Making the Case for "Living Without Oil"

University of Victoria
Retirees Association

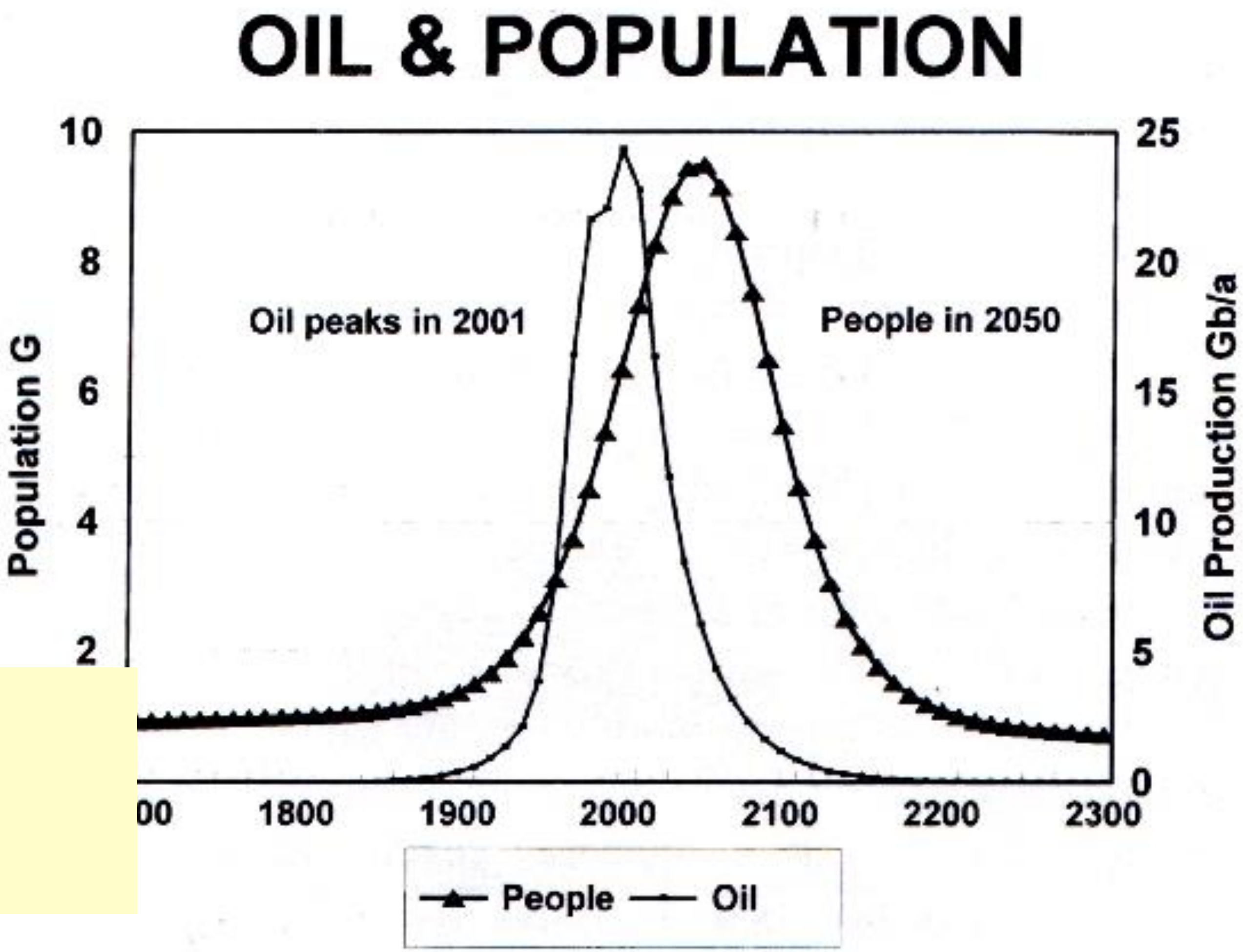
January 30, 2020
John Gunton

Why? - 2 reasons
How? – 2 ways (in combination)
Result ?– net zero GHG emissions by 2060 -70

PEAK OIL

Dr Colin Campbell
1998 FORECAST

THE ASSOCIATION FOR
THE STUDY OF PEAK OIL & GAS
FOUNDED IN 2000 www.peakoil.net



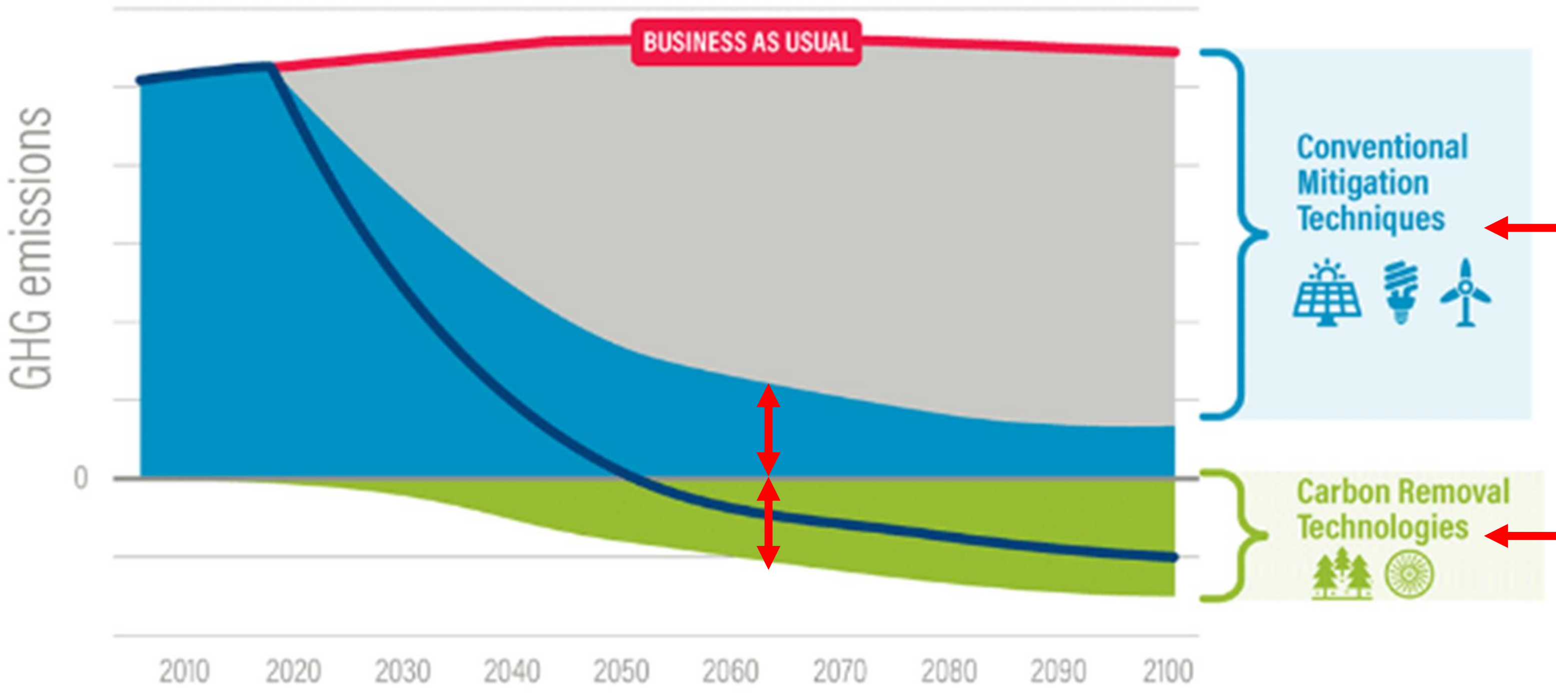
"the end of the Petroleum Interval will be gradual wherein no crisis point is reached, just slow change. **But especially with rising populations, and no sufficient substitutes for oil at hand, there is the possibility of a chaotic breakdown of society**" - Youngquist

The 2 Imperatives

Paris Agreement , 2015
Report published Oct 2018
IPCC Special Report On Global Warming of 1.5^{O}C

FIRST: The planet is running out of Oil (Hydrocarbons)

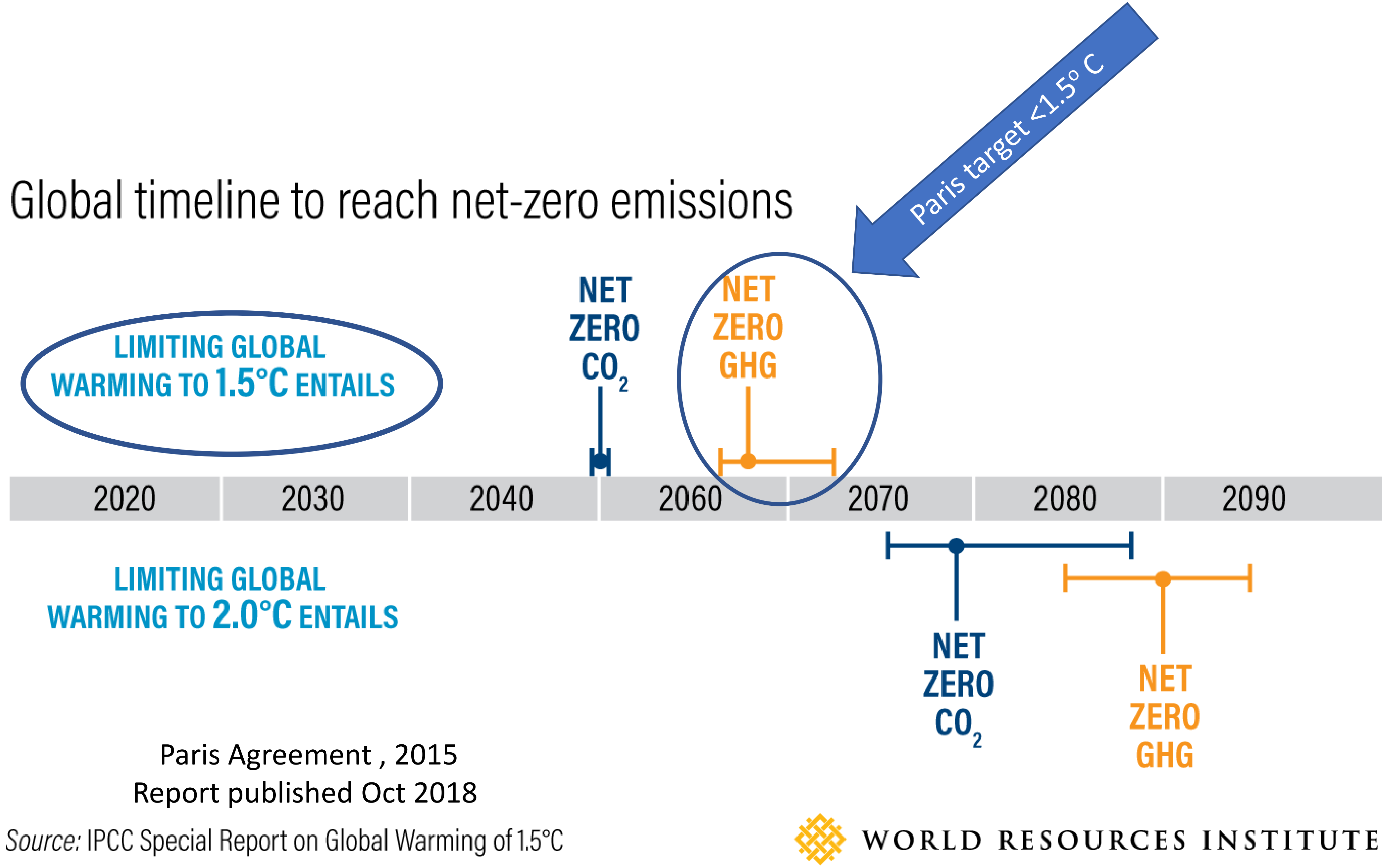
SECOND: Burning Hydrocarbons at the current rate is causing runaway global warming by rising Greenhouse Gas emissions



What can we do?

