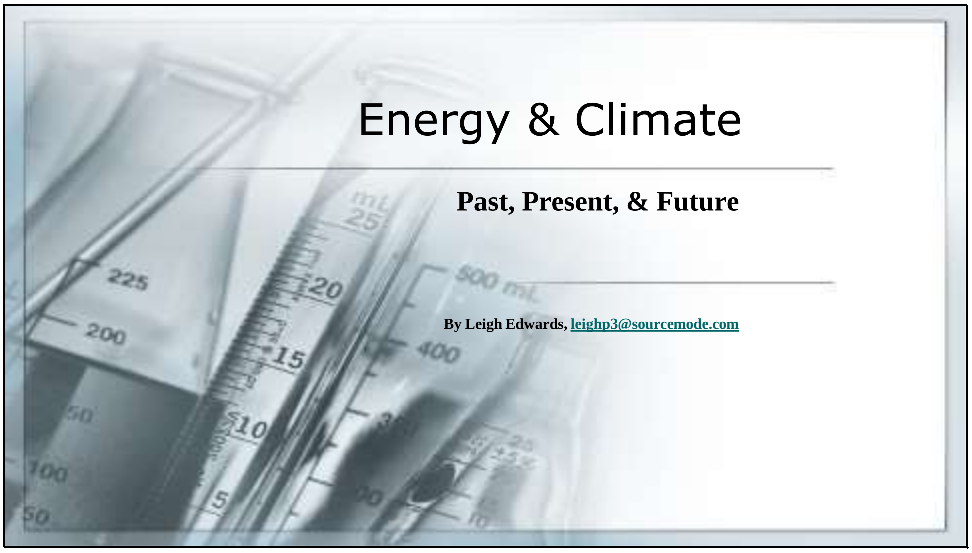

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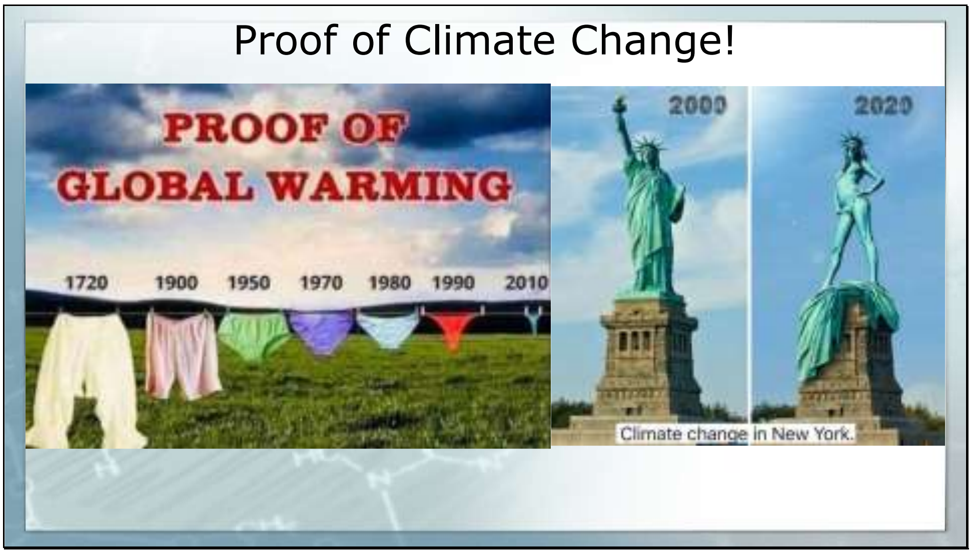


Slide 3

Climate – The Evidence

But seriously climate change is real

Apart from actual measurements of surface temperature rises, one of the most obvious signs are in global ice

Mountain glaciers are shrinking everywhere, in the Peruvian Andes, Puncak Jaya on the island of New Guinea, the Alaskan ranges, the Himalayas, in the Alps

In Chile, a glacier called HPS-12, retreated eight miles between 1985 & 2017

Sea ice has receded drastically; & as it does so less solar radiation is reflected back into space, & the heat is absorbed by the ocean, disrupting currents & ecosystems; Arctic Ocean sea ice has reduced by 40% since the 1980's

The great ice sheets on Greenland & Antarctica are melting adding enormous volumes of water to the world's oceans

Every year 400 billion tons of ice melting, adding 1mm to global sea levels each year; we are losing huge areas of land

In the vast boreal (forested) regions of the Arctic, permafrost is thawing, upending homes, buildings & other infrastructure, releasing CO_2 & CH_4, a particularly potent greenhouse gas

What is the meaning of boreal region? Definition: A forest that grows in regions of the northern hemisphere with cold temperatures. Made up mostly of cold tolerant coniferous species such as spruce and fir.

Greenland has lost 15 trillion tonnes of ice since the 1880's and half of that since the 1970! – Dr Zeke Hausfather

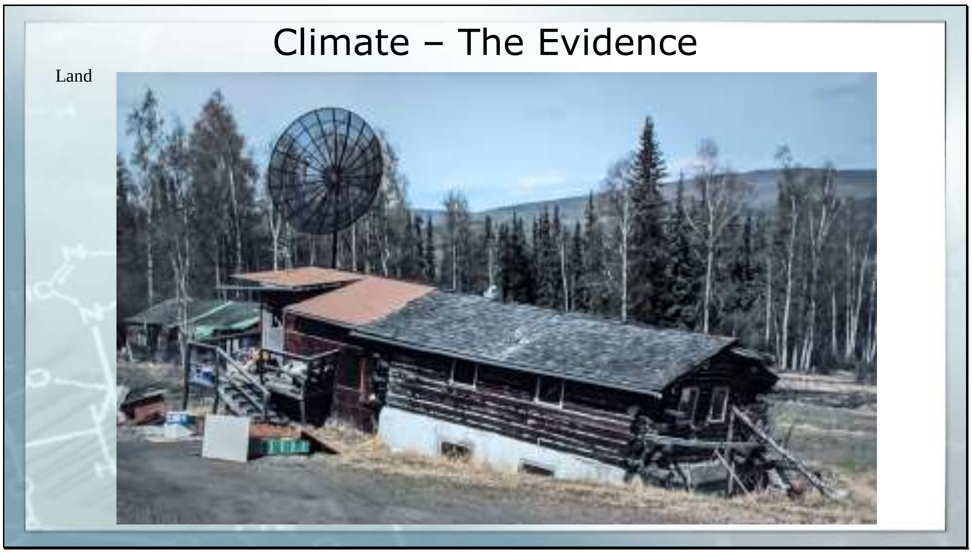
Slide 4

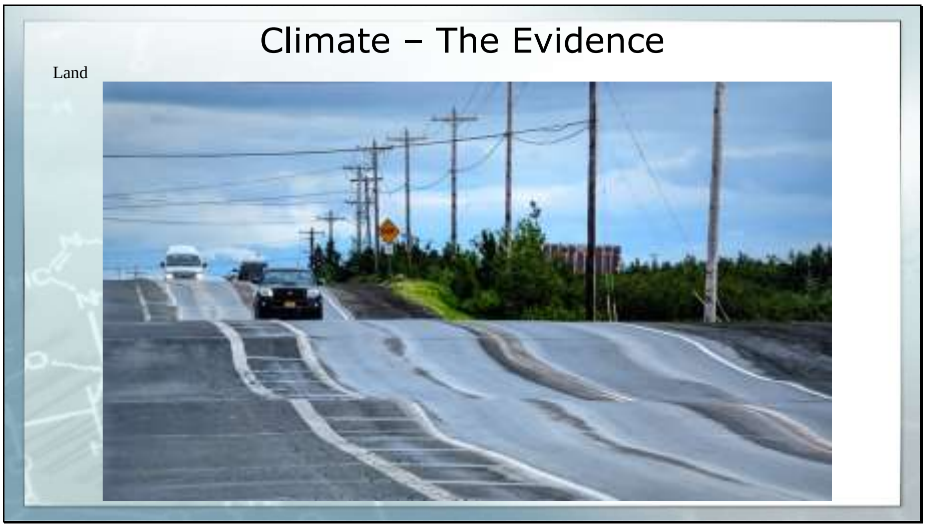
Climate – The Evidence

Land

Slide 5

Slide 6



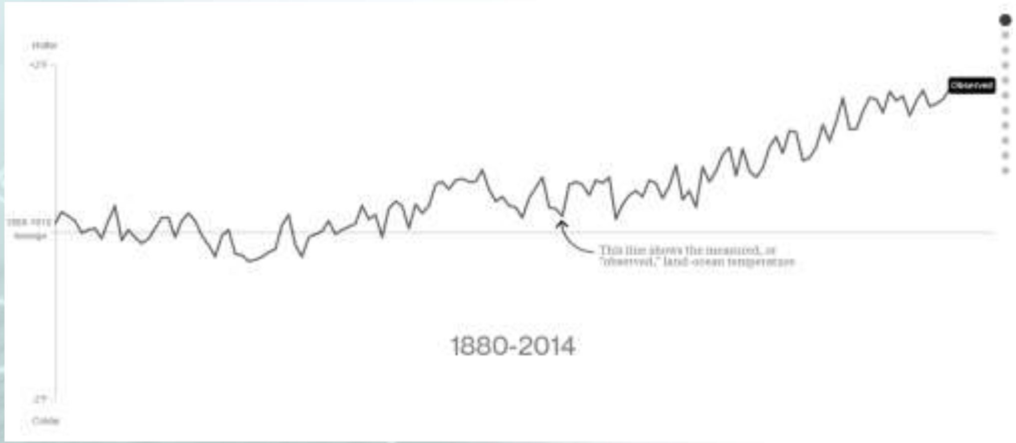


Slide 7

Slide 8

Climate – The Evidence

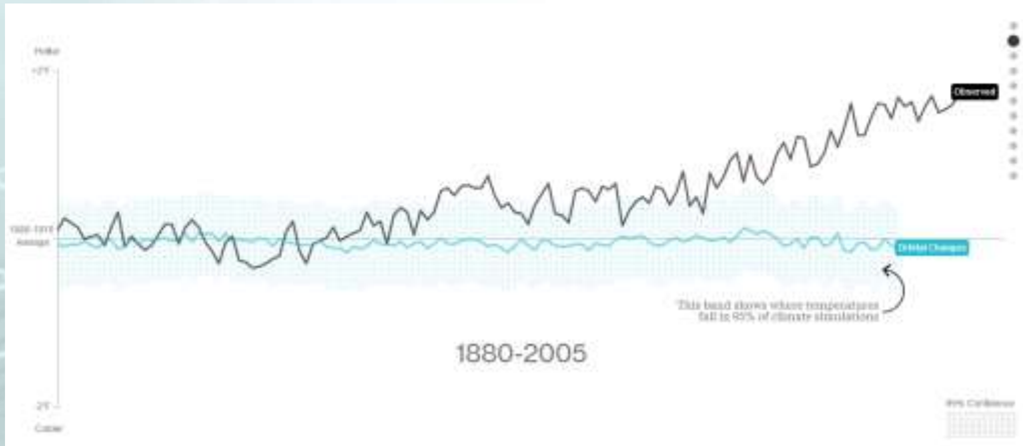
So, what has warmed the world?



Slide 9

Climate – The Evidence

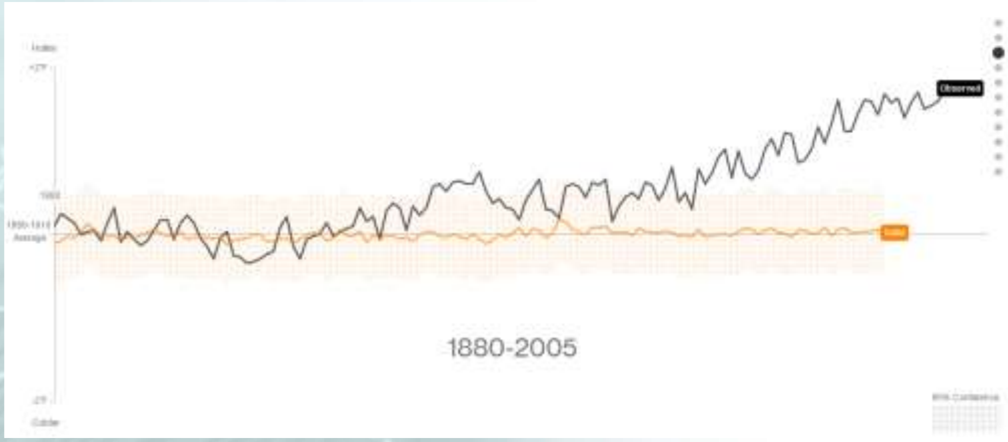
It’s not due to changes in the Earth’s orbit



Slide 10

Climate – The Evidence

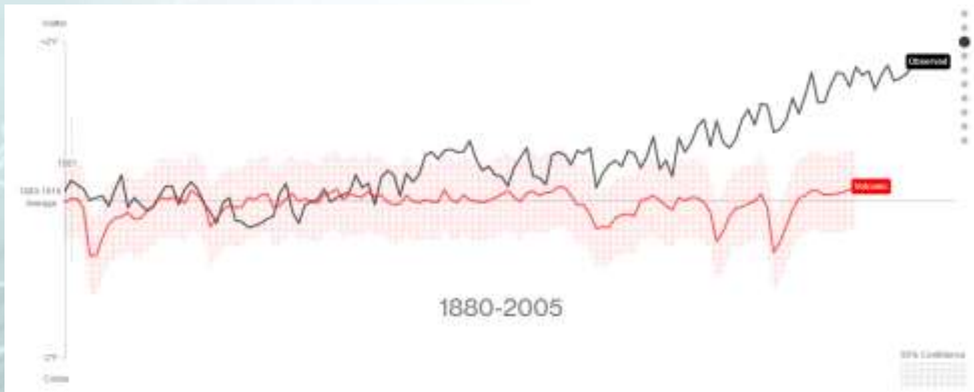
It's not due to changes in the Sun's output



Slide 11

Climate – The Evidence

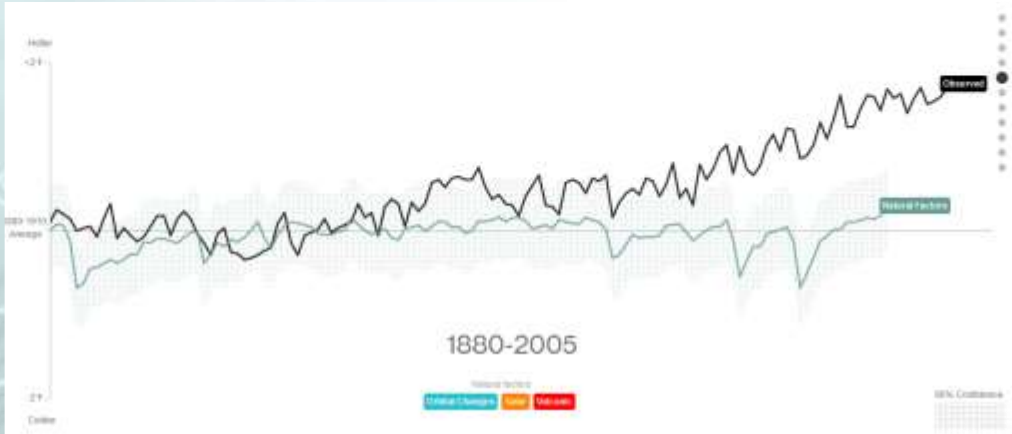
It's not due to volcanic CO_2 – humans emit 100 times more, or sulphates – they causes cooling