Substitution & Reduction in Consumption

Sequestration



Paris target <1.5° C
Global timeline to reach net-zero emissions
LIMITING GLOBAL WARMING TO 1.5°C ENTAILS
NET ZERO CO2
NET ZERO GHG
2020
2030
2040
2060
2070
2080
2090
LIMITING GLOBAL WARMING TO 2.0°C ENTAILS
NET ZERO CO2
NET ZERO GHG
Paris Agreement , 2015
Report published Oct 2018
Source: IPCC Special Report on Global Warming of 1.5°C
WORLD RESOURCES INSTITUTE

Sources of Energy – World

BP Statistical review 2019: Consumption statistics for 2018
(percentages calculated based on total consumption of 13,864 million tonnes oil equivalent per yr)

Hydrocarbons (84 - 90%)

- **Oil = 34%**
- **Gas = 24%**
- **Coal = 27%**
- **Biofuel = <1%**
- **Biomass***

92% combustible fuels

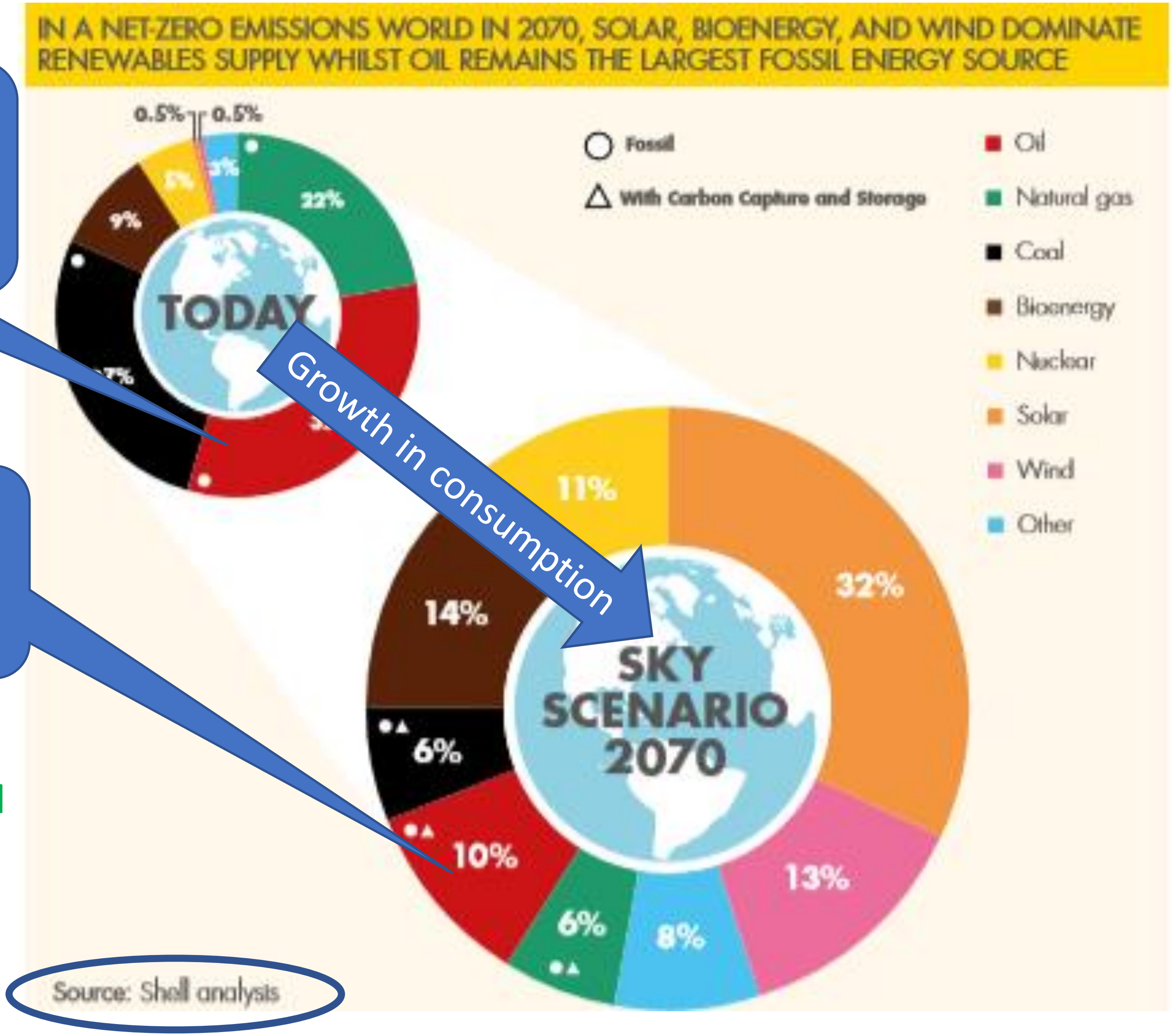
Non Hydrocarbons (16%)

- **Geothermal ***
- **Nuclear = 4.4%**
- **Hydro = 6.8%**
- **Solar**
- **Wind**
- **Tide**
- **Wave**
- **Hydrogen**

= 4.0% includes* biomass, geothermal (Solar, Wind)

36% combustible fuels

Growth in consumption



Fossil Fuels | **Biofuels**

CO_2 Emission

HYDROCARBON COMBUSTION

ENERGY CONSUMING

TRANSPORTATION
- rail, car, marine, aircraft, truck, tractor

HEATING
- Steel Blast Furnaces
- Cement & Fertilizer
- Residential Buildings
- Commercial Buildings
- Waste Reduction – Biomass
- Petrochemical Fractionation

ELECTRICITY
- Coal fired
- Oil fired
- Gas fired

PETROCHEMICAL PRODUCTS

FABRICS
- nylon, rayon, polyester, Orlon, Kevlar,

CARBON FIBRE & RESINS

CARBON BLACK
- Tyres, paints and plastics

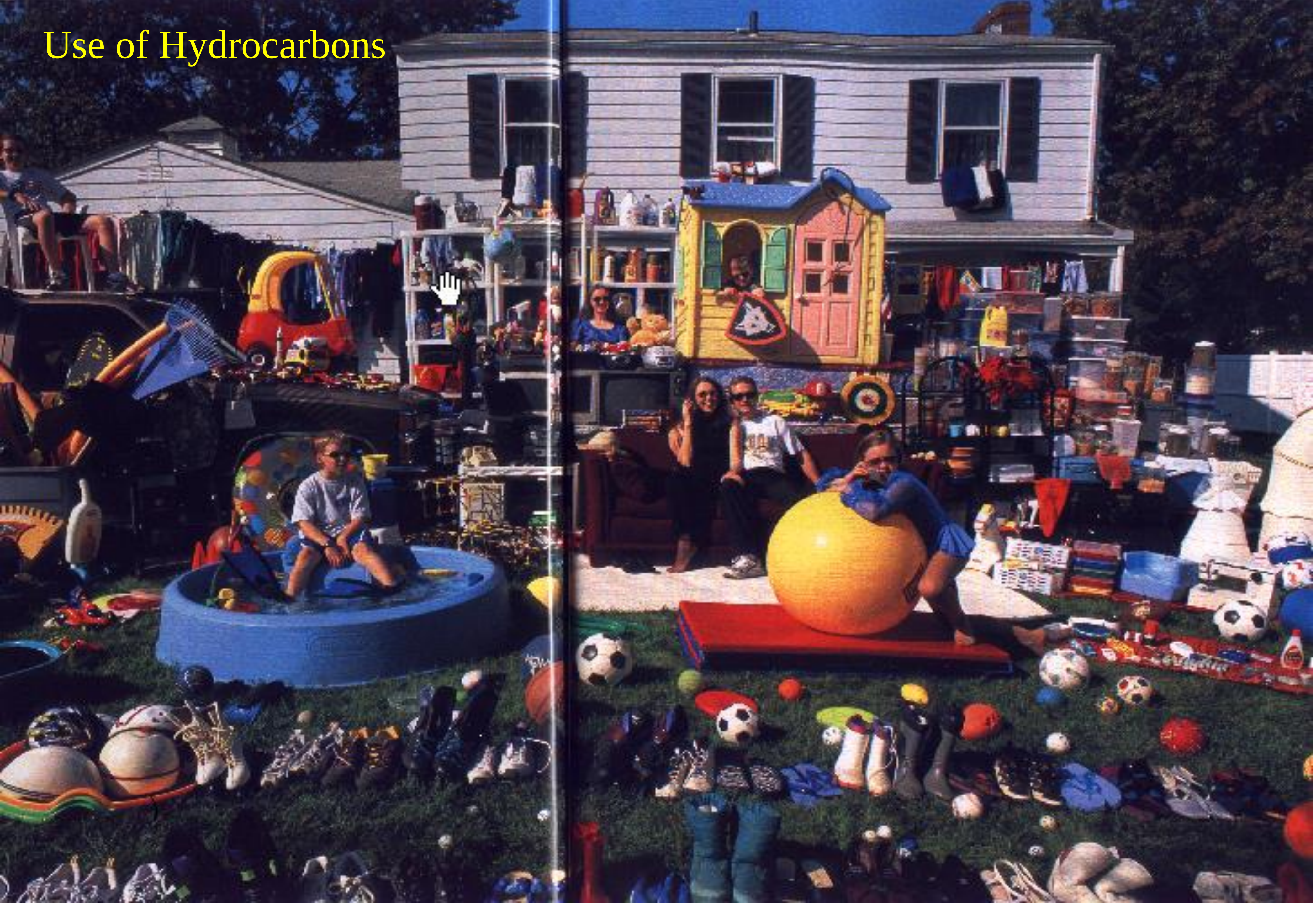
AMMONIA
- Fertilizer, explosives, mineral processing

SULPHUR
- Fertilizer, acid, cellulose (paper/pulp)

POLYETHYLENE
- Plastics, films, laminates

OTHER
- Pigments, pharmaceuticals/cosmetics

Use of Hydrocarbons

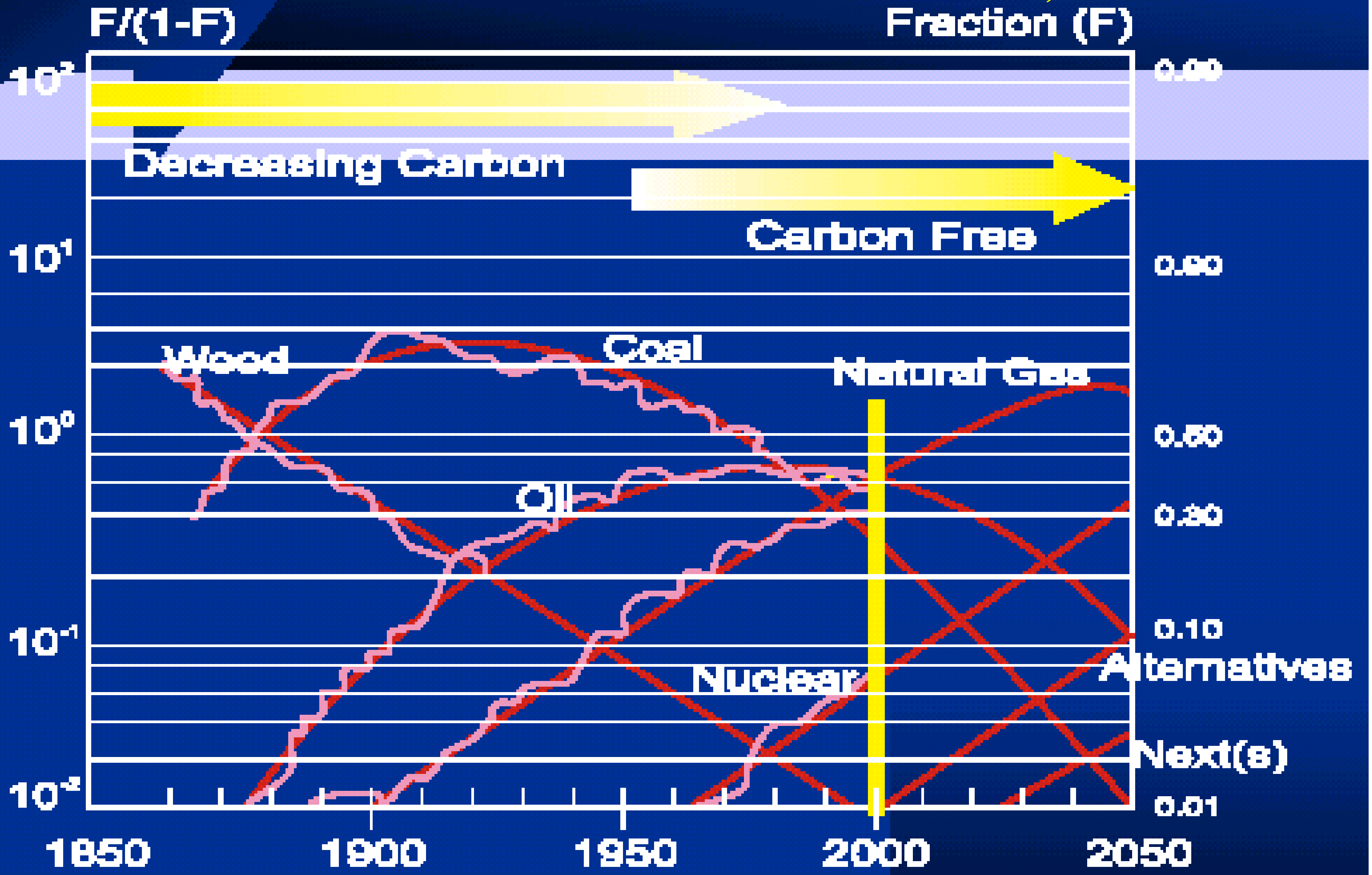


“Stuff” made from Hydrocarbons:
Photo: NG ~2003

Energy Consumption

DECARBONISING

BALLARD, 2004



Use of Oil

- World consumption ~100,000,000 bpd
- Decreasingly used to generate electrical power
- Provides 95% of world transportation needs. Convenient fuel
- 45,000,000 bpd (45% of world consumption) for transportation increasing as the developing world becomes “motorized”
- Manufacturing of plastics, artificial fibres consumes 1,250,000 bpd in US (7% of US consumption)
- Asphalt Paving? (~1,000,000 bpd in US & Europe)

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SERIES DOES NOT DISCUSS BIOFUELS/BIOMASS GEOTHERMAL

Non Hydrocarbons (16%)

- **Geothermal ***
- **Nuclear = 4.4%**
- **Hydro = 6.8%**
- **Solar**
- **Wind**

= 4.0% includes biomass, geothermal *

- **Tide**
- **Wave**
- **Hydrogen**

University of Victoria

Retirees Association

AN ELDER ACADEMY EVENT

February Saturday Speaker Series

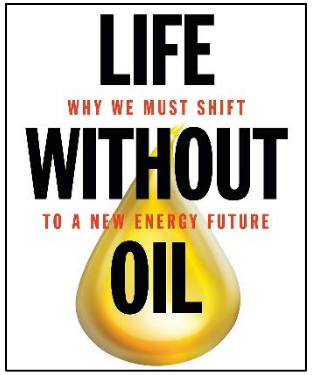
LIVING WITHOUT OIL? Part 1

TIME: 10:00am to noon

University of Victoria, David Turpin Building (DTB), A Wing, Room A110

COST: $20 for whole series

Registration & Payment through Eventbrite or email uvraevents@uvic.ca



FEB 8: "The Role of Hydrogen and the Fuel Cell in Future Energy Transition"

Presenter: Nicolas Pocard, MChem Eng, MSc, Director, Ballard Power.

FEB 15: "Solar: Cost and Limiting Efficiency of Silicon Solar Panels"

Presenter: Tom Tiedje, BASc, MSc, PhD, FRSC, PEng, Professor ECE Dept, U.Vic.

FEB 22: "Wind Energy Opportunities: Terrestrial, offshore and airborne variants"

Presenter: Curran Crawford, BEng, SM (MIT), PhD, PEng, Professor Mech Eng, U. Vic.

FEB 29: "Cleaning BC: Wave Supplied Power in a Low-Carbon Energy System"

Presenter: Brad Buckham, PhD, PEng, Professor Mech Eng, U.Vic.

University of Victoria

Retirees Association

AN ELDER ACADEMY EVENT

March Saturday Speaker Series

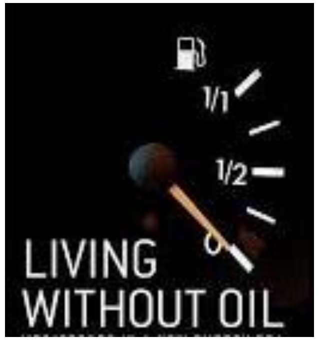
LIVING WITHOUT OIL? Part 2

TIME: 10:00am to noon

University of Victoria, David Turpin Building (DTB), A Wing, Room A110

COST: $20 for whole series

Registration & Payment through Eventbrite or email uvraevents@uvic.ca



MAR 7: "Are Big Hydro and Run of River Resources Maximised?"

Presenter: Heather Matthews: BC Hydro Power Group. Director Generation System Operations

MAR 14: "Nuclear Re-visited - Canadian SMRs (Small Modular Reactors)"

Presenter: John Stewart, Canadian Nuclear Association , Director of Policy and Research

MAR 21: "Energy Storage and Electrification"

Presenter: BEng (Royal Military College of Canada), MASc., (UVic), Ph.D. (UVic), PEng. Professor Mech Eng

MAR 28: "Series Summary & Panel Discussion"

Moderator: Chris Kennedy, MASc, Ph.D., P.Eng., Professor and Chair, U.Vic.

Panelist: Madelaine McPherson

Panelist: Katya Rhodes

Panelist: Robert Gifford

Fossil Fuels

Biofuels

CO_2 Emission

HYDROCARBON COMBUSTION

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rail, car, marine, aircraft, truck, tractor

HEATING

Steel Blast Furnaces

Cement & Fertilizer

Residential Buildings

Commercial Buildings

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Coal fired

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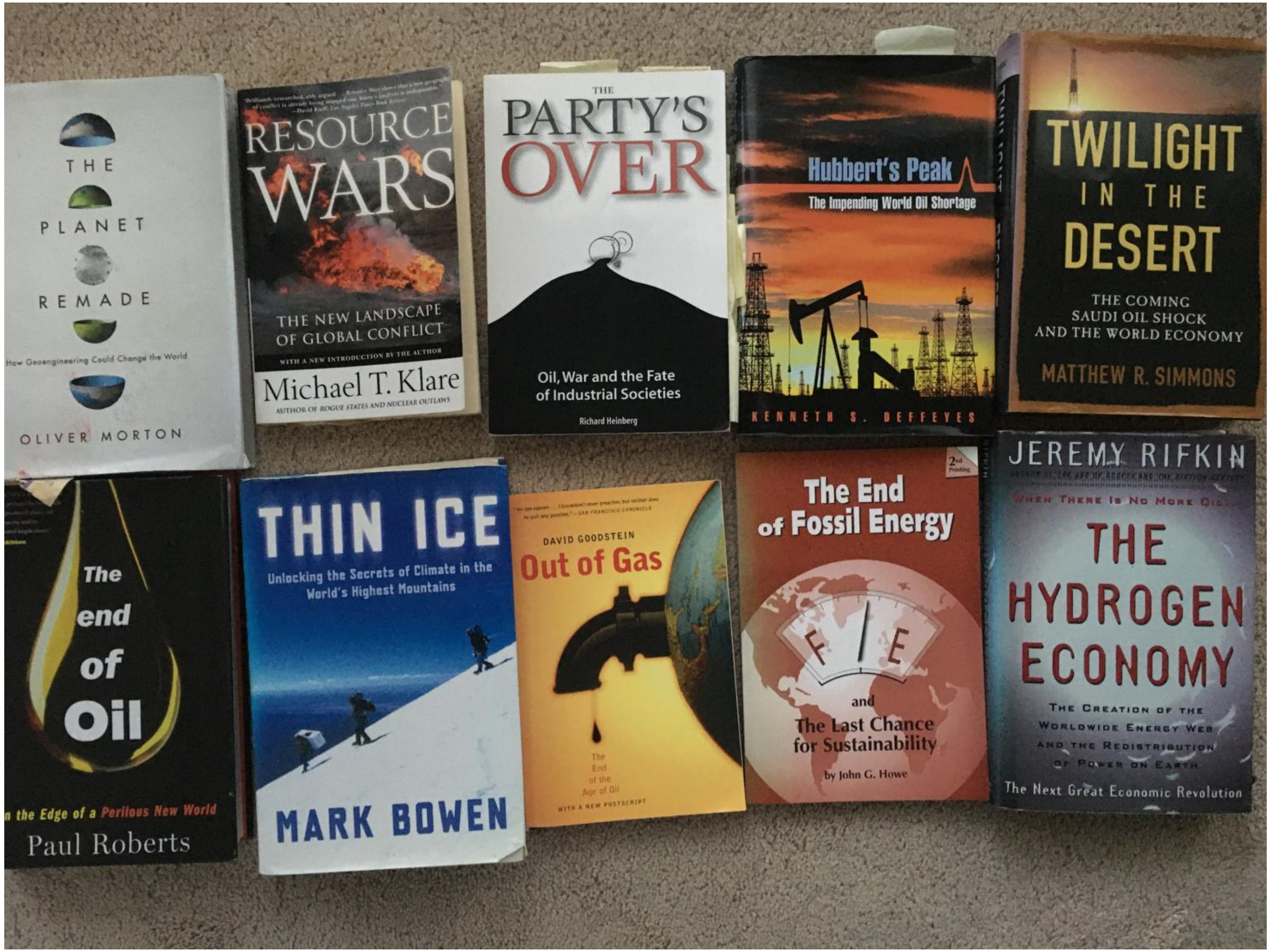
Living Without Oil - References

NEWS ARTICLES

- National Geographic – June 2003 “The End of Cheap Oil”
- National Geographic – Sept 2004 “Global Warming”
- Discover – May 2003 “Anything Into Oil”
- Globe & Mail – April 1, 2005 “ Are You Ready for Oil at $105 a barrel?”
- Van Sun – Oct 8 2005 “World’s Oil Supply Outlook Not so Bleak, Nor so Rosy
- Globe & Mail Nov 8, 2005 “There’s still lots of oil – at a price: IEA”
- Globe & Mail Nov 15, 2005 “Saudi Oil: Ample or Apocalyptically low”

Living Without Oil - References

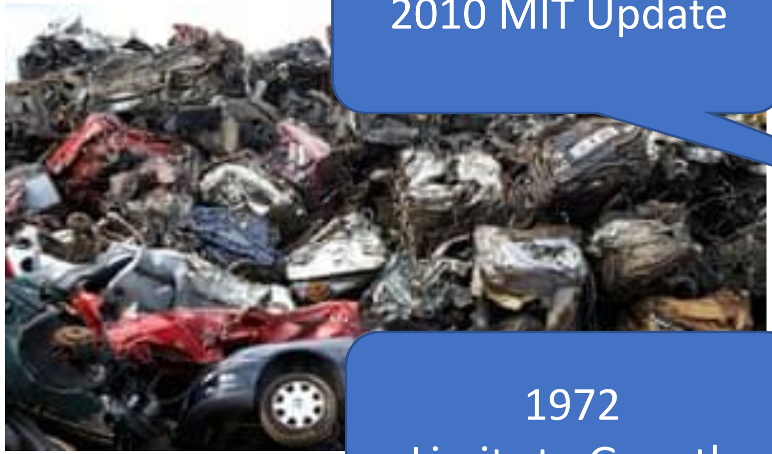
- Ken Deffeyes –"Hubbert's Peak"
- Ken Deffeyes – "Beyond Oil"
- Walter Youngquist – "GeoDestines"
- Jeremy Rifkin – "The Hydrogen Economy"
- Michael Klare – "Resource Wars"
- Richard Heinberg – "The Party's Over"
- Richard Heinberg – "Powerdown"
- Matt Savinar – "The Oil Age is Over"
- James Howard Kunstler – "The Long Emergency"
- Mark Bowen - "Thin Ice"
- Peter Foster – "The Blue-eyed Sheiks"
- Anthony Sampson – "The Seven Sisters"
- Matthew Simmons – "Twilight in the Desert"
- David Goodstein – "Out of Gas"
- John G Howe – "The End of Fossil Energy"
- Julian Darley – "High Noon for Natural Gas"
- Daniel Yergin – "The Prize"
- Oliver Morton – "The Planet Remade"
- David Yager - "From Miracle to Menace"
- Paul Roberts – "The End of Oil"