Slide 12

Climate – The Evidence

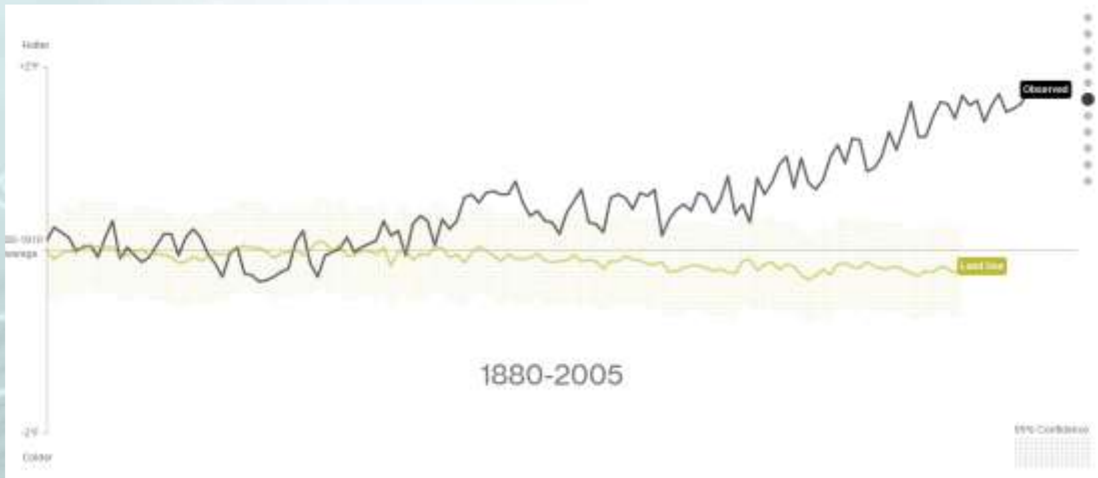
It’s not due to all three combined – Orbit, Solar & Volcanic



Slide 13

Climate – The Evidence

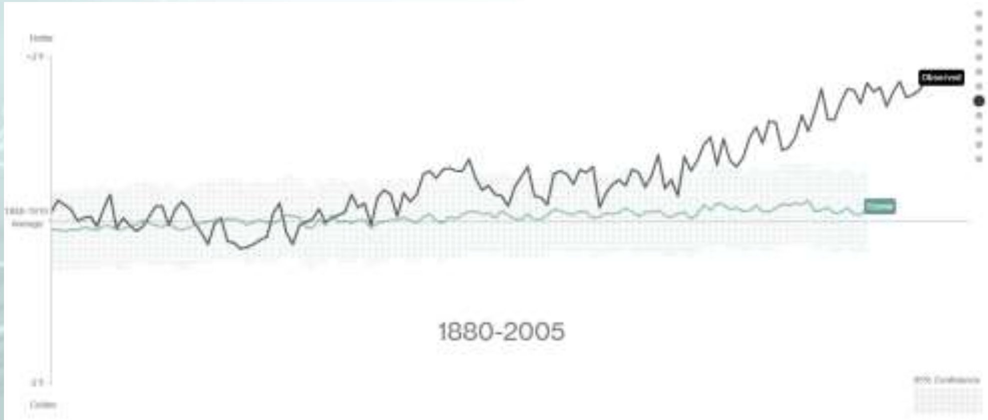
It’s not due to deforestation – we have cut, paved & ploughed over half the land – forest loss gives lighter patches that reflect more sunlight back & have a slight cooling effect



Slide 14

Climate – The Evidence

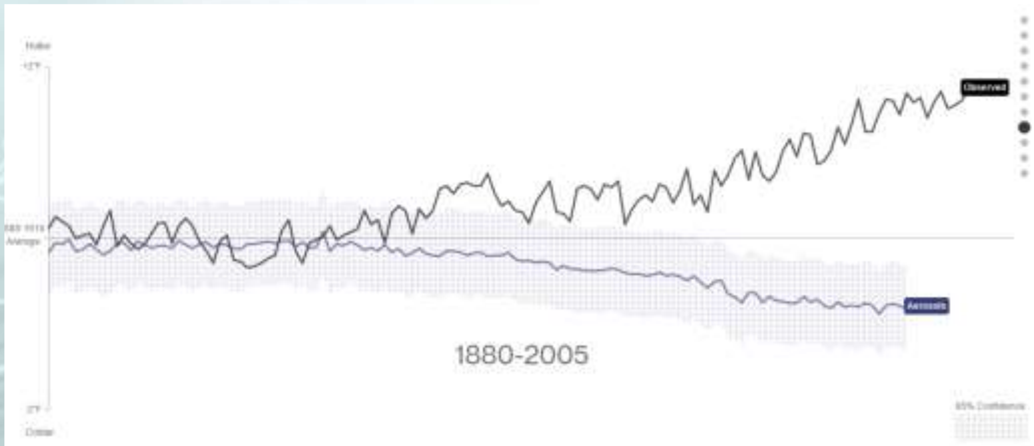
It's not due to Ozone pollution – high up it blocks sunlight & cools things, lower down ozone created by pollution traps heat & warms things



Slide 15

Climate – The Evidence

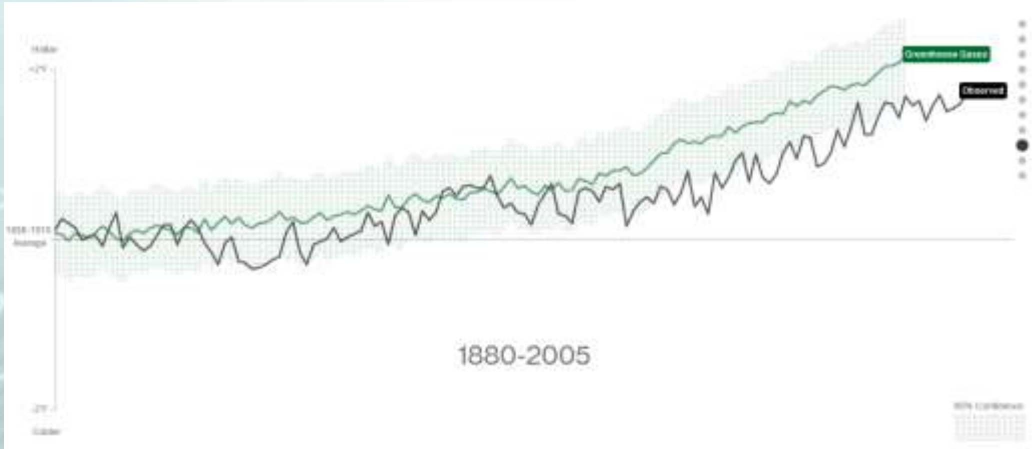
It's not due to aerosol pollution – sulphates cause cooling, but also acid rain



Slide 16

Climate – The Evidence

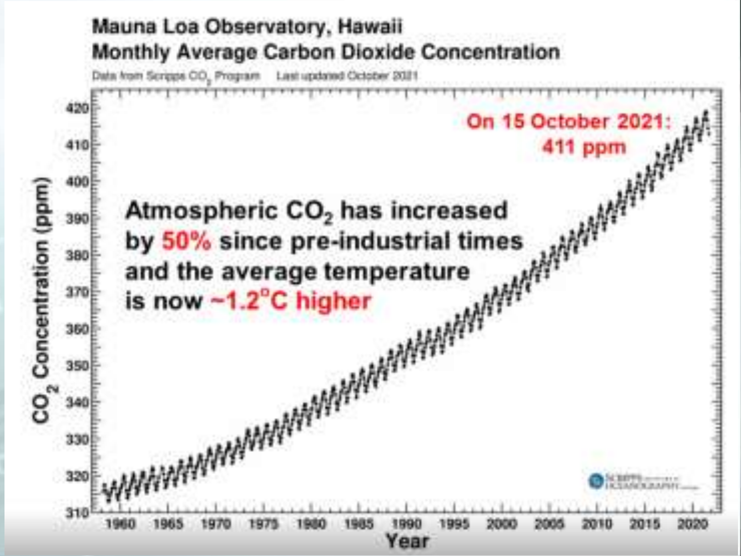
No, it really is greenhouse gasses – CO_2 is 50% higher than in 1750 – the green line show their influence



Slide 17

Climate – The Evidence

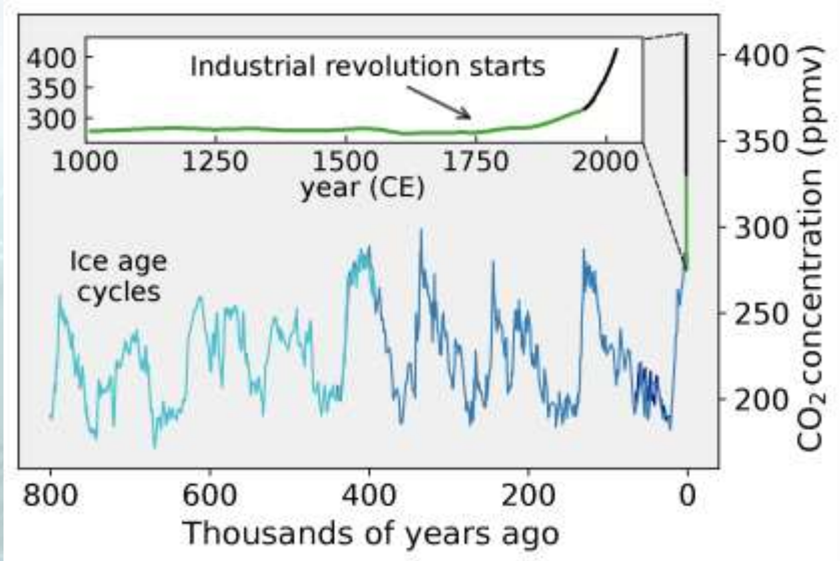
Higher CO_2 than at anytime for the last 2 million years!



Slide 18

Climate – The Evidence

Higher CO_2 than at anytime for the last 2 million years!



Slide 19

Weather vs Climate

Weather in not climate – the difference is …

- Weather is how you choose your outfit; climate is how you chose your wardrobe
- Weather is the mix of events that happen each day in our atmosphere, including temperature, rainfall, & humidity; it's not the same everywhere & depends on where you live
- Climate, in your place on the globe, controls the weather where you live, & is the average weather pattern in a place over very many years

Slide 20

Weather vs Climate

Weather prediction is difficult, but getting better, but chaos theory sometimes plays a role, & destroys our predictions

- E.g., The major storm / cyclone 15-16th October 1987 defied all weather predictions at the time – 122 mph winds!
- Too many Navier-Stokes equations of fluid dynamics to solve, & the sheer scale of the computational task
- Bigger computers, ensemble forecasts now, plus probabilistic information about the conditions to come

Climate change prediction is difficult

- If we can't accurately predict the weather, then how can we predict the climate?
- "The theory of global warming is a gigantic weather forecast for a century or more. However interesting the scientific enquiries involved, therefore it can have almost no value as a prediction." Charles Moore – The Telegraph 6th April 2014
- And his qualifications? – a 2.1 BA in English & History!
- He is a Trustee of:
  - The Global Warming Policy Foundation (GWPF) is a lobby group in the UK whose stated aims are to challenge "extremely damaging & harmful policies" envisaged by governments to mitigate anthropogenic global warming
  - The GWPF, & some of its prominent members individually, are practicing climate change denial!

Exaflop (10^18) computers now

Slide 21

Energy & Climate

On the other hand:

New York Times – 8th November 2019, "How Scientists Got Climate Change So Wrong"

"Few thought it would arrive so quickly. Now we're facing consequences once viewed as fringe scenarios." By Eugene Linden

Climate change is almost certainly brought about by human activities – this now the consensus of most scientists – IPCC Report of August 2021 (4000 pages!)

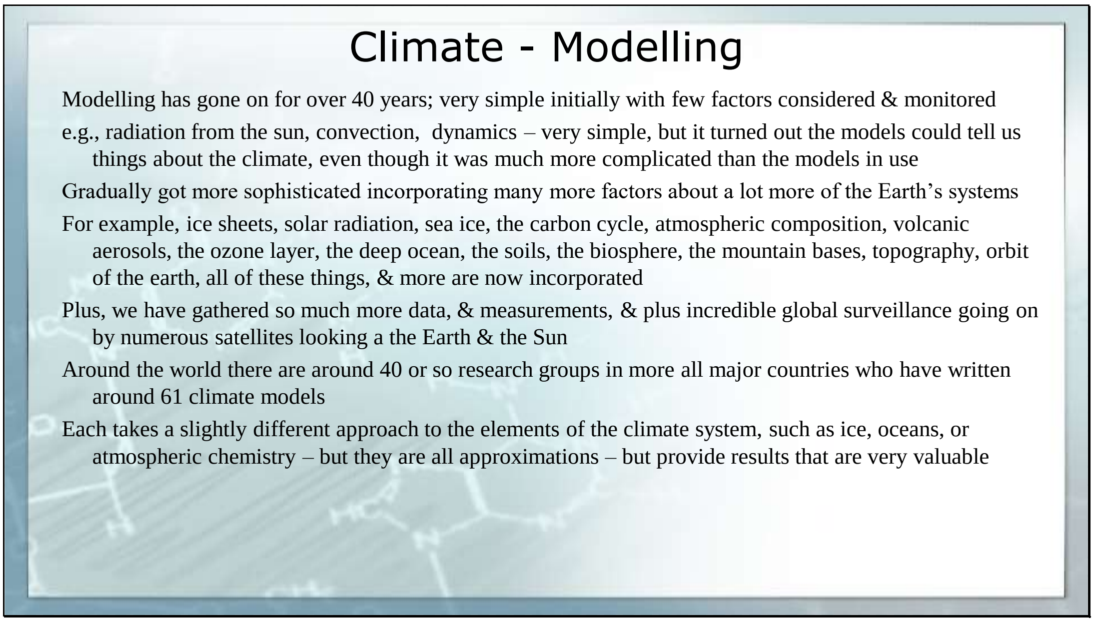
Due to our past, & ever-increasing, need for fuel & energy

So, in the rest of this presentation we'll:

- Look at climate modelling, & why we should take its predictions seriously
- Look at human energy sources & usage in the past & up to the present time
- Look at future predictions of the climate, depending on what actions we take?
- Also, at what actions could make a difference, & some of which cannot?
- Then we'll look at human energy usage, & options in the future, for generation methods & energy economies

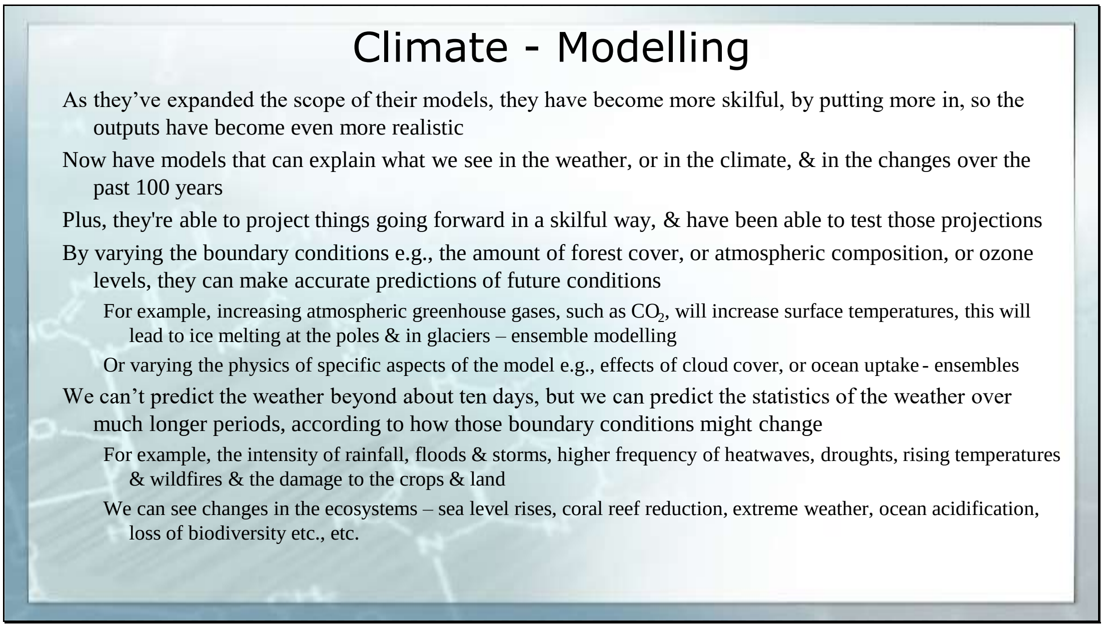
NYU Physicist Prof Emeritus Steve Kunin's recent book 'Unsettled' – was assessed for its scientific merit by a review panel of experts and assessed to be of very low scientific merit. He's cherry-picking data and studies and not considering the others!