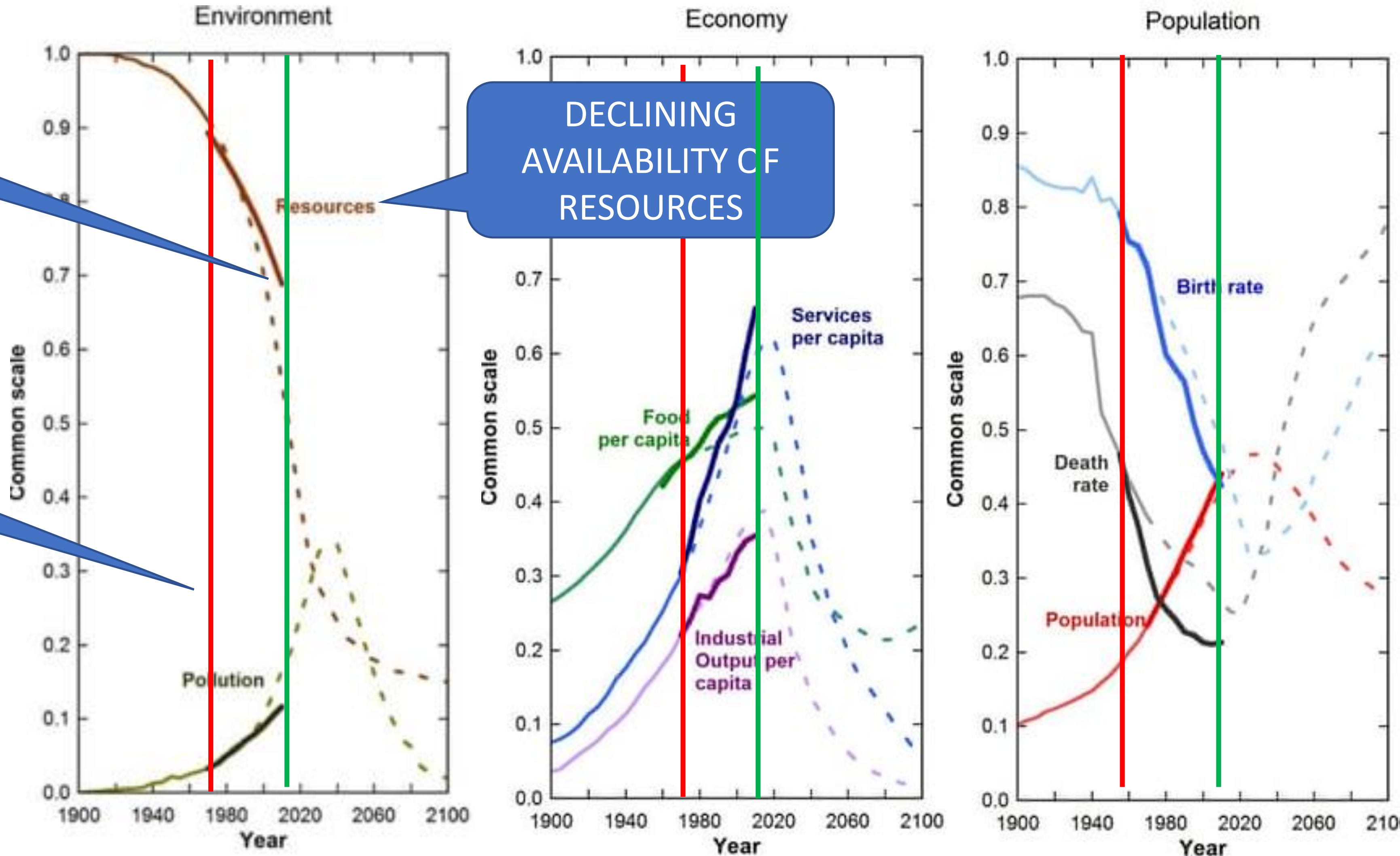
https://www.theguardian.com/commentisfree/2014/sep/02/limits-to-growth-was-right-new-research-shows-were-nearing-collapse

"Limits to Growth was right. New research shows we're nearing collapse"

Graham Turner and Cathy Alexander

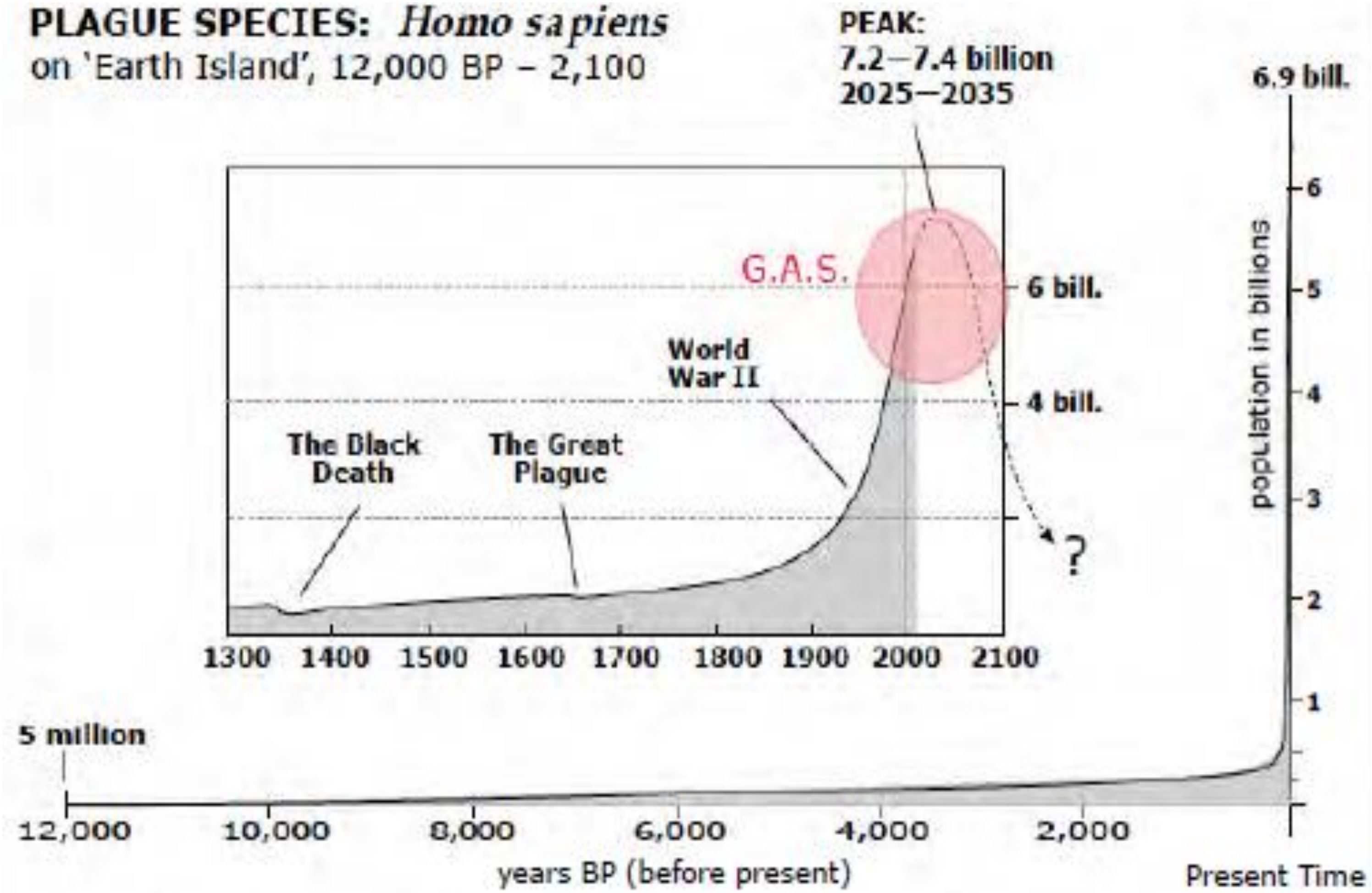


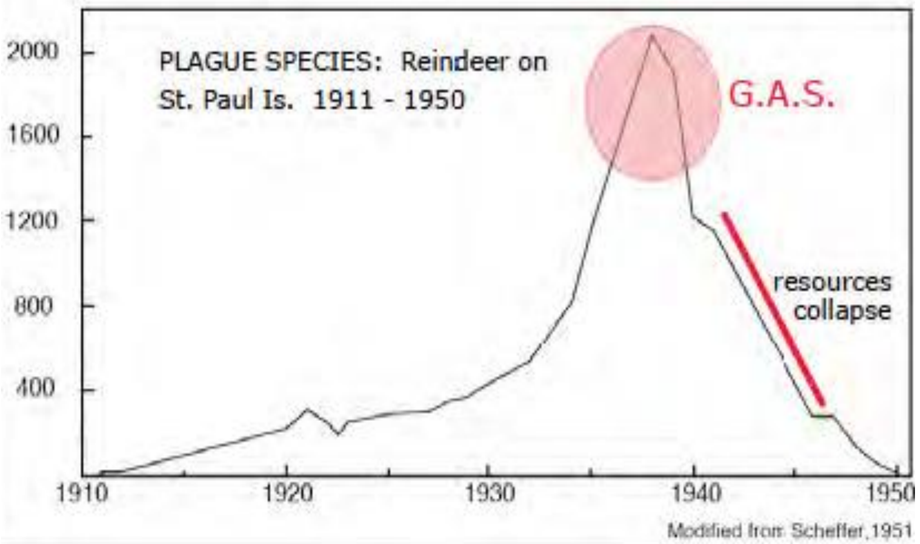
Solid line: MIT, with new research to 2010 in bold. Dotted line: Limits to Growth, 1972 'business-as-usual' scenario.

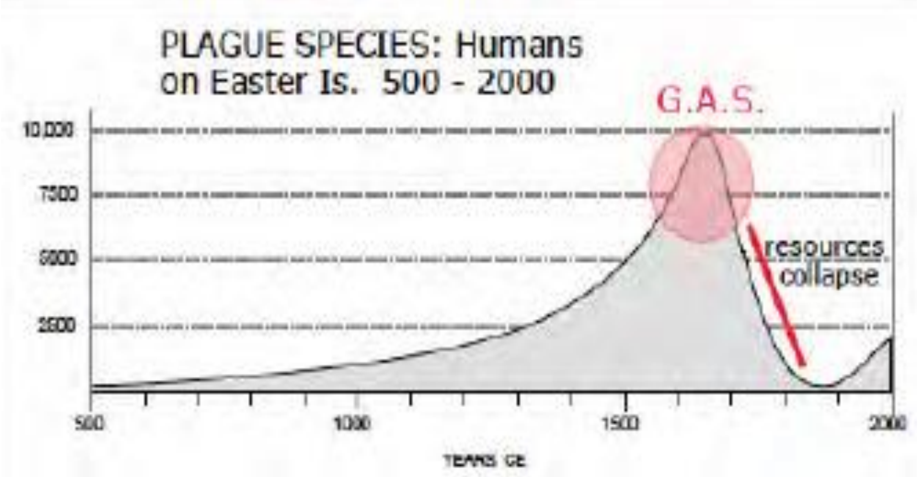


General Adaptation Syndrome

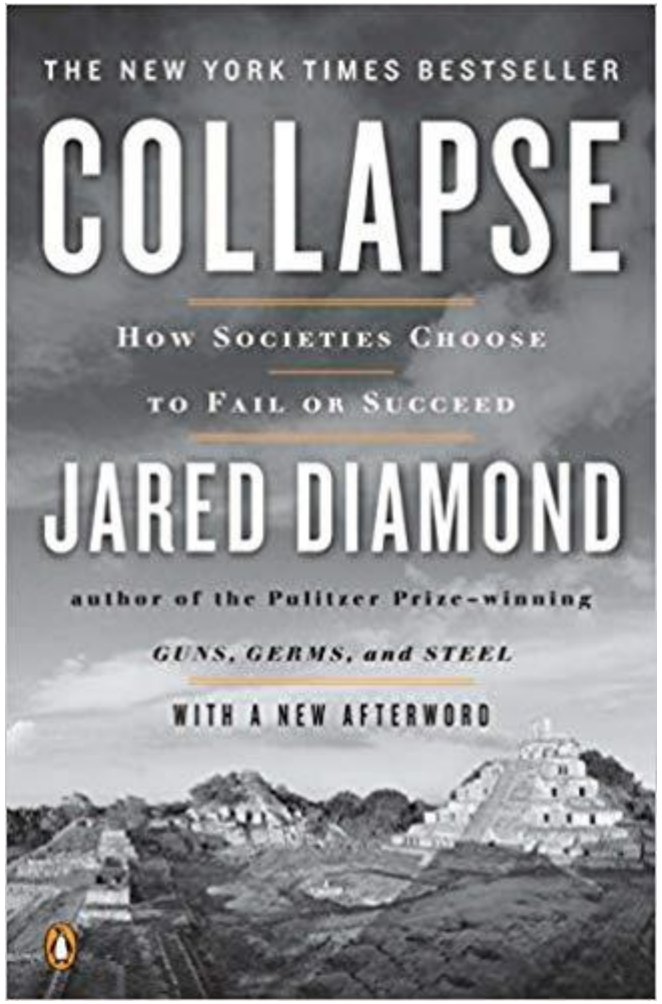
- this evolutionary safeguard was first detected in rodents and defined by **Canadian endocrinologist Hans Selye in 1936.**
- Termed the PLAGUE SPECIES by Australian Reg Morisson







A powerful book authored by Jared Diamond
published in 2005 by Penguin
Revised in 2011



"The root problem leading to collapse is overpopulation & carrying capacity of the environment.

One of the main lessons to be learned from the collapses of societies ... is that a society's steep decline may begin only a decade or two after the society reaches its peak numbers, wealth, and power. ...

The reason is simple: maximum population, wealth, resource consumption, and waste production mean maximum environmental impact, approaching the limit where impact outstrips resources."

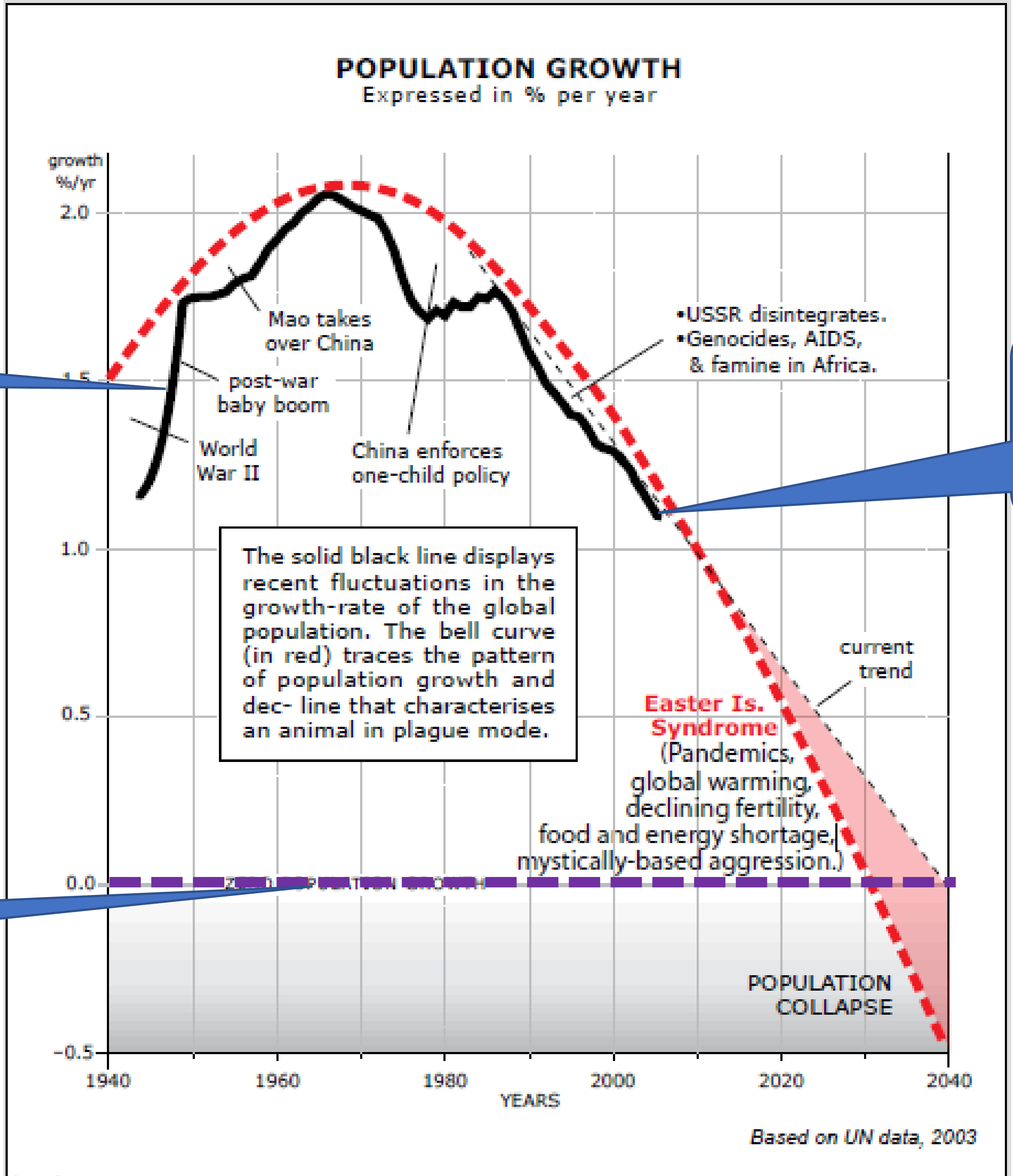
On a positive note:
Diamond gives suggestions to people who ask "What can I do as an individual?"

PEAK WORLD POPULATION GROWTH RATE

UN ACTUAL STATISTICS

UN DISCONTINUES REPORTING IN 2003

ZERO GROWTH



HUMANITY'S ECOLOGICAL FOOTPRINT

(our per capita impact on the planet's biosphere)

Earth surface area = 51 billion hectares
71% covered by oceans
14.5 billion hectares land
5.6 billion is non-productive
8.9 billion hectares productive
6.9 billion world population
2.1 hectares needed to support each person = footprint
14.5 billion hectares needed when productive area available is 8.9 billion hectares
1.6 Earths required to meet the needs of current earth population
55% over current carrying capacity (sustainable level)
1980 was when the limit was reached

http://regmorrison.edublogs.org/2012/03/05/population-debate/

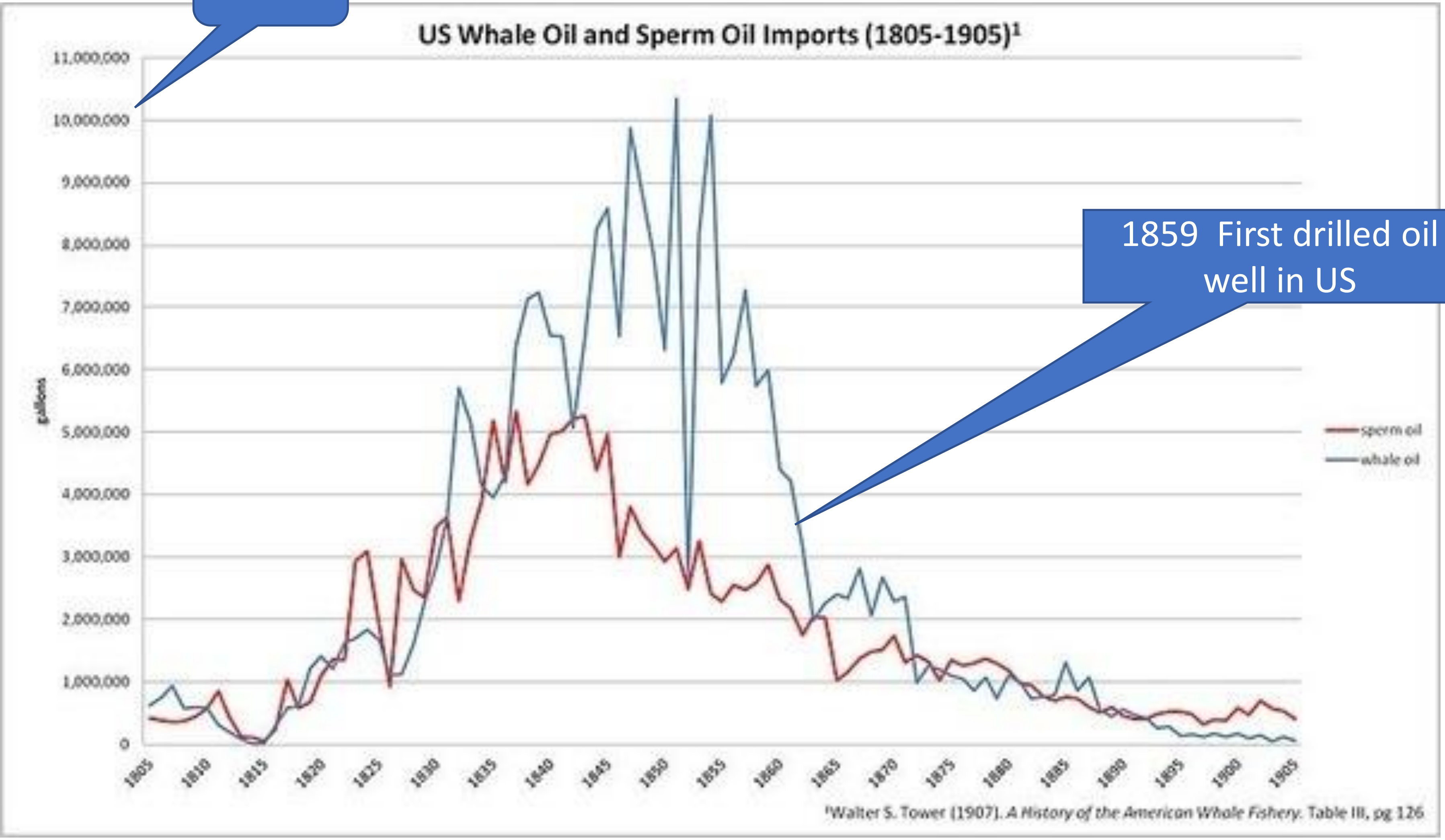
*ENERGY EXTRACTION ALWAYS ENTAILS A FAUSTIAN PENALTY**

Since the energy and resources consumed by our species already amounts to more than 1.6 times the bio-capacity of the entire planet, it means that we are consuming its resources 1.6 times faster than the Earth can replenish them. In economic terms, we are asset-stripping our cosmic home and shrinking its carrying capacity on a daily basis. If this growth in population and energy consumption continues, by 2050 we will need the resources of two Earths, just to sustain our population at its present level of consumption. Our species will then be ecologically bankrupt and primed for a swift extinction.