Slide 22



Dr Zeke Hausfather - models are not right or wrong; they're always wrong. They're always approximations. The question you must ask is whether a model tells you more information than you would have had otherwise. If it does, it's skillful.
1993 sea level measurements became very much more accurate due to satellite altimetry measurements.

Slide 23



Drought as far as crops are concerned there are two key factors – how much rainfall there is and how hot it is – and even if the rainfall has not changed much the moisture in the soil may be too low for the crops due to increased temperatures!

Slide 24

Climate - Modelling

We know that the planet has warmed more than a degree C over the last hundred odd years & most of that warming has come in the last 60 years – this is based on detailed measurements & records

But how do we determine the actual cause?

How can we really say it is due to CO_2, & not due to changes is the Sun’s output, or something else?

Well, the patterns are different!

If it were due to the sun’s output increasing, then yes, the surface would have warmed, but the whole atmosphere would have warmed up too – but that’s not the case

If it were due to CO_2 then that causes the surface to warm, but anything above the troposphere & the stratosphere causes it to cool, because carbon dioxide is more efficient in those areas at emitting than it is at absorbing due to the way spectral absorption works, & so you have a very different pattern for carbon dioxide driven change than you do for solar driven change

All other likely causes have been considered & ruled out

Solar radiation peaked in the 1950s & it's been slightly decreasing ever since, & it's not it's not a very big effect anyway, & even if we got it wrong by an order of magnitude it would still have the wrong pattern of change

Maybe the ocean is putting lots more heat into the atmosphere, but if that was the case the ocean should be cooling, but instead the oceans are warming!

Layers of the atmosphere – from bottom to top
Troposphere, Stratosphere, Mesosphere, Thermosphere, Exosphere

Slide 25

Climate - Modelling

Ocean warming tells us that something is changing at the top of the atmosphere, by conservation of energy

If more energy is coming into the system, then it must be coming in at the top

What changes the radiation balance at the top, things like greenhouse gases, or the sun, or atmospheric aerosols

They have looked at each of those things

The quantity of aerosols in the atmosphere have decreased

The amount of greenhouse gases have increased, so is that expected to cause more energy to be come in than is leaving, & yes, it is!

So where is that additional energy going - it's going into the oceans

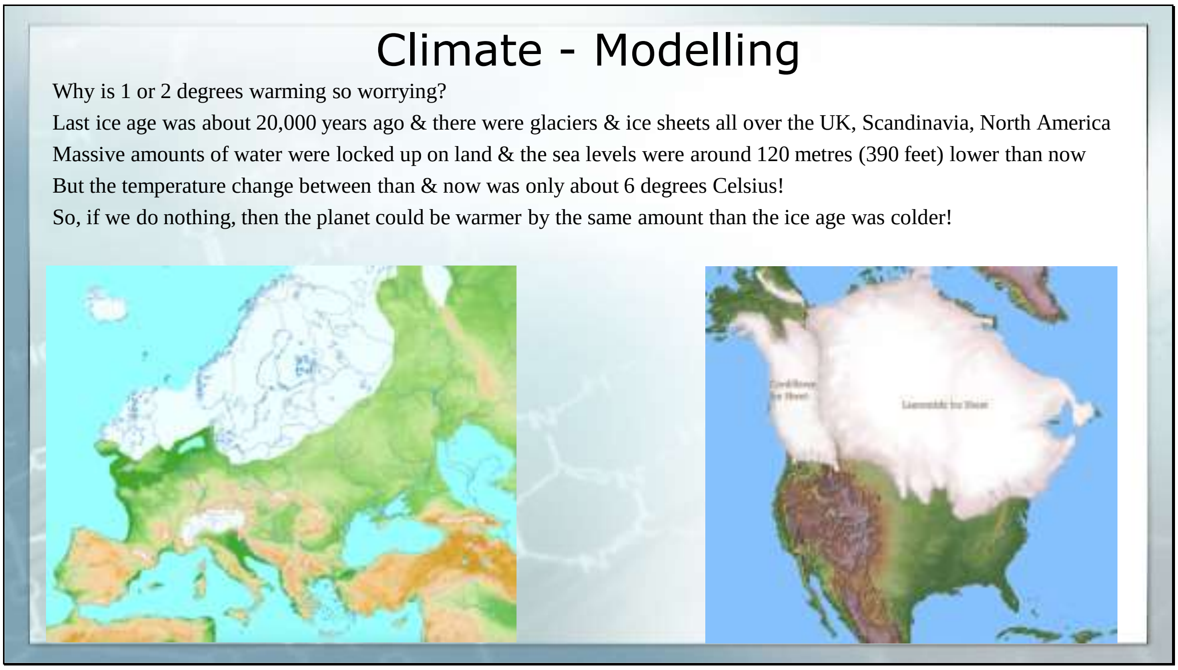
Now they have the data for the heating of the oceans, they saw it was exactly at the level & the rate that was expected, because of the increases in greenhouse gases

So, they've made real predictions, that have been verified, & that demonstrate that they have understood what’s is going on, & for the right reasons

CO_2 is largely transparent to Visible & UV radiation from the Sun, but it is opaque to outgoing Infrared radiation!

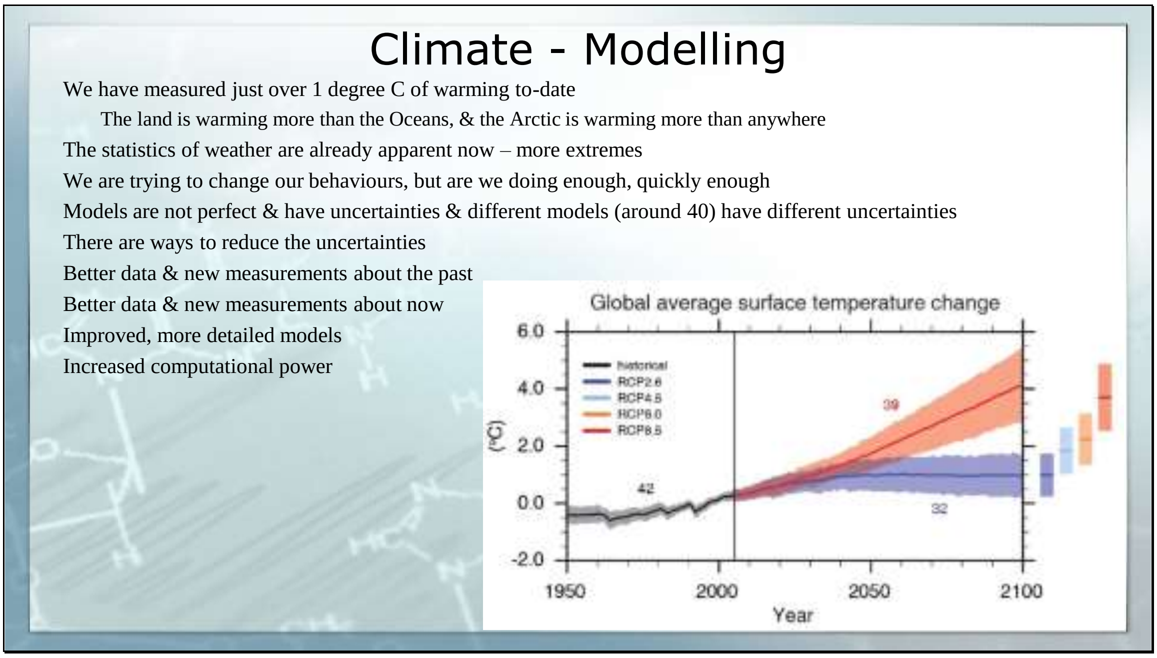
Three key uncertainties in climate modelling are – **human uncertainty** what we do and don’t do e.g., cutting tree, burning fossil fuels etc, **climate sensitivity** – how the planet will react to what happens and what humans do, and **carbon cycle feedback** – how the planet will deal with carbon and absorb it or not in the oceans and atmosphere and plants and other sinks

Slide 26



Greenland has lost 15 trillion tonnes of ice since the 1880's and half of that since the 1970! – Dr Zeke Hausfather

Slide 27



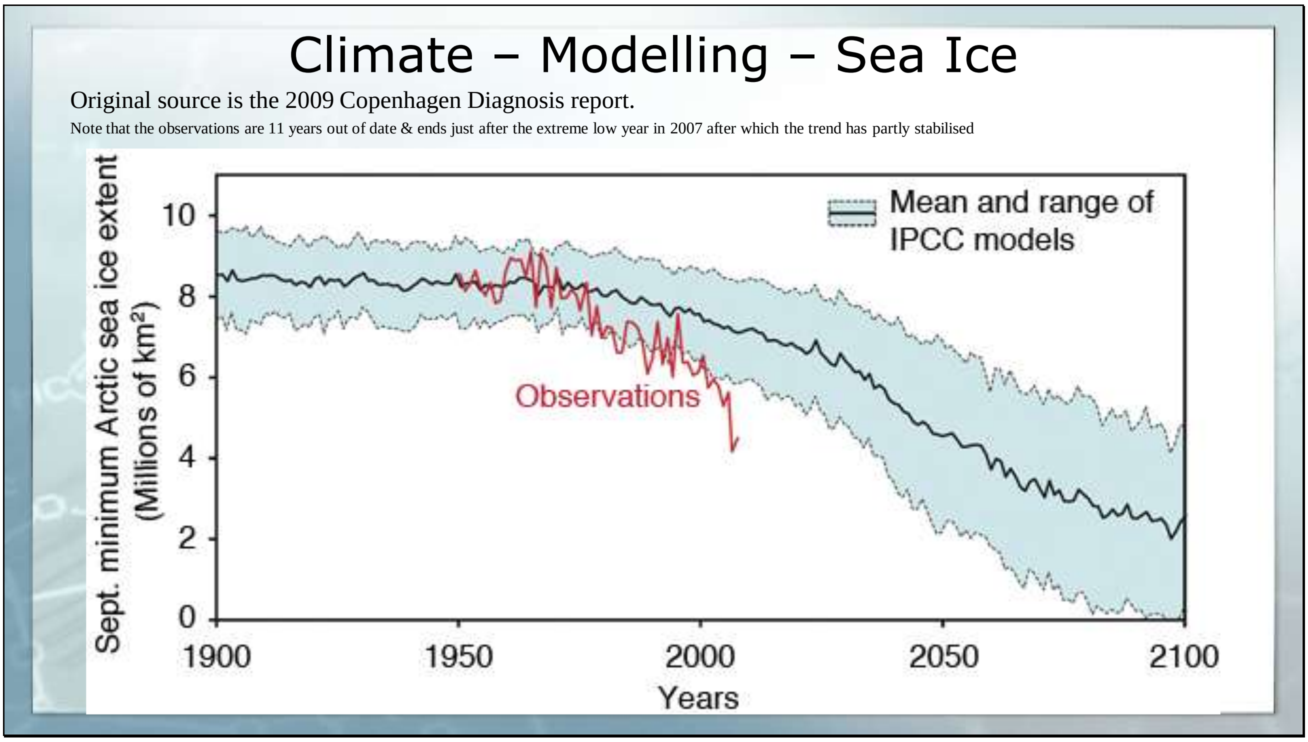
Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modeling and research for the IPCC fifth Assessment Report (AR5) in 2014.

The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come.

The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100

Between 2010 and 2020, 15 times more people died from floods, droughts and storms in very vulnerable regions including parts of Africa, South Asia and Central and South America, than in other parts of the world.
Nature is already seeing dramatic impacts at the current level of warming.
Coral reefs are being bleached and dying from rising temperatures, while many trees are succumbing to drought.

Slide 28



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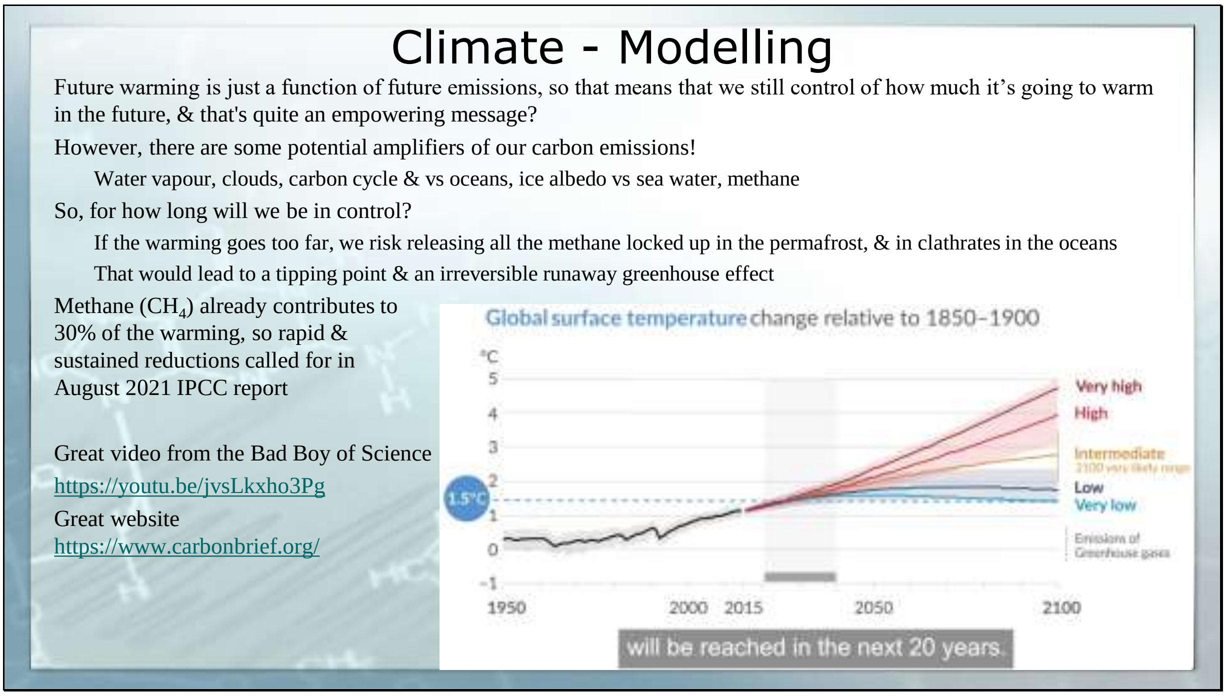
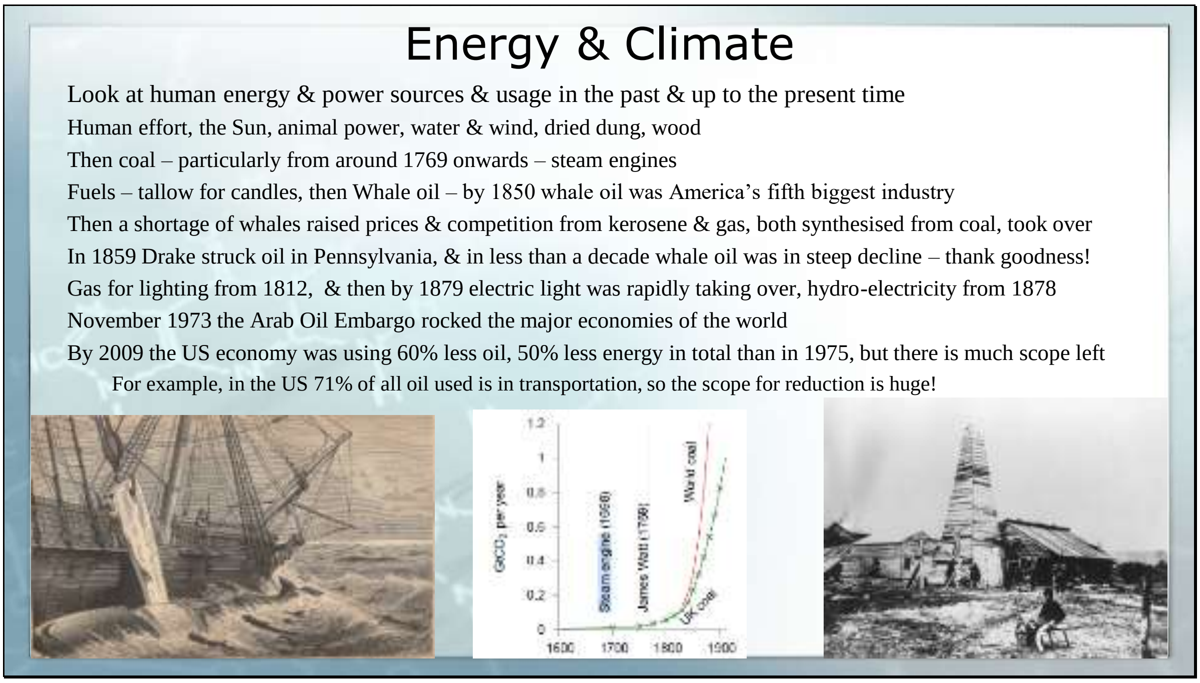


Methane comes from many natural sources, rice production (equal the whole of aviation) landfills, leaks from fossil fuel systems – accidental or deliberate

Slide 30



Whale oil is oil obtained from the blubber of whales. Whale oil from the bowhead whale was sometimes known as train oil, which comes from the Dutch word traan ("tear" or "drop"). Sperm oil, a special kind of oil obtained from the head cavities of sperm whales, differs chemically from ordinary whale oil: it is composed mostly of liquid wax. Its properties and applications differ from those of regular whale oil, and it is sold for a higher price.

This is the well near Titusville, Penn., that pumped the petroleum industry into existence 100 years ago. The picture was taken four years after **Col. Edwin L. Drake** struck oil on Aug. 27, 1859.

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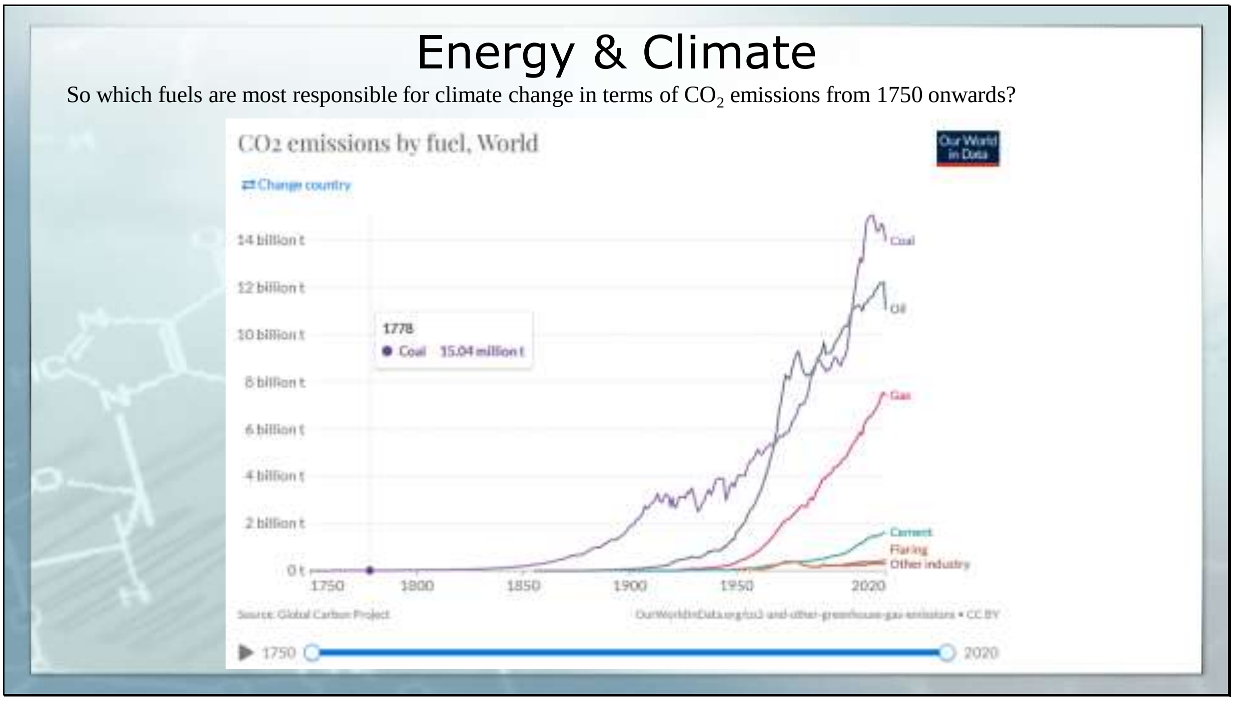

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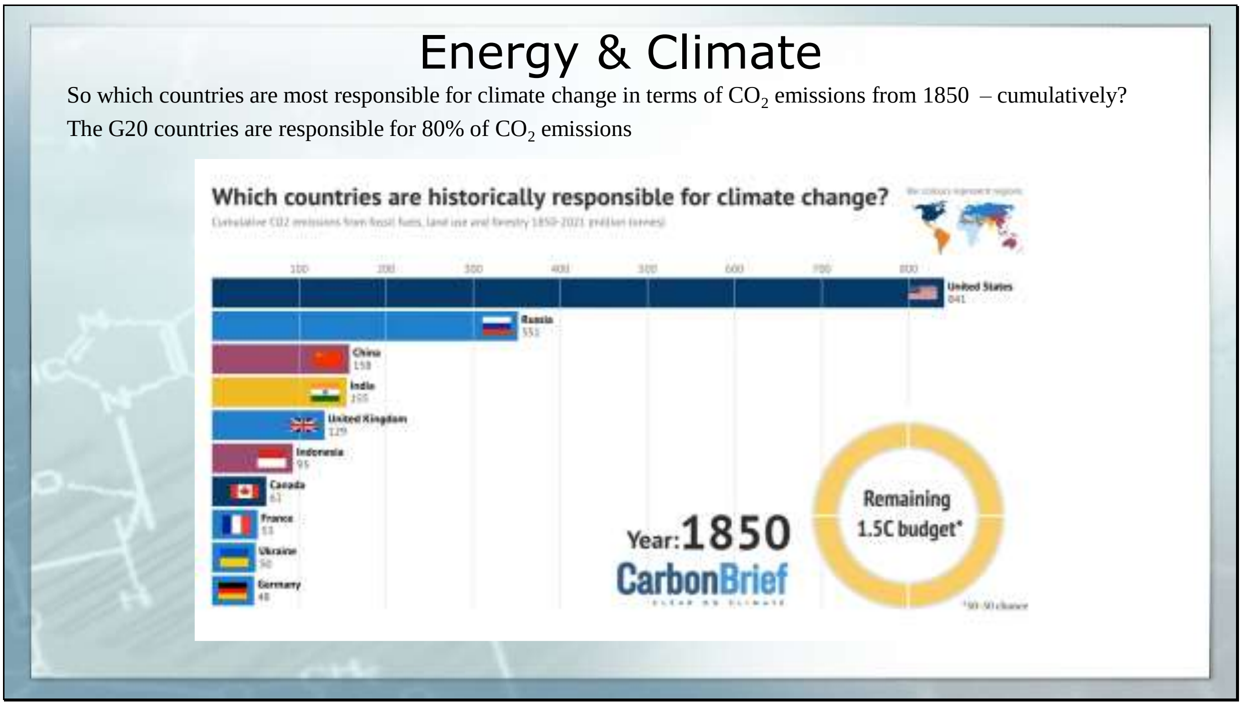

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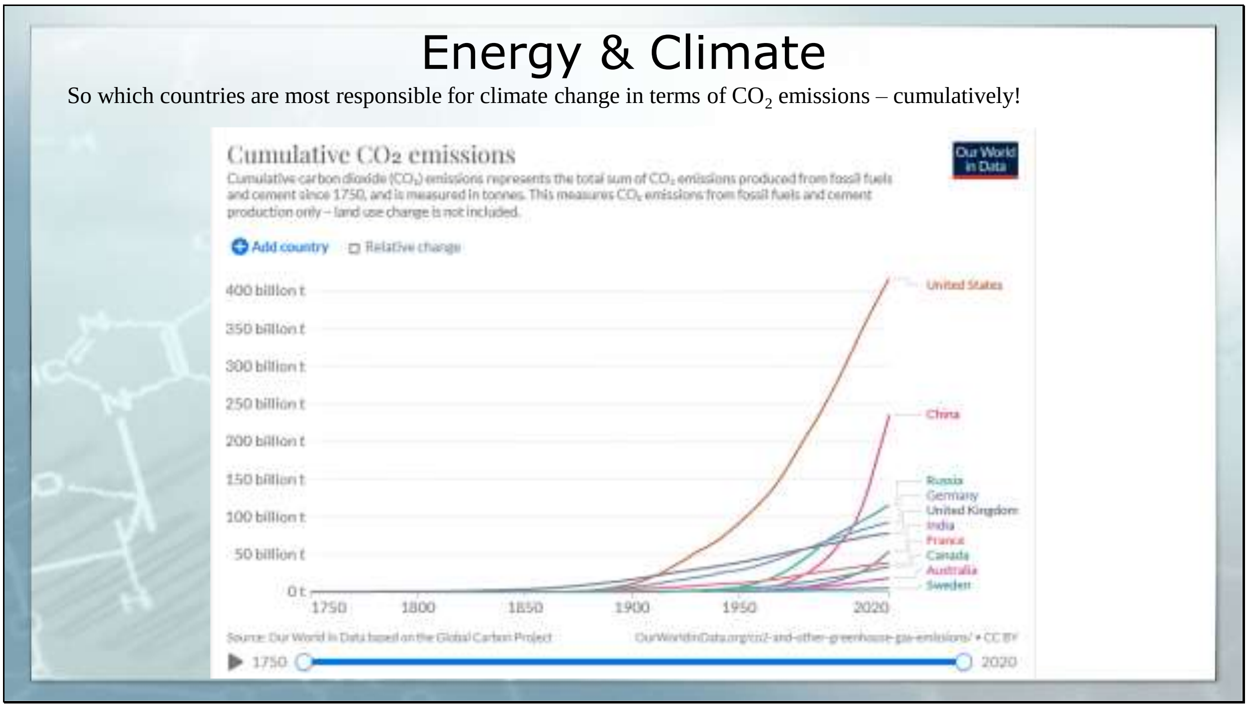

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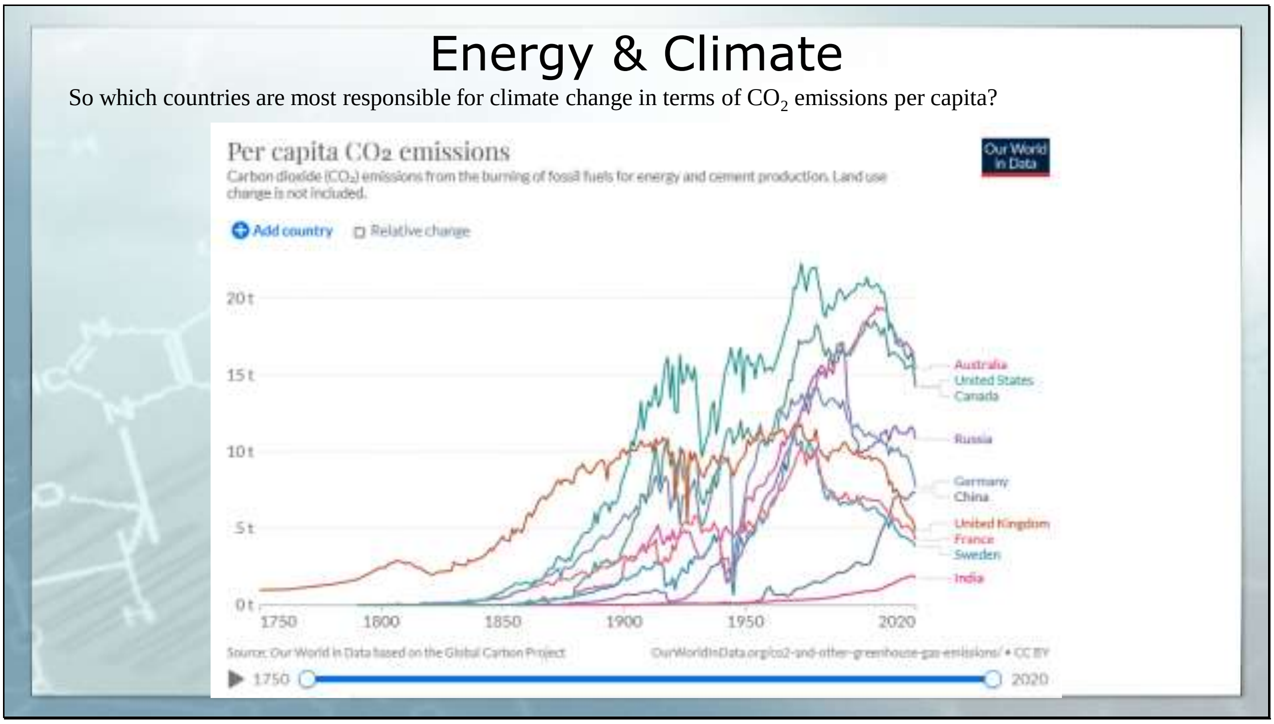
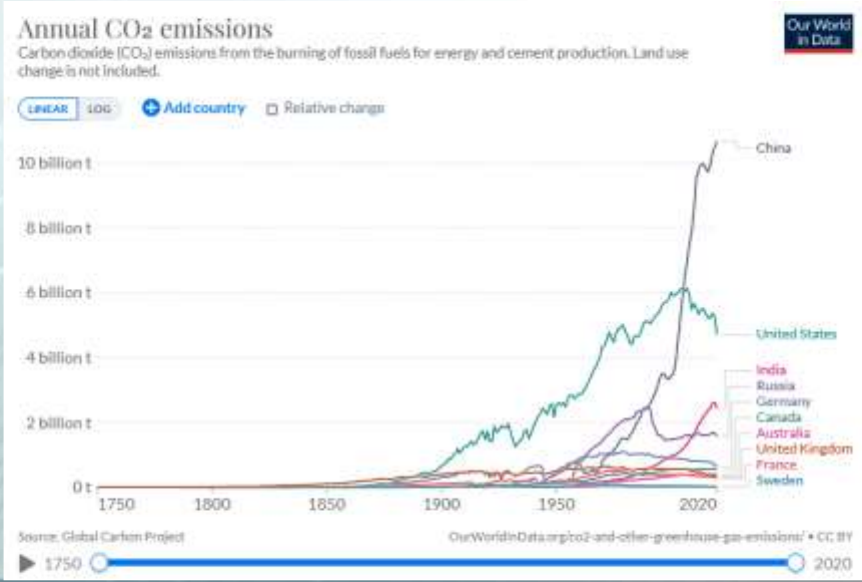


Slide 35

Energy & Climate

So which countries are most responsible for climate change in terms of CO_2 emissions annually?