**http://regmorrison.edublogs.org/2012/03/05/population-debate/*

US Imports of Whale Oil
1805 - 1905

gallons

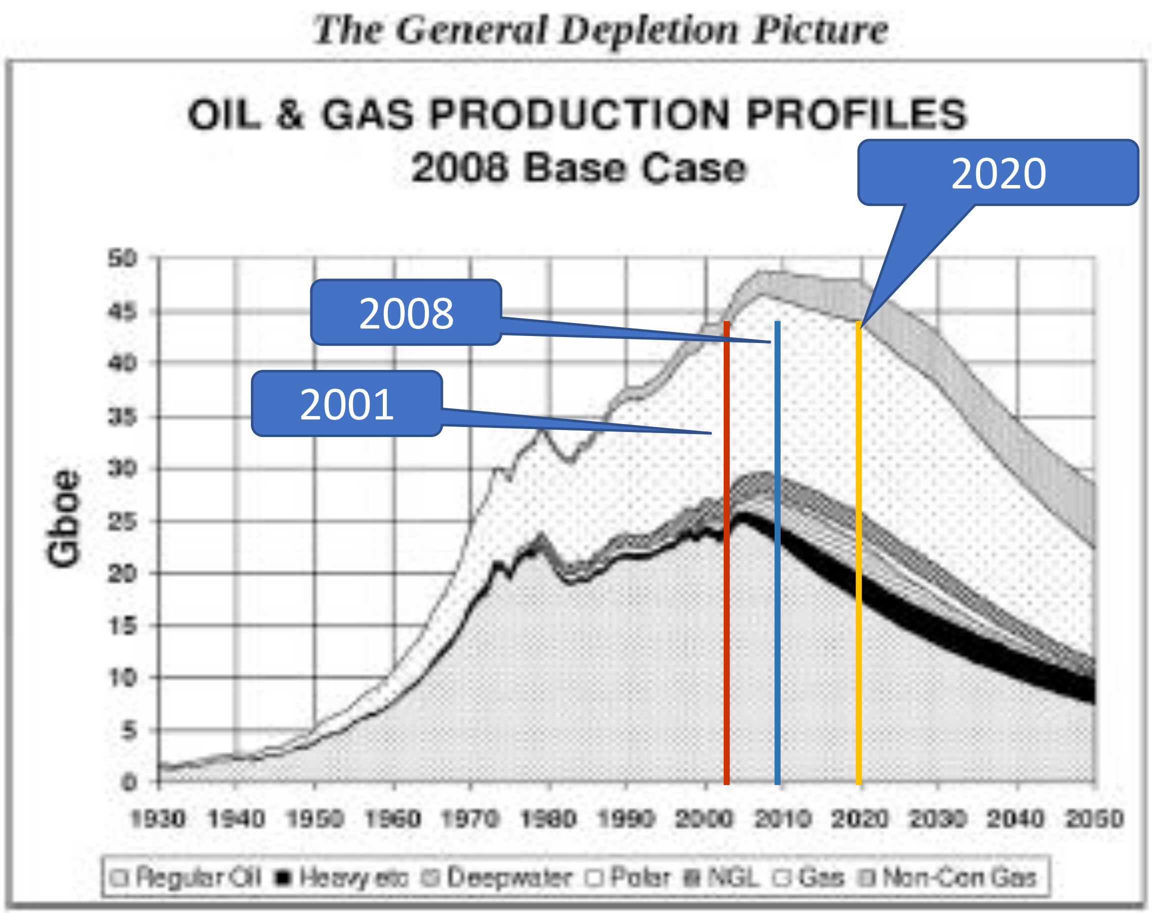


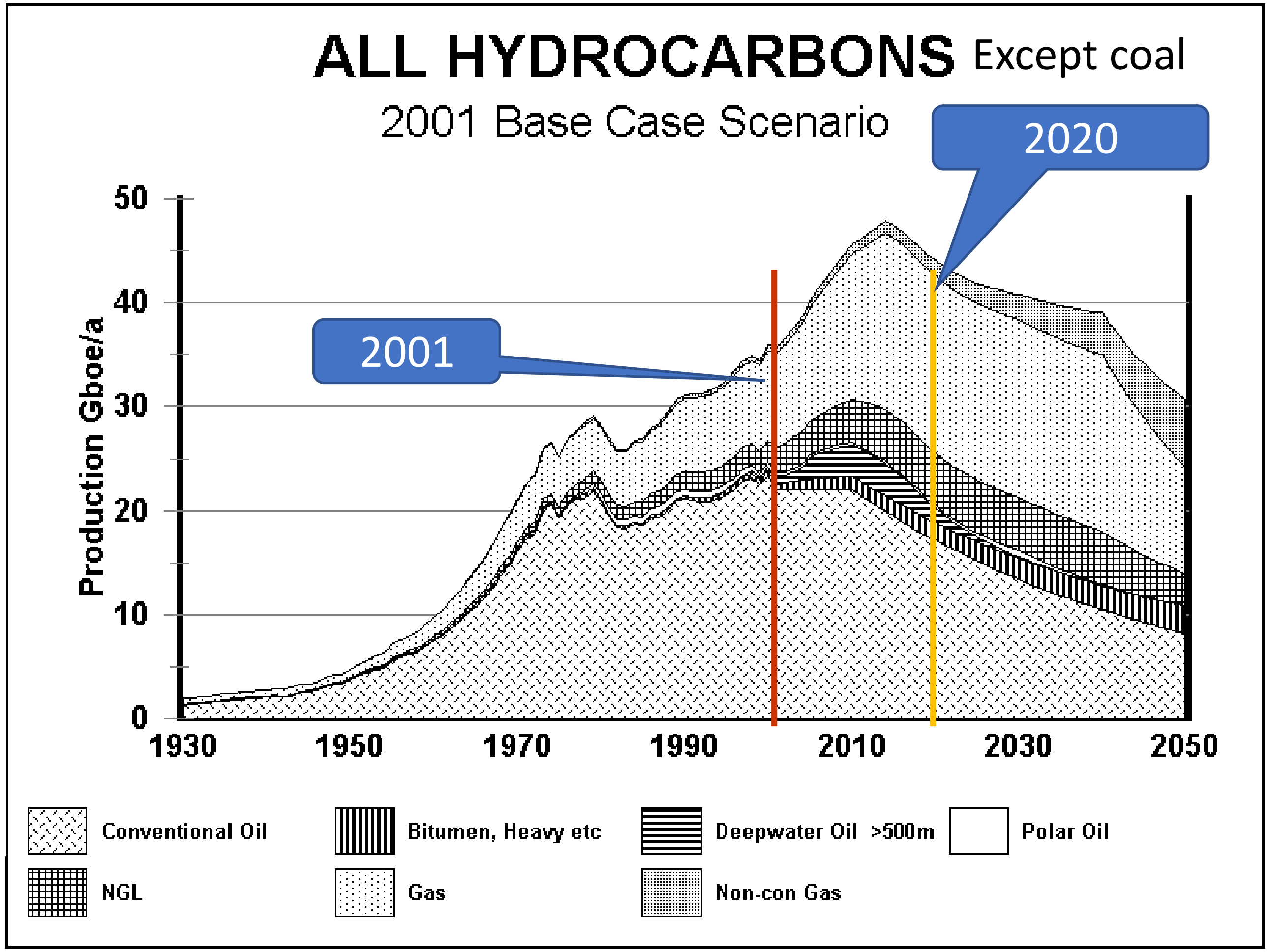
1859 First drilled oil well in US

In 1880 New York City population was 1, 206,299 people
170,000 horses
excreting 1800 tonnes of manure:
15,000 dead horses removed;

https://www.quora.com/How-was-the-world-living-without-and-before-discovery-of-Crude-Oil

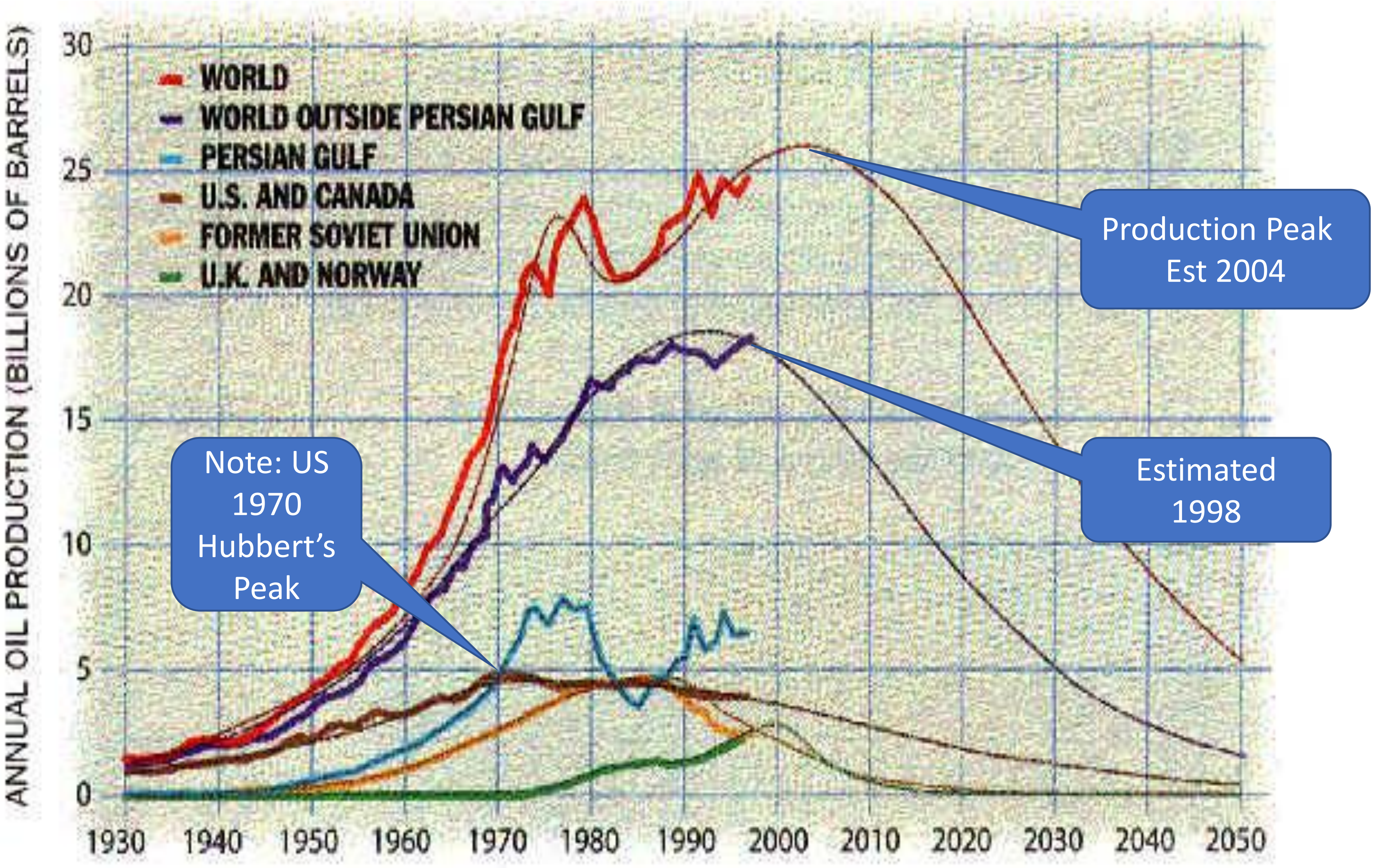
Campbell's Forecast (2001, 2008)