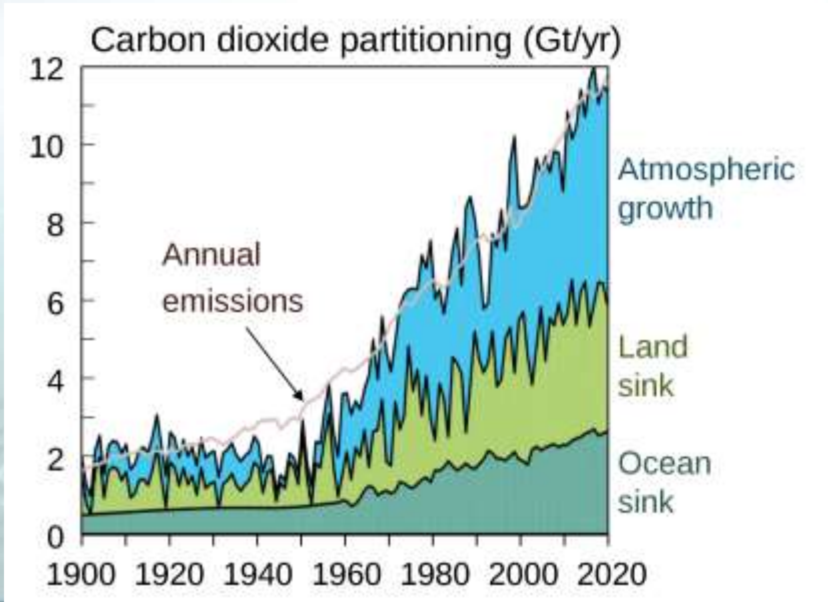


Slide 36

Energy & Climate

So where does all the vast amount of CO_2 emissions go?

Most CO_2 emissions have been absorbed by carbon sinks, including plant growth, soil uptake, ocean uptake, & of course the atmosphere!



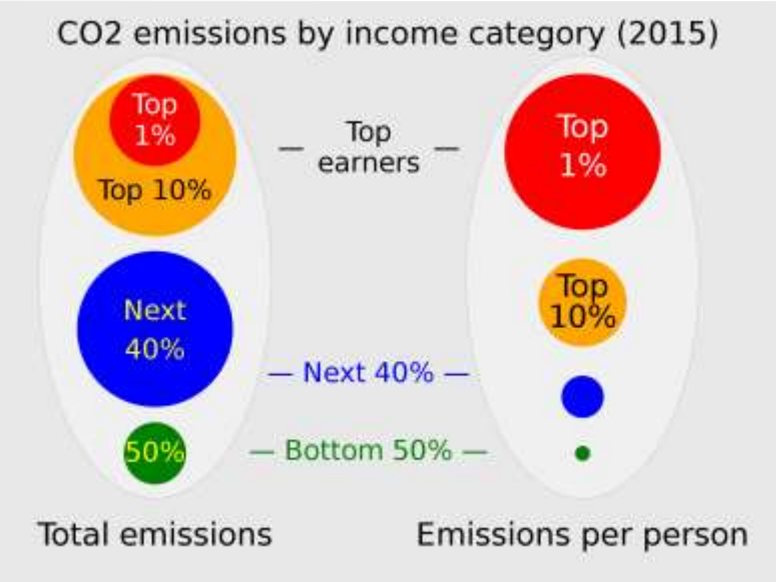
Slide 37

Energy & Climate – Climate Justice

Wealthiest vs poorest output of CO_2

The emissions of the richest 1% of the global population account for more than twice the combined share of the poorest 50%

Compliance with the 1.5°C goal of the Paris Agreement would require the richest 1% to reduce their current emissions by at least a factor of 30, while per-person emissions of the poorest 50% could increase by a factor of about 3



Slide 38

Energy & Climate – United Nations

United Nations IPCC – Intergovernmental Panel on Climate Change – the body responsible for assessing the science related to climate change

- Climate change has been brough about by the richer developed countries & the developing countries are the worst hit

United Nations Climate Change Conference 2021 (2022) COP26

- Keep 1.5 Deg C alive – was the aim
- Pledges made on methane, deforestation, coal, finance & so on
- If all the pledges made at COP26 are met, then we might limit warming to something like 1.8 or 1.9 degrees, so, there's still very big gap between doing that & 1.5 – few countries are sufficient Gabon & Bhutan
- Ratchet mechanism, every five years countries must come back with greater ambitions
- So, all countries are to come back by the end of 2022 & strengthen their pledges as necessary to meet the goals of the Paris agreement (2015) of 1.5 or well below 2 Deg C
- Best estimates from the IPCC suggest we need to cut emissions by 45% below 2010 levels, by 2030, however under current commitments, global emissions are set to increase by almost 14% over the current decade!
- Rich countries pledged to provide poorer countries with $100 billion worth of climate finance every year from 2020, the report basically said sorry we haven't done it
- The Glasgow climate pact urges rich countries to deliver what they promised as soon as possible, & to do that every year through to 2025
- Also sets in place this process through which a new target of climate finance is going to be worked out which is going to kick in from 2025
- The reporting requirements on progress & emissions & on promises met have been made far more stringent for all

During the coronavirus pandemic CO2 emissions were reduced by 7% for 2020!

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Energy & Climate – United Nations

COP26 & Climate Justice

The question about finance for loss & damage, the World's already warmed by more than 1 Deg C, we're already seeing increases in extreme weather around the world, storms, flooding & such

Some of the most vulnerable countries don't have the financial resources to quickly bounce back & rebuild after they've faced disaster, so they have been asking for a long time for specific financial support, separate climate finance, to help them meet their climate pledges, which would actually help address this loss & damage

They didn't get that, they got was what's called 'the Glasgow dialogue', effectively a talking shop to think about how finance for this problem might be provided in the years ahead

The provision of climate finance hasn't reached that $100 billion p.a. target, as promised, & the majority of the money's been going towards mitigation, in other words helping countries to cut emissions

It is easier to fund a project for a wind farm, or to help someone install efficiency measures at industrial plants, whereas Adaptation Funding is less defined i.e., such as building sea defences, or early warning systems to help people prepare for extreme weather events, or mechanisms to help farmers shift the kinds of crops they are growing etc.,

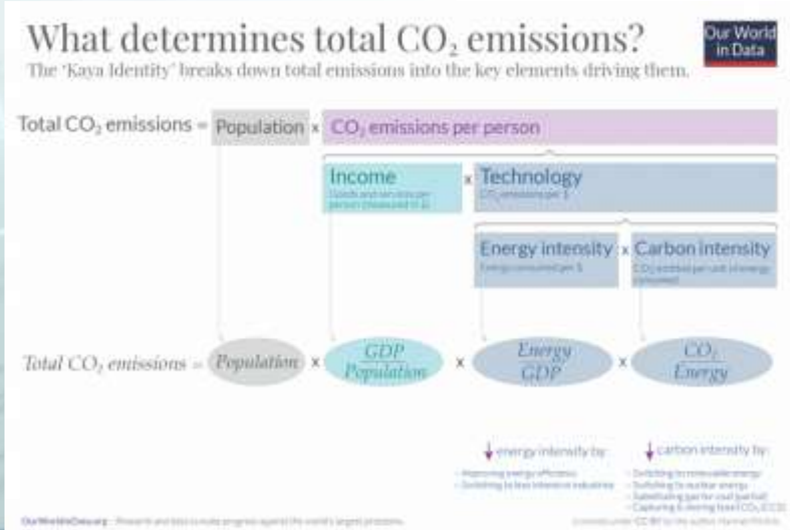
Glasgow agreed add to double Adaptation Finance, from a specific baseline of 2019, so that over the next few years countries are going to have to make a significant increase in provision

Slide 40

Energy & Climate – The Kaya Identity

The Kaya identity was developed by Japanese energy economist Yoichi Kaya

It is the subject of his book Environment, Energy, & Economy: strategies for sustainability co-authored with Keiichi Yokobori as the output of the Conference on Global Environment, Energy, & Economic Development (1993 : Tokyo, Japan)



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Energy & Climate – The Kaya Identitiy

Developed by Japanese energy economist Yoichi Kaya - total emissions, in the simplest description, are determined by:

- Population: number of people
- Per capita impact: average emissions per person

Per capita emissions are determined by:

- Income: GDP per capita – richer people tend to emit more CO_2
- Technology: how much CO_2 is emitted per dollar spent

Technology is determined by two factors:

- Energy intensity: the amount of energy consumed per unit of GDP
- Carbon intensity: the amount of CO_2 emitter per unit of energy

This means that total emissions are driven by the equation:

$$Emissions = Population * GDP * \text{Energy intensity} * \text{Carbon intensity}$$

$$Emissions = Population * GDP * \frac{Energy}{GDP} * \frac{CO2}{Energy}$$

Slide 42

Energy & Climate

Sector by sector: global greenhouse gas emissions

Energy (electricity, heat & transport): 73.2%

- Energy use in industry: 24.2%
- Transport: 16.2%
- Energy use in buildings: 17.5%
- Unallocated fuel combustion (7.8%)
- Fugitive emissions from energy production: 5.8%
- Energy use in agriculture & fishing (1.7%)

Direct Industrial Processes: 5.2%

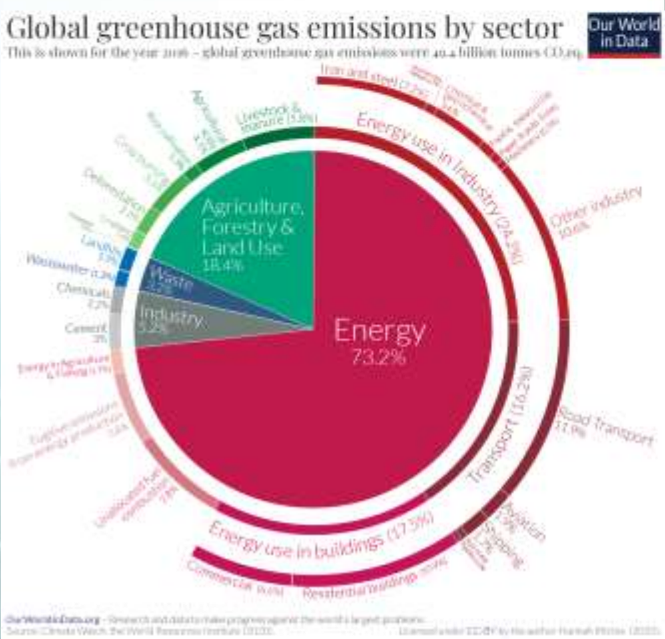
- Cement (3%)
- Chemicals & petrochemicals (2.2%)

Waste: 3.2%

- Wastewater (1.3%)
- Landfills (1.9%)

Agriculture, Forestry & Land Use: 18.4%

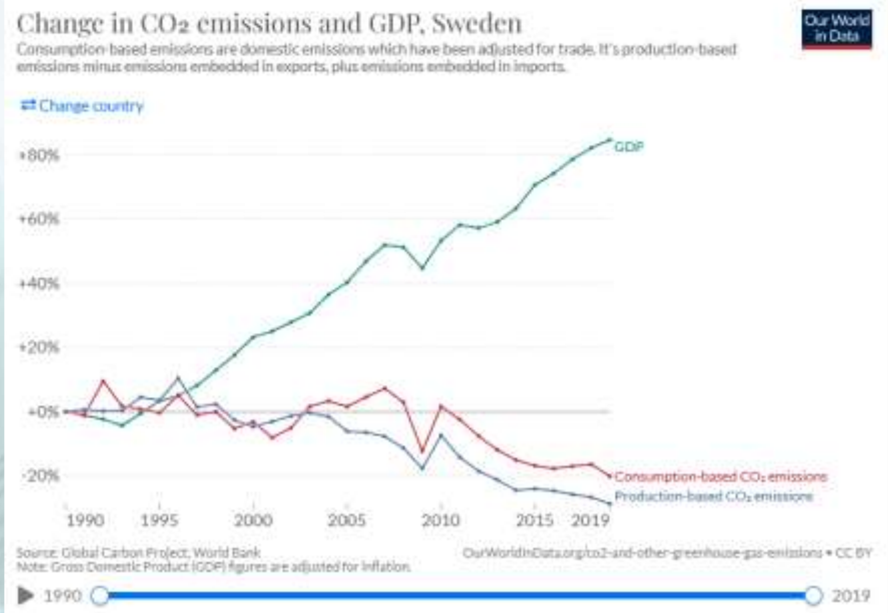
- Grassland (0.1%), Cropland (1.4%), Deforestation (2.2%), Crop burning (3.5%), Rice cultivation (1.3%), Agricultural soils (4.1%), Livestock & manure (5.8%)



Slide 43

Energy & Climate – Can It Be Done?

Sweden as an example



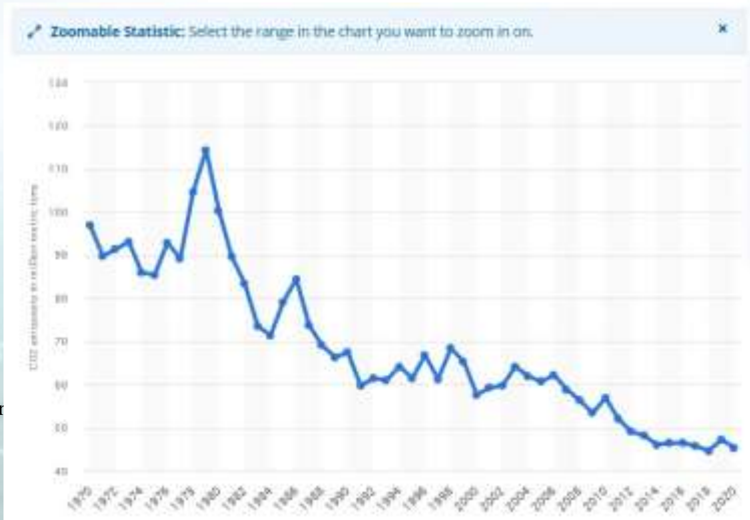
Slide 44

Energy & Climate – Can It Be Done?

Sweden as an example:

- Produced 45.4 million metric tons of carbon dioxide emissions in 2020, a reduction of nearly four percent compared to 2019 levels
- CO_2 emissions have fallen considerably since peaking in 1979, & since 1990 they have reduced by more than 30%
- Resulting from the heating of homes & premises drastically reduced, waste reduction, industry & agriculture
- As of 2018, had the lowest greenhouse gas emissions per capita in the European Union, at 5.4 metric tonnes of CO_2 equivalent
- Electricity mainly from hydroelectric & nuclear, as well as wind energy
  - Clean & renewable sources now account for mor than 60% of electricity generation
- Carbon taxes - recognized as an environmental leader, in 1991 became the second country in the world to introduce carbon taxes
  - As of April 2021, the highest carbon tax worldwide at $137 per metric tonne of CO_2 equivalent

Sweden CO_2 emissions from 1970 to 2020 in millions of metric tonnes



Slide 45

Energy & Climate – What Can Be Done?

What actions could make a difference, & which cannot?

David JC MacKay – Energy Without the Hot Air, 2009 – free online

"We are inundated with a flood of crazy innumerate codswallop
- The BBC doles out advice on how we can do our bit to save the planet
- For example, "switch off your mobile phone charger when it's not in use;"
- If anyone objects that phone chargers are not actually our number one form of energy consumption, the mantra "every little helps" is wheeled out
- A more realistic mantra is: if everyone does a little, we'll achieve only a little!"

Slide 46

Energy & Climate – What Can Be Done?

Decarbonize our energy & fuel systems

- Shift towards low-carbon electricity (reduce carbon intensity – carbon per unit energy)
  - Renewables
  - Nuclear energy
  - Shift from coal to gas (which emits less CO_2 per unit energy) as an interim step
  - Use biomass
  - Carbon capture & storage
    - Ideally needs to be at source where it is most concentrated – but it costs more fuel/energy to do it
    - Taking it out of the atmosphere is very difficult, biomass capture, direct capture is very energy consumptive
- Shift sectors such as transport, towards electricity
  - Some energy sectors are harder to decarbonize – for example, air travel & transport
- Develop low-cost low-carbon energy, plus energy storage technologies
  - To do this quickly, & allow lower-income countries to avoid high-carbon development pathways, low-carbon energy needs to be cost-effective & the default choice
  - Change from storing/using energy as fossil fuels to green hydrogen or ammonia storage/usage
- Improve energy efficiency – energy per unit GDP

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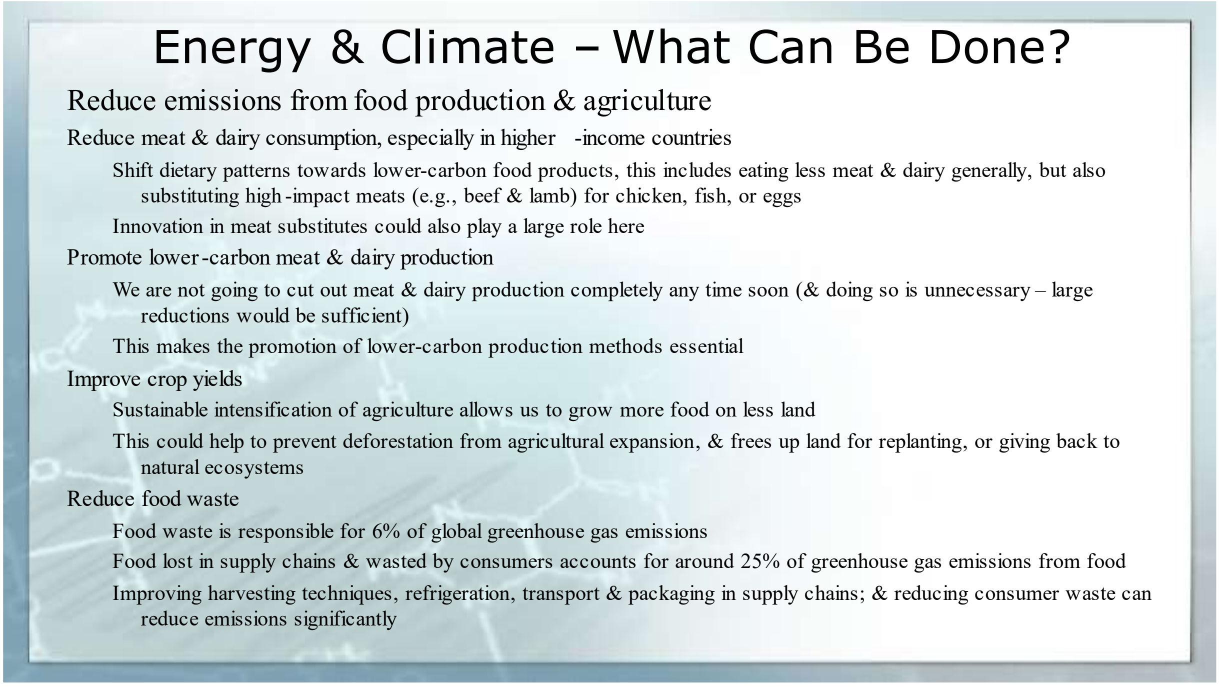

The world now produces more than three times the quantity of meat as it did fifty years ago. In 2018, production was around 340 million tonnes.
Pork is the most popular meat globally, but the production of poultry is increasing most rapidly.
80 billion animals are slaughtered each year for meat. The average person in the world consumed around 43 kilograms of meat in 2014. This ranges from over 100kg in the US and Australia to only 5kg in India.

Meat consumption increases as the world is getting richer.

The world now produces around 800 million tonnes of milk each year – more than double the amount fifty years ago. Richer countries tend to consume more milk per person.

The amount of meat produced for a given animal varies significantly across the world based on production systems.

Livestock production has large environmental impacts on greenhouse gas emissions, land and water use. Beef and lamb have much larger environmental impact than pork and poultry.

Seafood production – fish and seafood is another key source of protein and nutrition for populations across the world. How much fish do people eat, and what are the environmental impacts?

Diet compositions – varied diets are essential for good health and nutrition. But the quality and diversity of diets varies significantly across the world. What do people eat?

Micronutrient deficiency – poor dietary diversity means many people lack the essential vitamins and minerals they need for good health. How common is micronutrient deficiency and who is most at risk?

Land use – half of the world's habitable land is used for agriculture, and more than three-quarters of this is used for livestock.

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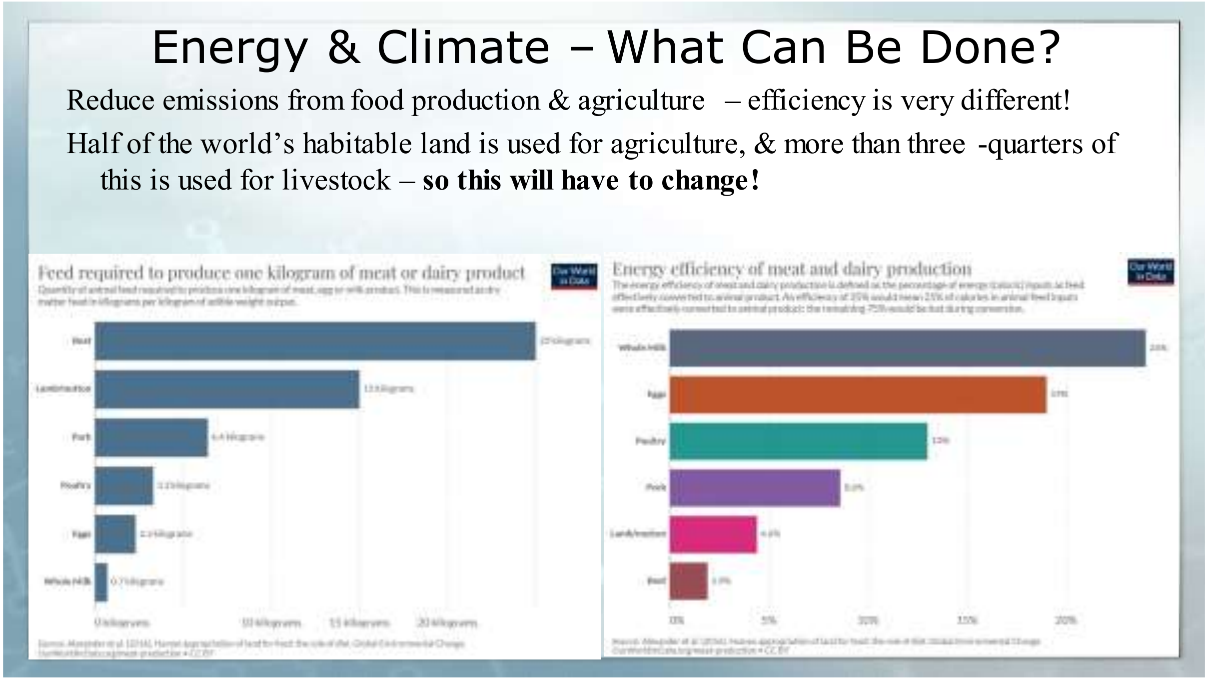

Around 57% of food emissions come from animal-based foods, although they make up only 18% of the world's calories, and 37% of its protein. And as people across the world grow richer, they want more meat. Traditional diets in most cultures were primarily plant based with a little meat on top. But with the rise of industrial style meat production and factory farming, meat has become a staple food, a regular indulgence in developed countries and a symbol of status and wealth in developing countries.

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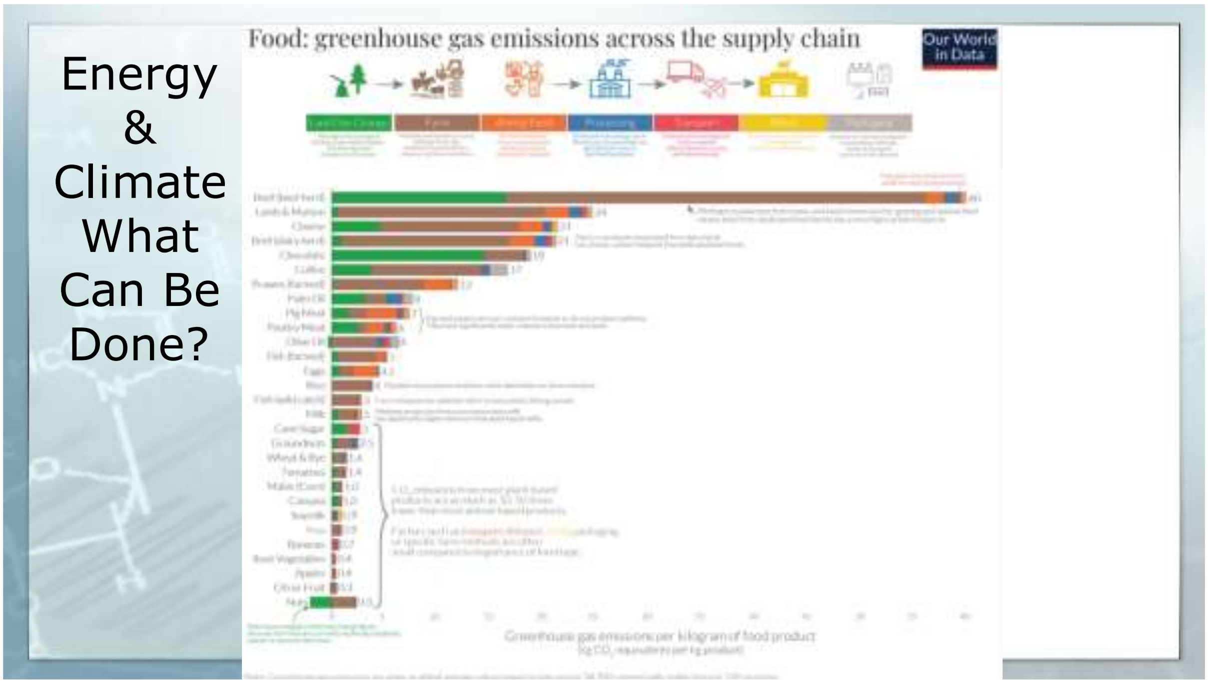

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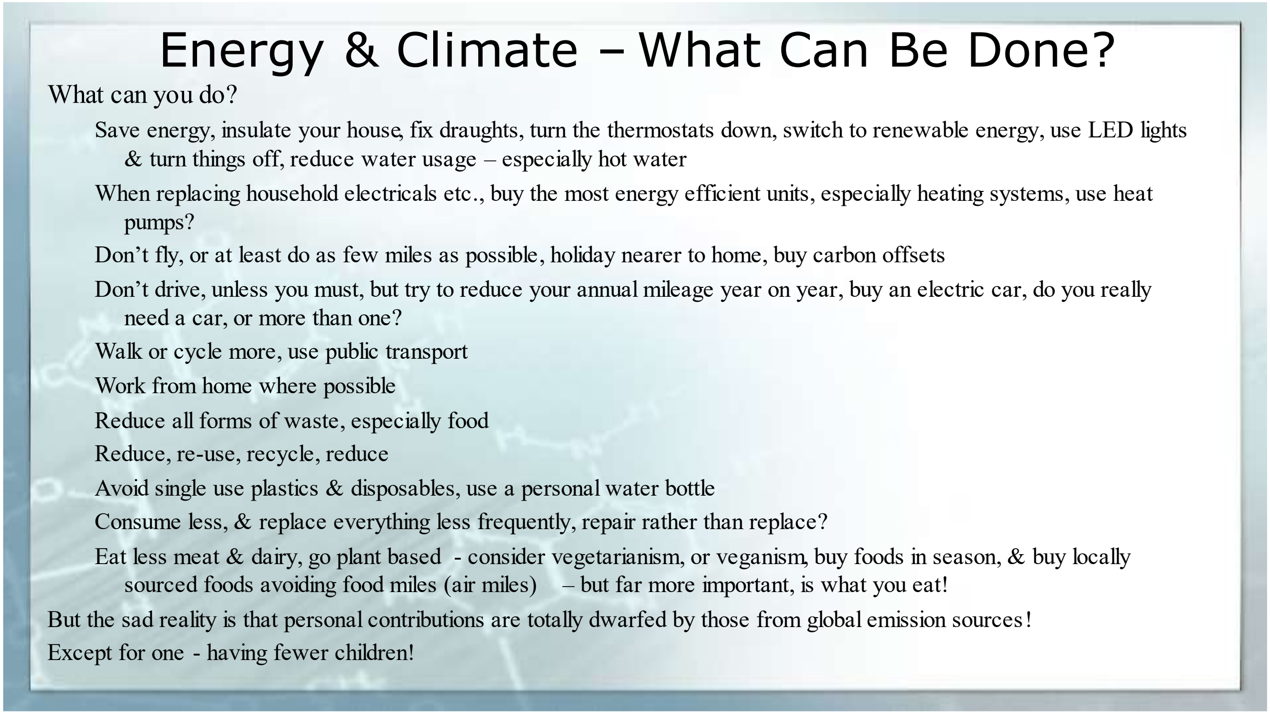

If you eliminated 100% of your emissions for the rest of your life, you would save one second's worth of emissions from the global energy sector. Even the most motivated person can't even make a tiny dent!
Carbon offsets come from certified green-energy projects such as solar power projects, wind farms and methane-recapture operations at landfills or dairy farms, and projects that plant trees or work toward forest preservation. Though customers still receive liquid fossil fuels, purchasing carbon offsets helps keep these projects running and allows project owners to create more of them, which helps lead to cleaner air and reduced carbon emissions.
They estimated that if the average household substituted their calories from red meat and dairy to chicken, fish or eggs just one day per week they would save 0.3 tCO2eq. If they replaced it with plant-based alternatives, they would save 0.46 tCO2eq. In other words, going 'red meat and dairy-free' (not totally meat-free) one day per week would achieve the same as having a diet with zero food miles. There are also a number of cases where eating locally might in fact increase emissions. In most countries, many foods can only be grown and harvested at certain times of the year. But consumers want them year-round. This gives us three options: import goods from countries where they are in-season; use energy-intensive production methods (such as greenhouses) to produce them year-round; or use refrigeration and other preservation methods to store them for several months. There are many examples of studies which show that importing often has a lower footprint.