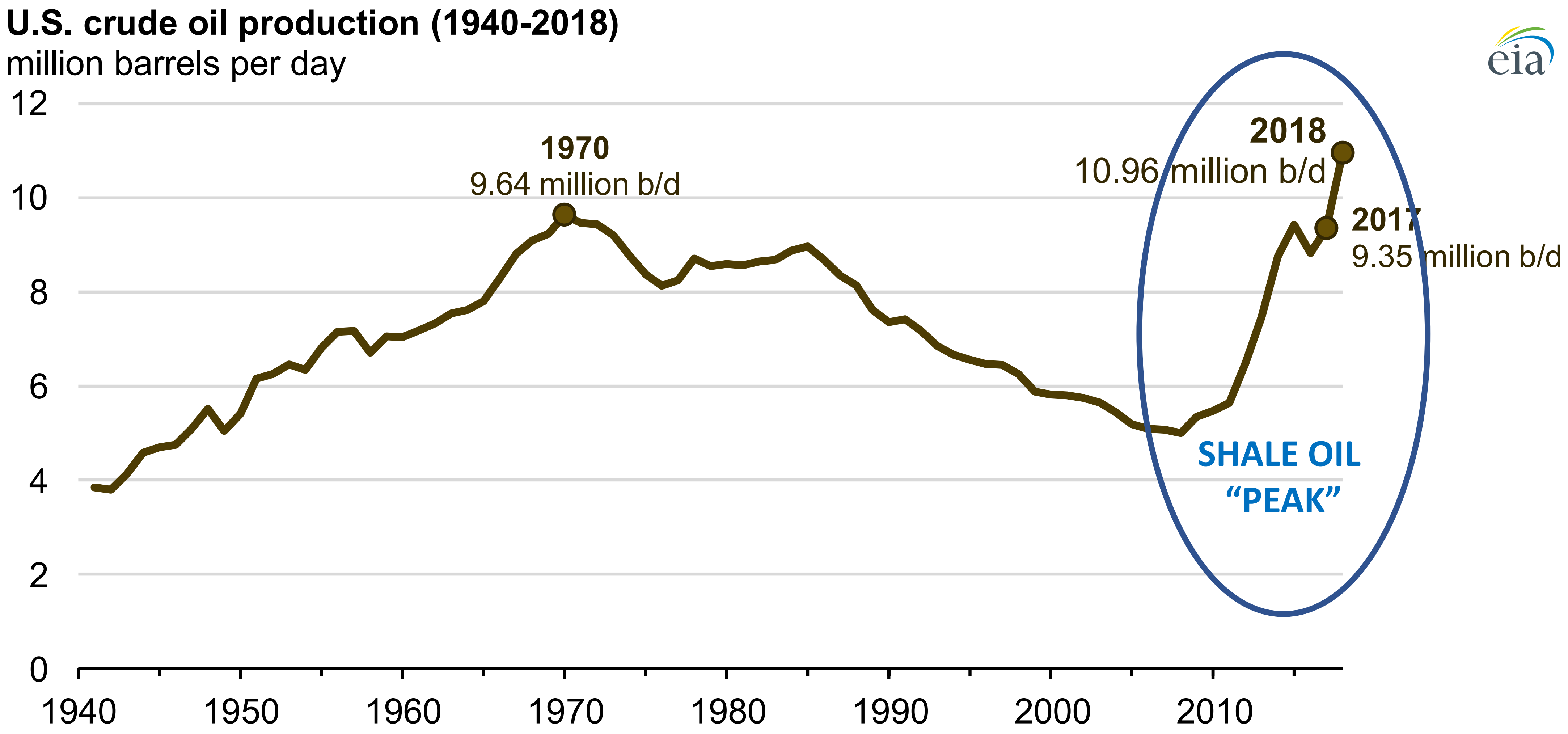


Campbell-Laherrère World Oil Production Estimates, 1930-2050

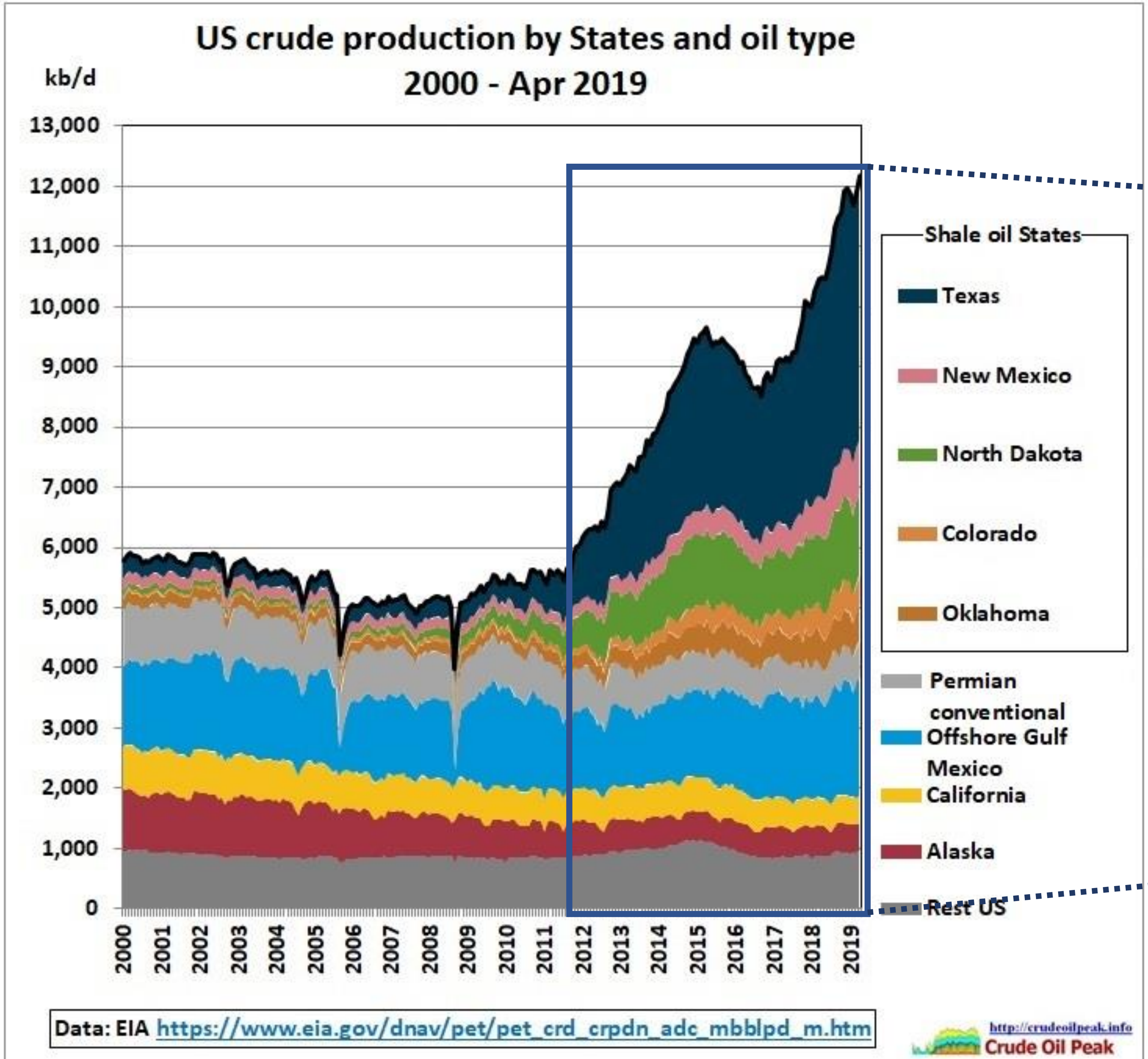
Scientific American ("The End of Cheap Oil?," March 1998).