Hospido et al. (2009) estimate that importing Spanish lettuce to the UK during winter months results in three to eight times lower emissions than producing it locally. The same applies for other foods: tomatoes produced in greenhouses in Sweden used 10 times as much energy as importing tomatoes from Southern Europe where they were in-season.
The impact of transport is small for most products, but there is one exception: those which travel by air.

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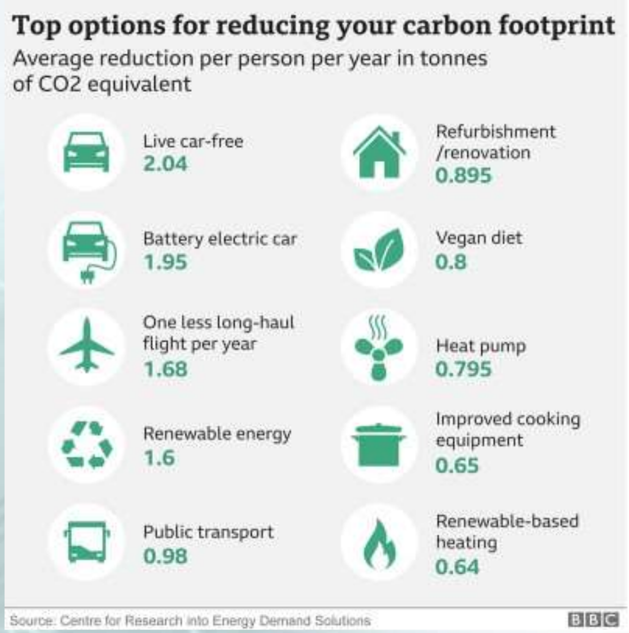
Energy & Climate – What Can Be Done?

What can you do?



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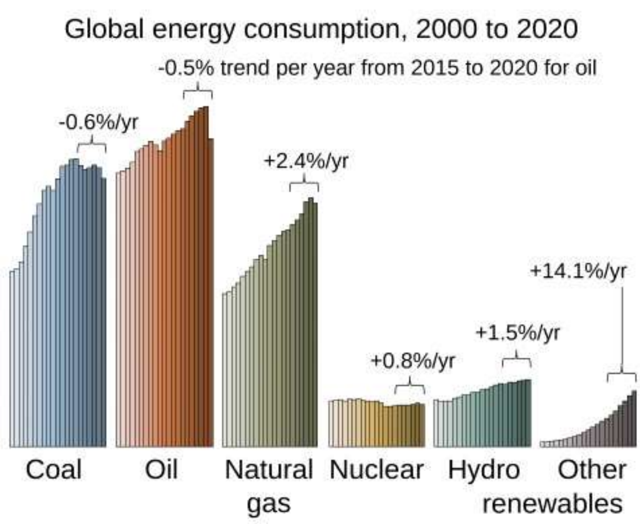
Energy & Climate – Current Energy

Burning fossil fuels is sacrilege – we need it as supply stock for future chemicals, fertilisers, polymers etc., etc.

If we waste it all now, it will take a lot of extra energy in the future to regenerate the equivalent chemical resources

But we really should stop subsidising fossil fuels such as oil & gas – to keep everyday goods low in price!



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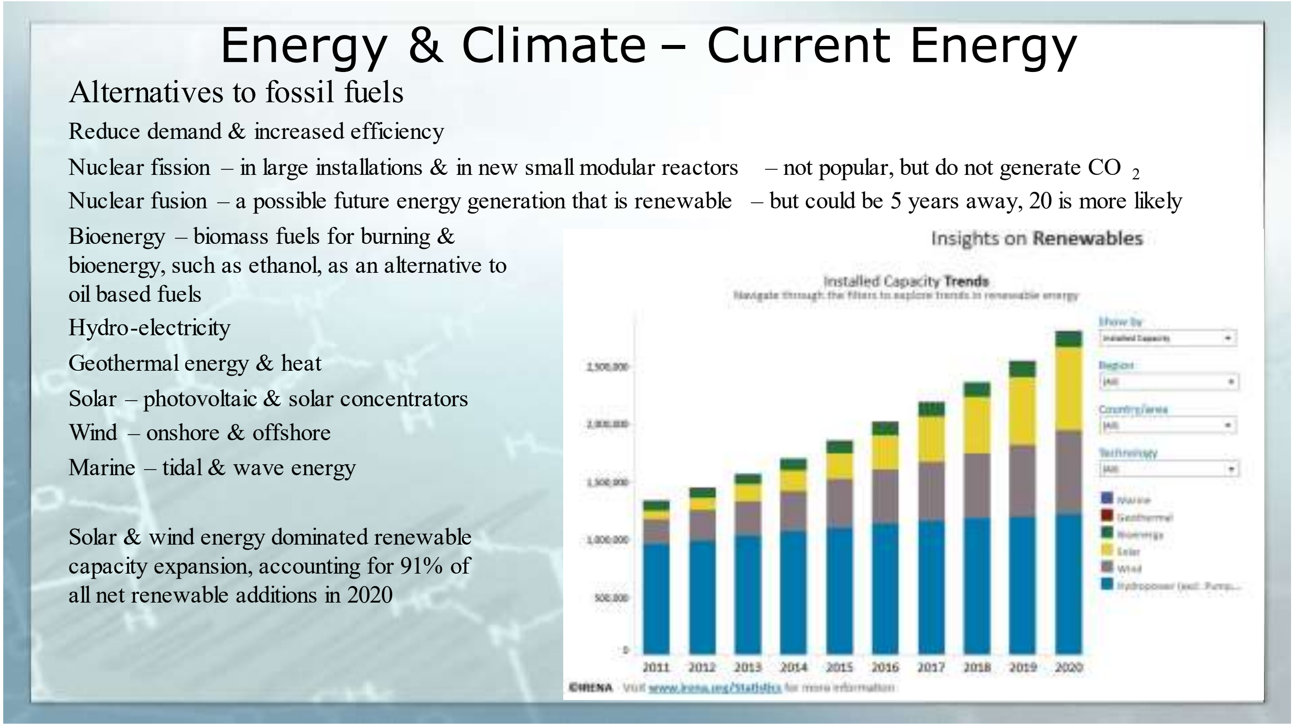

At the end of 2020, global renewable generation capacity amounted to 2 799 GW. Renewable generation capacity increased by 260 GW (+10.3%) in 2020. Solar energy continued to lead capacity expansion, with an increase of 127 GW (+22%), followed closely by wind energy with 111 GW (+18%). Hydropower capacity increased by 20 GW (+2%) and bioenergy by 2 GW (+2%). Geothermal energy increased by 164 MW. Solar and wind energy continued to dominate renewable capacity expansion, jointly accounting for 91% of all net renewable additions in 2020.

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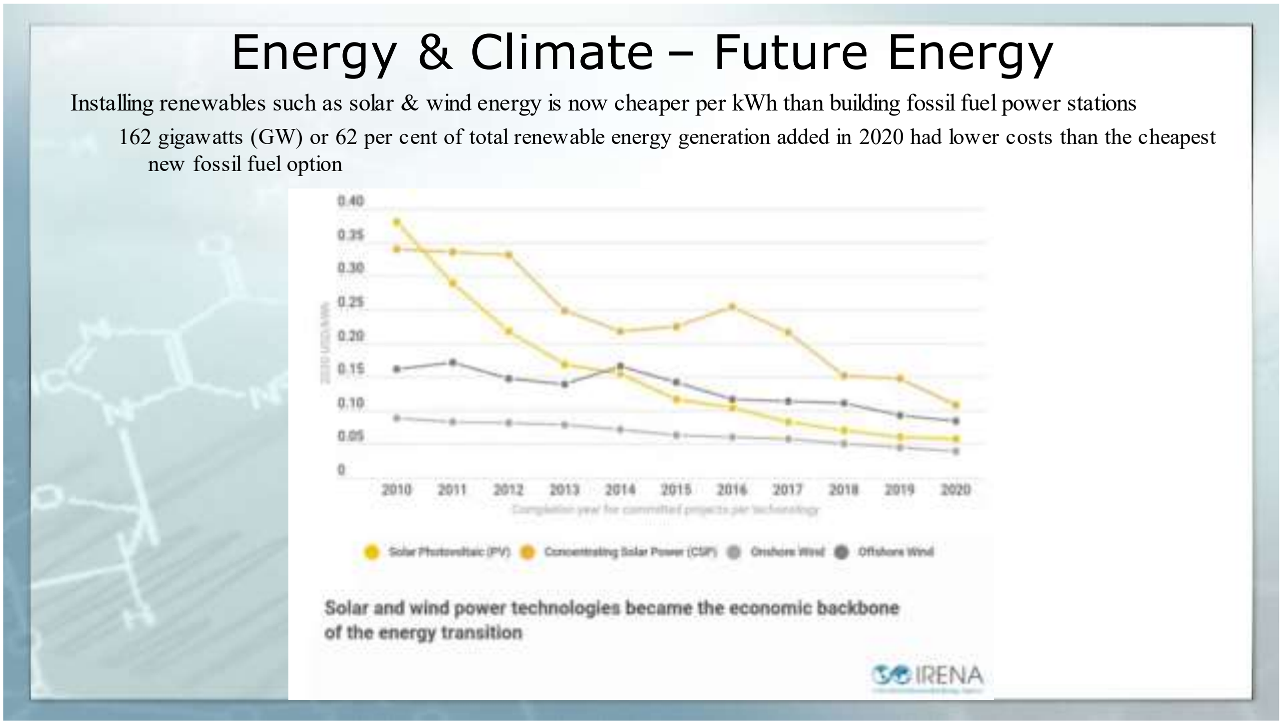

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Energy & Climate – Future Energy

Using electricity from renewables, such as solar & wind, in new more efficient ways

- Mini & micro-grids - a set of small-scale electricity generators (e.g., solar) & possibly energy storage systems interconnected to a distribution network that supplies electricity to a small, localised group of customers & operates independently from the national transmission grid
  - Have the potential to provide electricity to as many as 500 million people by 2030, with the right policies & about $220 billion of investment to build around 210,000 mini grids
  - Over the past decade, mini grid costs have declined significantly, while the quality of service has increased
  - The per kWh cost of mini grid electricity is expected to decrease by two thirds by 2030.
  - Significantly more mini grids will need to be deployed in the top 20 electricity access deficit countries – from 10 - 50 mini grids currently deployed each year per country to over 1,600
- Home batteries– e.g., Tesla Power Wall
- Electric vehicles as local domestic electrical storage
- Home energy stores– e.g., heating insulated hot water storage units via excess solar– I have this at my home!

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Energy & Climate – Future Energy

The crucial issues with renewables such as solar & wind are:

- Capacity – we need very much more than we need at anyone time
- Constancy – when the Sun is not shining, & the wind is still, we have no energy!
- Storage of energy, & loads of it, solves both problems
  - Turning night into day is easy, we need enough storage capacity to turn winter into summer – not hours or days, but months or years!
- Energy storage options:
  - Mechanical, spring, compressed air energy storage (CAES), fireless locomotive, flywheels, solid mass gravitational, hydraulic accumulator, pumped-storage hydroelectric
  - Electrical, electromagnetic, supercapacitor, superconducting magnetic storage
  - Electrochemical, flow battery, rechargeable battery, ultra-battery
  - Thermal, brick storage heater, cryogenic energy storage, liquid air energy storage (LAES), liquid nitrogen engine, ice storage for air conditioning, molten salt storage, seasonal thermal energy storage, steam accumulator, thermal energy storage (general)
  - Chemical, biofuels, hydrogen storage (ammonia), hydrogen peroxide, power to gas (e.g., methane)

The Chinese State Grid Corporation opened another five pumped hydro stations last year (2021) and plans to increase its pumped storage capacity from the current 26.3GW to 100GW by 2030. All over the world, grid operators are desperately searching for long-duration energy storage solutions to leverage renewable energy as baseload power and address the variable nature of clean resources.

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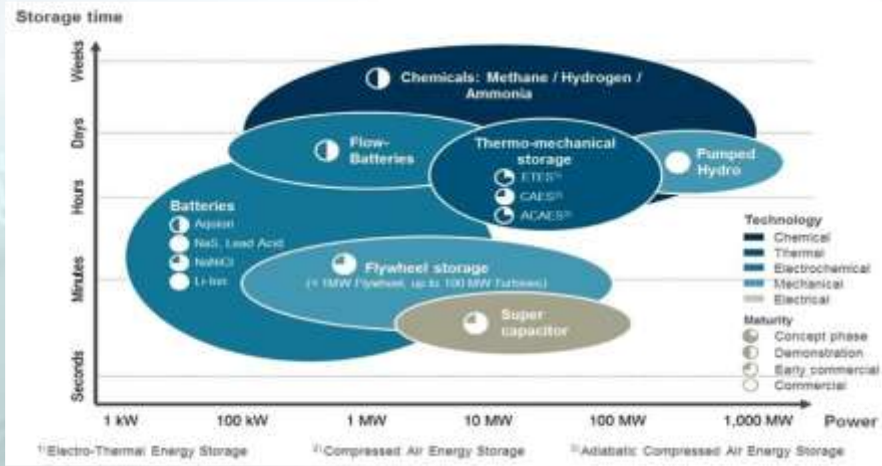
Energy & Climate – Future Energy

Storage of renewable energy– Summary courtesy of Dr Ian Wilkinson, Siemens



Four are worth highlighting – batteries, pumped storage, gravity storage, & hydrogen / ammonia

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Energy & Climate – Future Energy

Storage of renewable energy– batteries

Capacity – 10s to 100s MW

Duration - hours only

e.g., Tehachapi, California

Fixed in place

Mornington project in Victoria Australia 2021 for a 480 MWh battery energy storage system (BESS)

Battery energy storage at grid scale is not cheap, but it is probably the most cost-effective proven technology to date. Announcements of projects for battery energy storage systems rarely include total project values. However, an October 2021 article on the Mornington project in Victoria Australia for a 480 MWh battery energy storage system (BESS) states this is to be installed on Victoria’s Mornington Peninsula at a cost of “upwards of $190 million”. AUD 190 million is about GBP 100 million. The 2021 UK energy storage requirement is 19 million MWh, which equals about 40,000 Mornington BESSs. Or close to £4,000 billion, roughly ten times what the UK spent on Covid-19 emergency measures.

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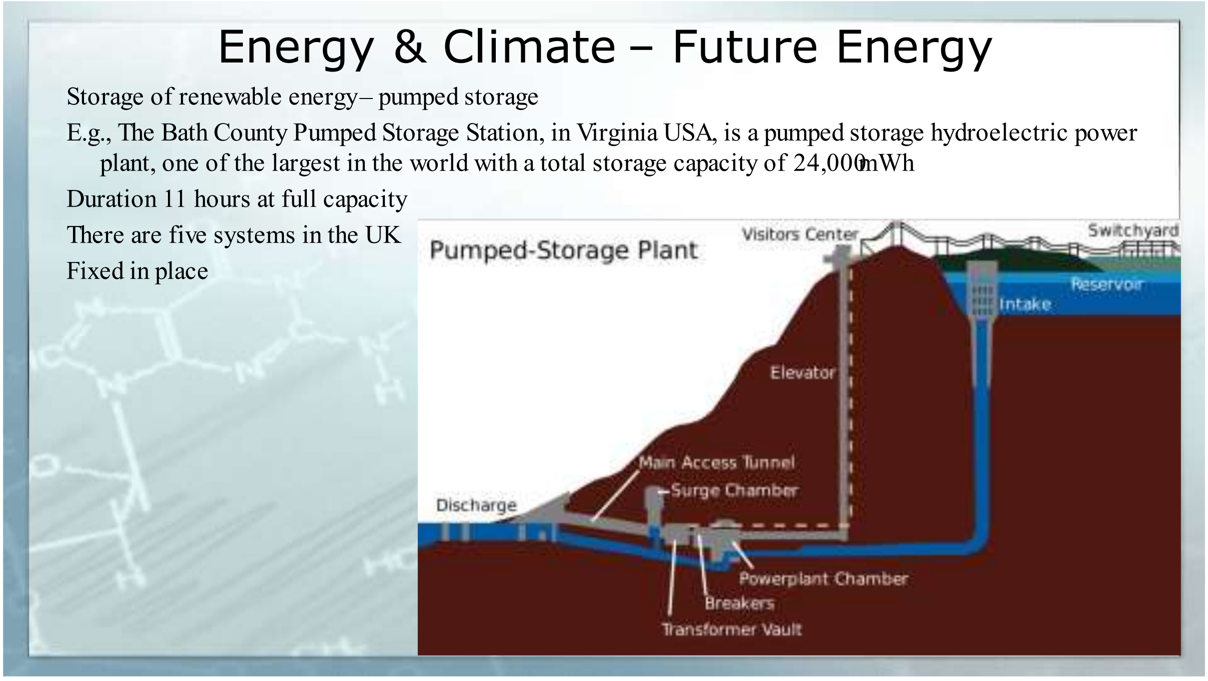

Dinorwig Pumped Power Plant in North Wales has a rare combination of features: two bodies of water separated by a large difference in elevation but only ~3 km from each other (no other equivalent site exists in the UK). The upper reservoir, Marchlyn Mawr, is about 500 m above the lower reservoir, Llyn Peris. The two reservoirs are connected by man-made tunnels. At full power, water flows down and through the generator turbines at 400 cubic metres per second.

The Dinorwig station's six reversible turbine generator/pump units are hidden within Europe's largest man-made cavern. They can reach maximum power output in less than 16 seconds. The units act as pumps to move water from the lower reservoir back up to Marchlyn Mawr using off-peak electricity.
Overall energy storage efficiency is around 75%.
Dinorwig was commissioned in 1984 and is the largest scheme of its kind in Europe.

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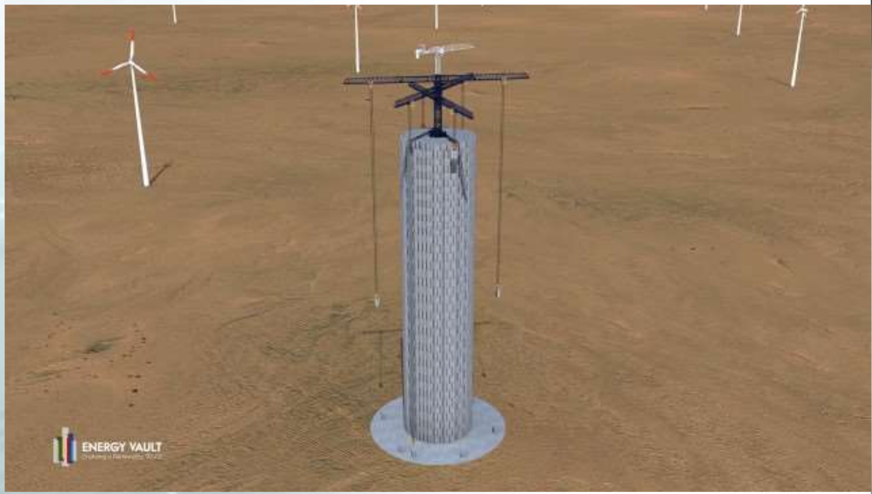
Energy & Climate – Future Energy

Storage of renewable energy – gravity storage

Between 1 & 10 GWh

Fixed in place



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Energy & Climate – Future Energy

Storage of renewable energy – hydrogen / ammonia

- Advantages are mobility & transportability – you can move it round with you & ship it to where it's needed
- Hydrogen comes in many colours (too many!), but the ideal label is green!
  - Green hydrogen is made from renewable energy sources
  - Blue from fossil fuels (methane) where the CO_2 is captured & stored
  - Grey is created from natural gas (methane) by steam reforming & the water gas shift reaction releasing CO_2
  - Orange is made from biogas or biogenic waste (mainly methane)
  - Brown or black is made from the gasification of coal & where the CO_2 is released
  - Gold is recovered naturally from deep drilling into the Earth
  - Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen & solid carbon
- Worldwide 95% of all hydrogen is grey – but that is about to change dramatically towards green
- Hydrogen (or ammonia) from green sources could replace fossil fuels derived from oil in shipping & aircraft
  - Hydrogen for transport, via electric fuel cells, or internal combustion engines (JCB & Hyundai & Renault)
  - Hydrogen is proposed for domestic use also, e.g., in heating, & as local storage for electricity via fuel cells

Maersk has made the decision to order 12 ocean-going ships which run on methanol. Each costs $175m (£130m) and is capable of carrying 16,000 containers. "We think this will unlock the scaling that needs to happen," says Jacob Sterling, Maersk's head of decarbonisation innovation and business development.

Global shipping would take 500 million tonnes of green ammonia per annum.

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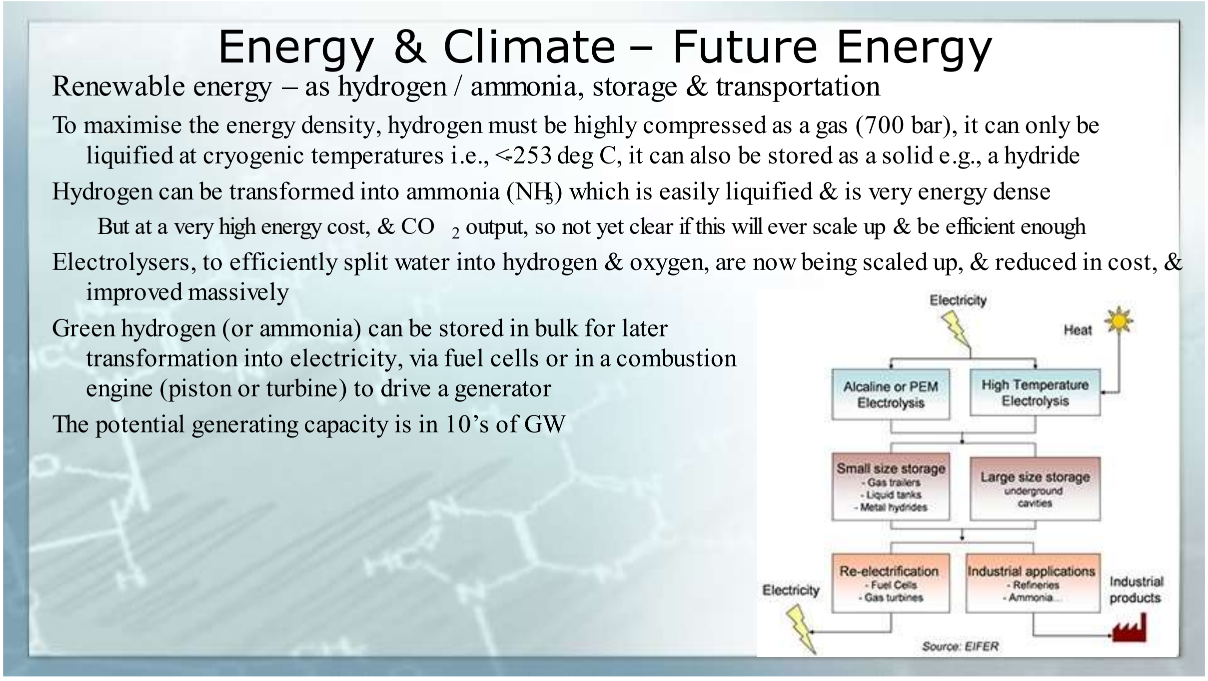

So, at 700 bar, which is 700 times normal atmospheric pressure, hydrogen has a density of 42 kg/m3, compared with 0.090 kg/m3 under normal pressure and temperature conditions.
At this pressure, 5 kg of hydrogen can be stored in a 125-liter tank.

Today, most car manufacturers have opted for the solution that consists in storing hydrogen in the gaseous form, at high pressure.
This technology enables us to store enough hydrogen to allow a car that runs on a fuel cell battery to cover between 500 and 600 km between fill-ups.

Hydrogen turns into a liquid when it is cooled to a temperature below -252,87 °C and 1.013 bar, liquid hydrogen has a density of close to 71 kg/m3.
At this pressure, 5 kg of hydrogen can be stored in a 75-liter tank.

In order to maintain liquid hydrogen at this temperature, tanks must be perfectly isolated.

Hydrogen Production

Alkaline electrolysis is a mature technology for large systems, whereas PEM (Proton Exchange Membrane) electrolysers are more flexible and can be used for small decentralized solutions. The conversion efficiency for both technologies is about 65%~70% (lower heating value). High temperature electrolysers are currently under development and could represent a very efficient alternative to PEM and alkaline systems, with efficiencies up to 90%.

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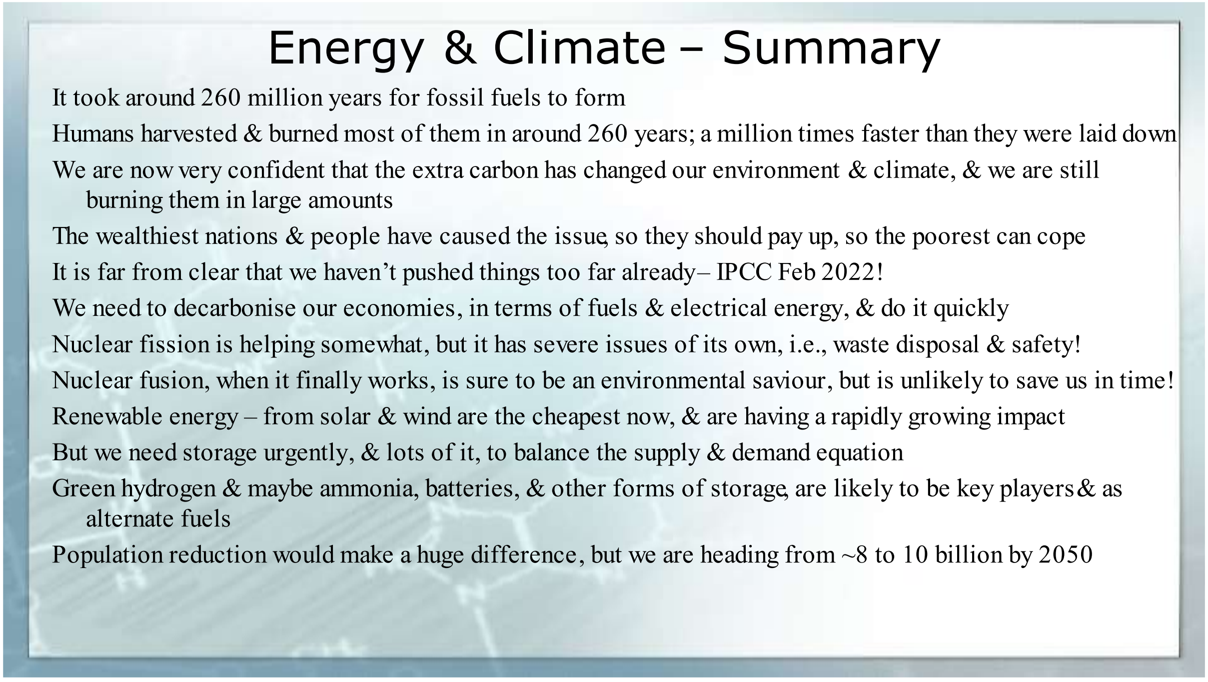

If we reduced our CO2 to zero it would stop further warming but would not reduce it.

If wanted to reduce temperatures down, to say those of the 1970's, then we would need to reduce CO2 in the atmosphere to the levels then, and that would take all the energy we produced globally since then and more to do that!

The good news is global emissions have been flattening out for the last few years um so now emissions are only increasing by one percent a year instead of three percent a year
Our emissions from fossil fuels that is uh global coal use peaked back in 2013 and has been modestly declining and a lot of that is due to the fact that we've been pretty successful in making clean energy technologies a lot cheaper

The price of solar panels has fallen by a factor of 10 in the last decade, the price of batteries has fallen by a factor of 10 in the last decade, electric vehicles were 14 of global vehicle sales in the last two quarters, so we're reaching an inflection point. A lot of these clean energy technologies where they're becoming cheaper than fossil fuel alternatives and the reason that's important is it means that they can help drive emission reductions even in the absence of stringent policies taken by countries so that's the good news and that seems to be putting us more on track for a warming of around three degrees by the end of the century the bad news is that you know even a flattening of global emissions means the world is going to keep warming. We're still going to end up at three degrees by 2100, and you know four degrees by 2150 and five degrees by 2200 if emissions stay flat, and so it's in some ways the easiest part to stop emissions from increasing it becomes much harder particularly in a world of growing economies of billions of people in poorer countries you know aspiring to the things we take for granted uh to have emissions decrease and so technology alone is not going to save us.

We need a combination of technology and a lot more ambitious policy commitments than we've seen so far um and so countries have started making long-term pledges that are consistent with solving the problem. In the last two years we've seen countries that represent uh about three-quarters of global emissions commit to get their emissions to zero or net zero uh by mid to late century but there's a big question of how seriously we should take those commitments.

It's one thing for countries to say we're going to do this thing next year or even five years from now it's another thing to say we're going to do this thing 50 years from now when none of us are going to be in power or even alive

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Thank you

Any questions?