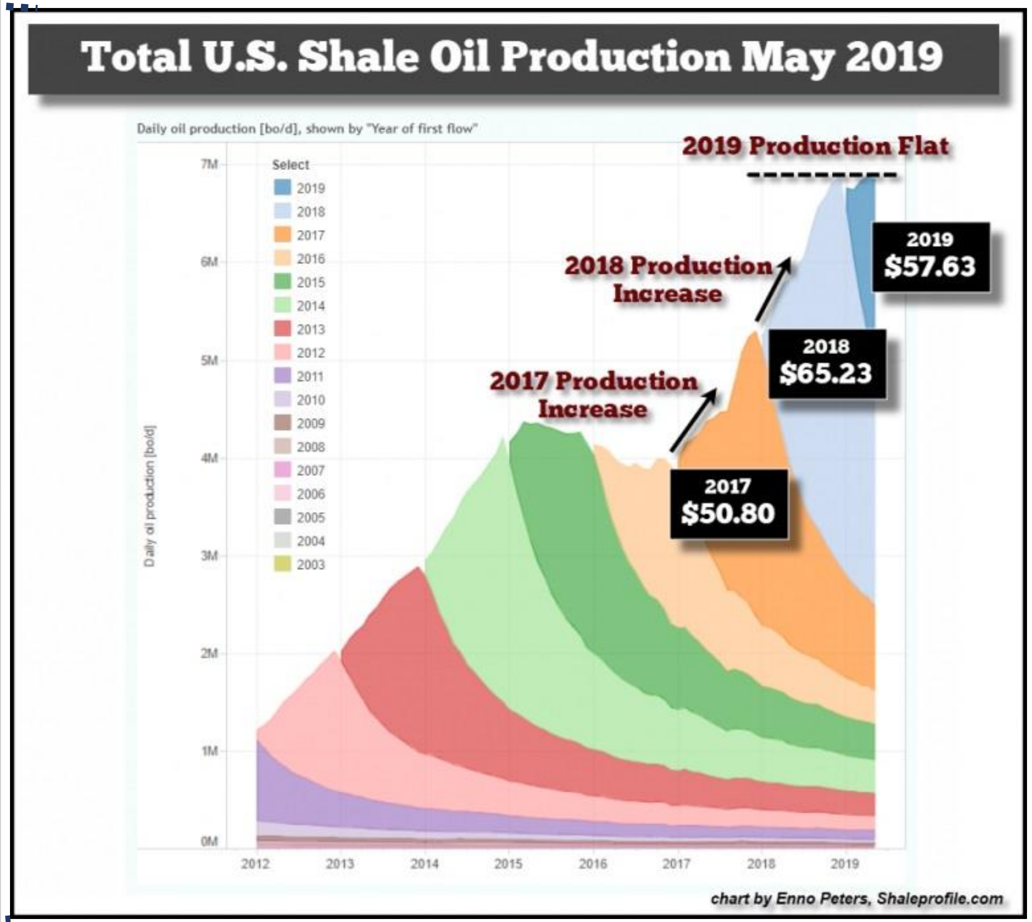


US “Peak Oil” occurred in 1970 as predicted by Hubbert in 1956

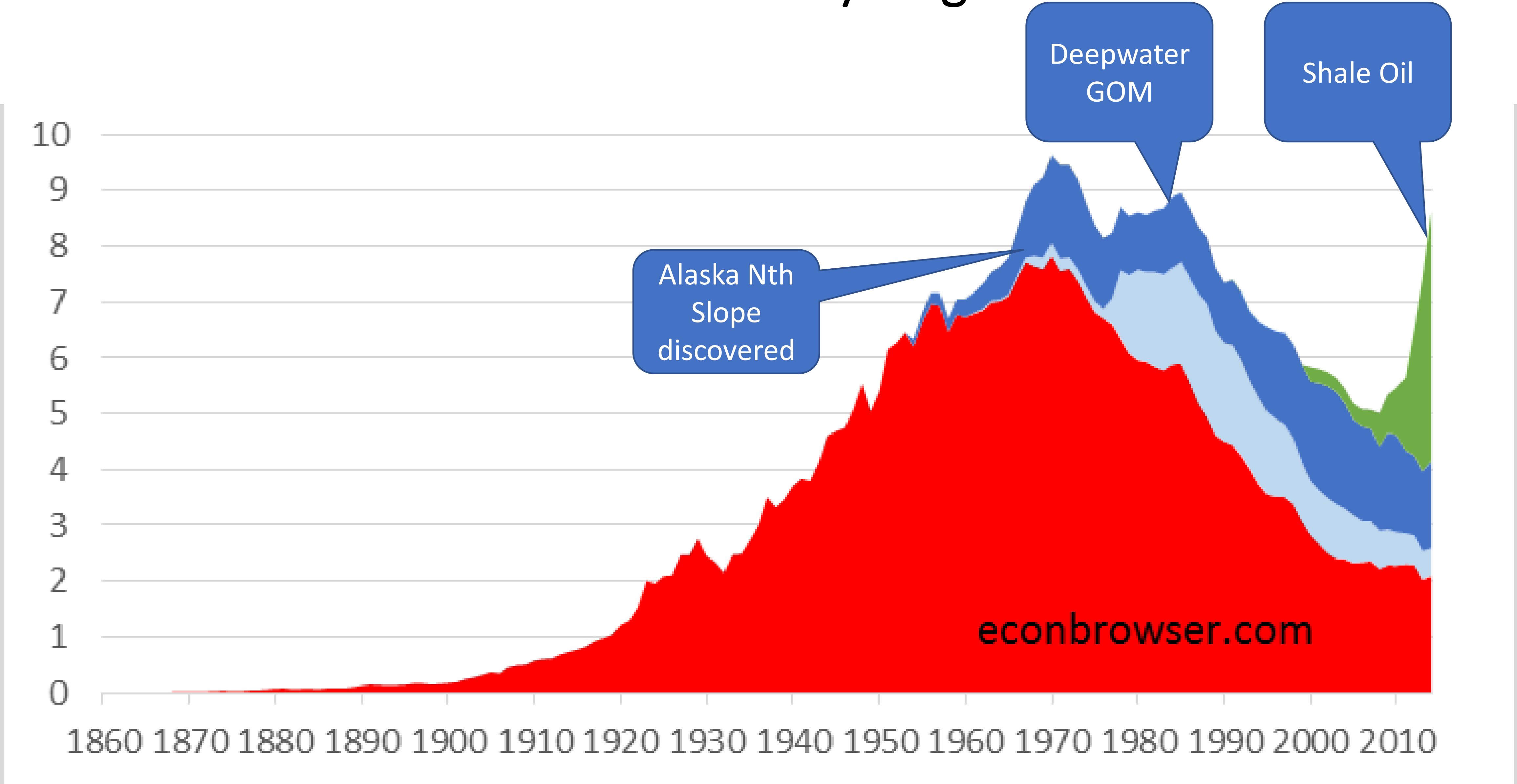


Shale OIL Production Treadmill

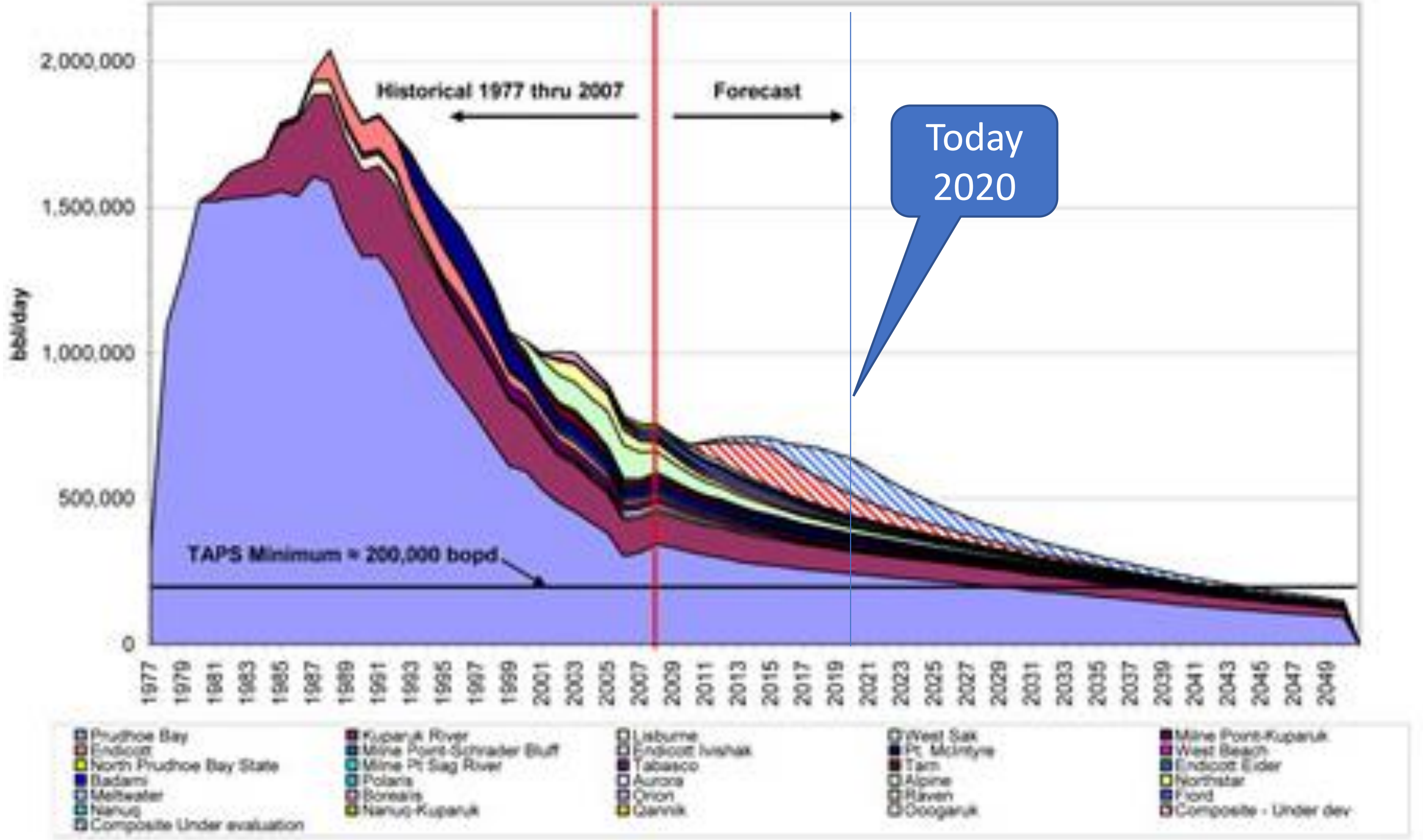




US Oil Production: by "region"

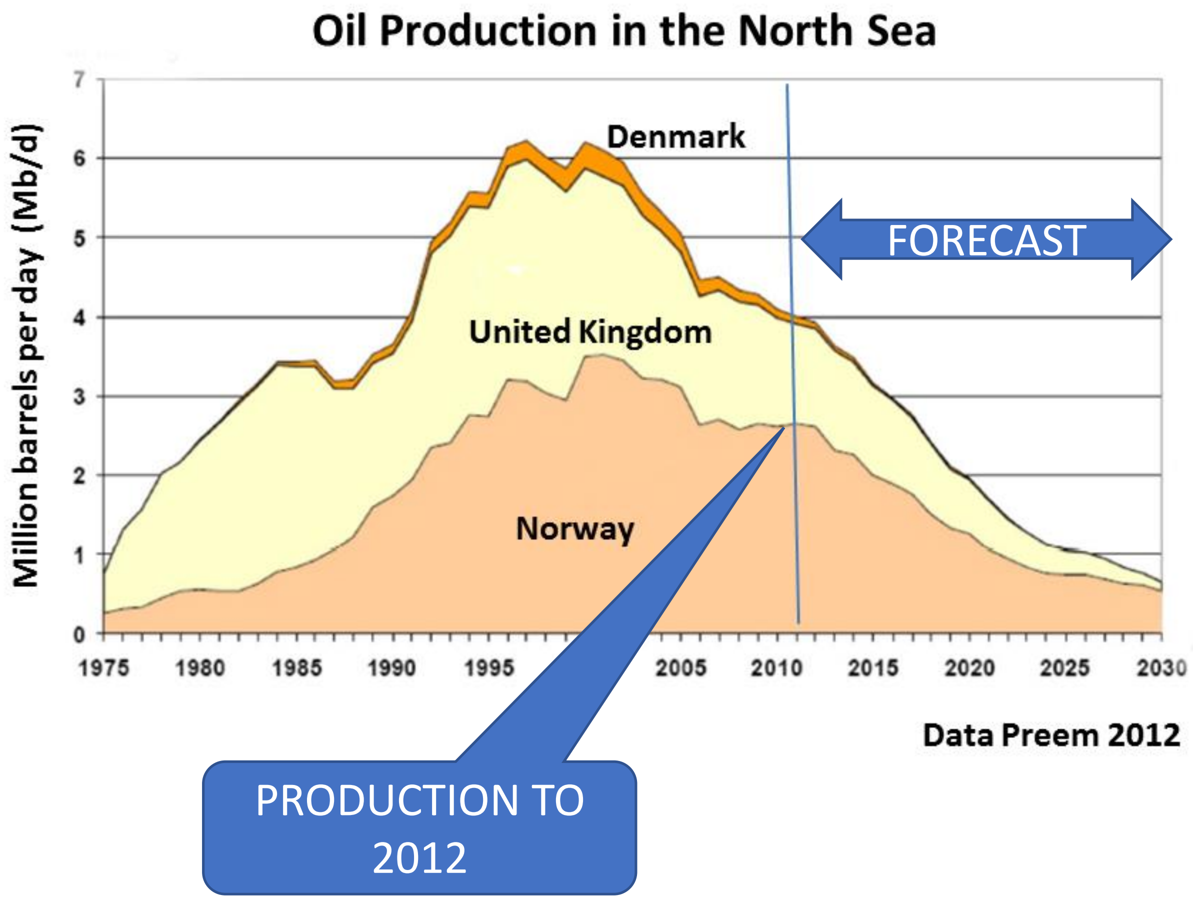


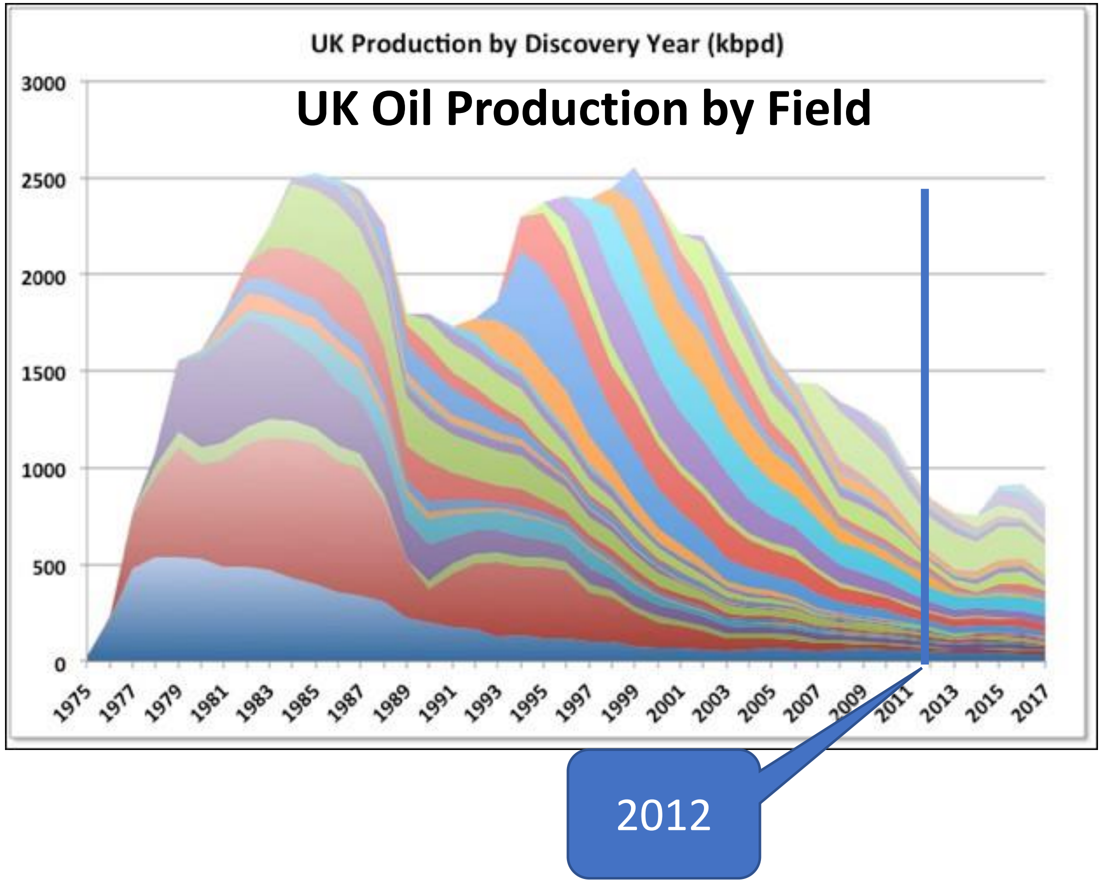
Alaska (Nth Slope) Conventional Oil Production In Decline



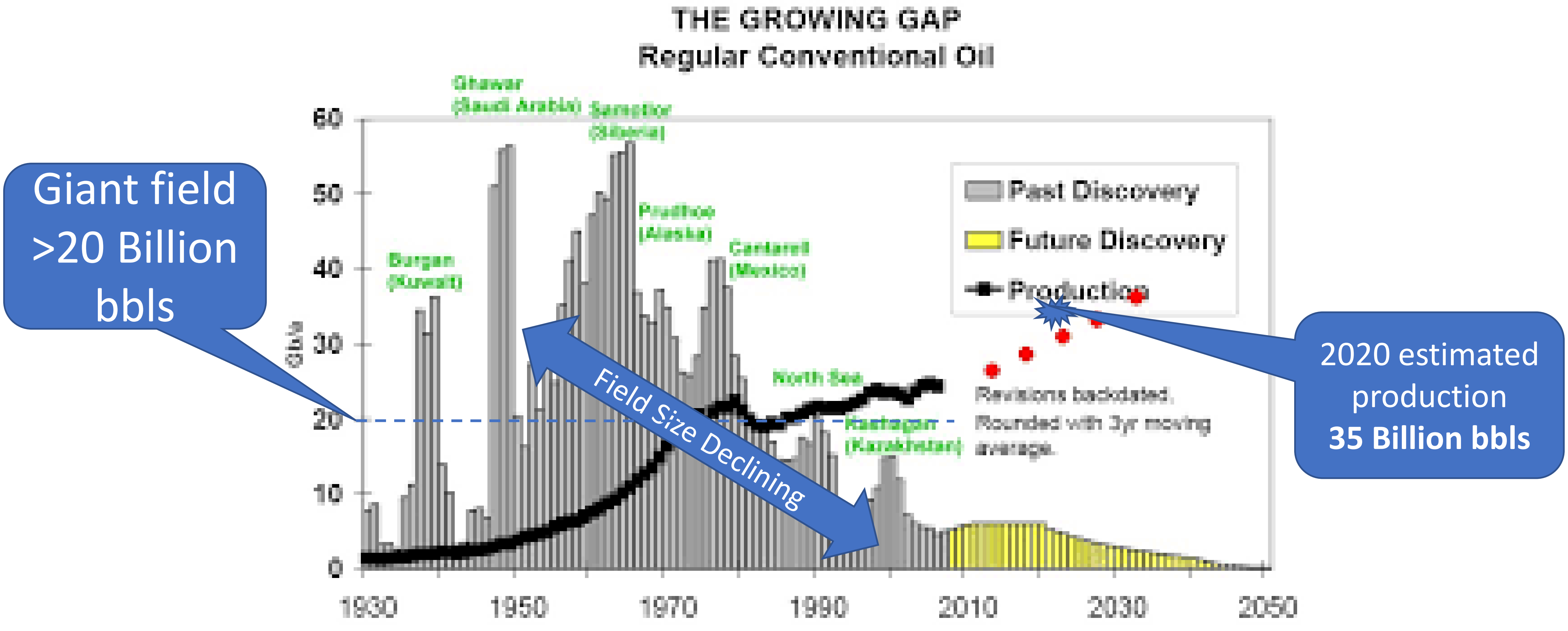
(Source: Alaska North Slope Oil and Gas: A Promising Future or An Area in Decline?)

North Sea in Decline





World Annual Field Discovery (Reserves & Production)



THE SECOND REASON

To consider Living Without Oil

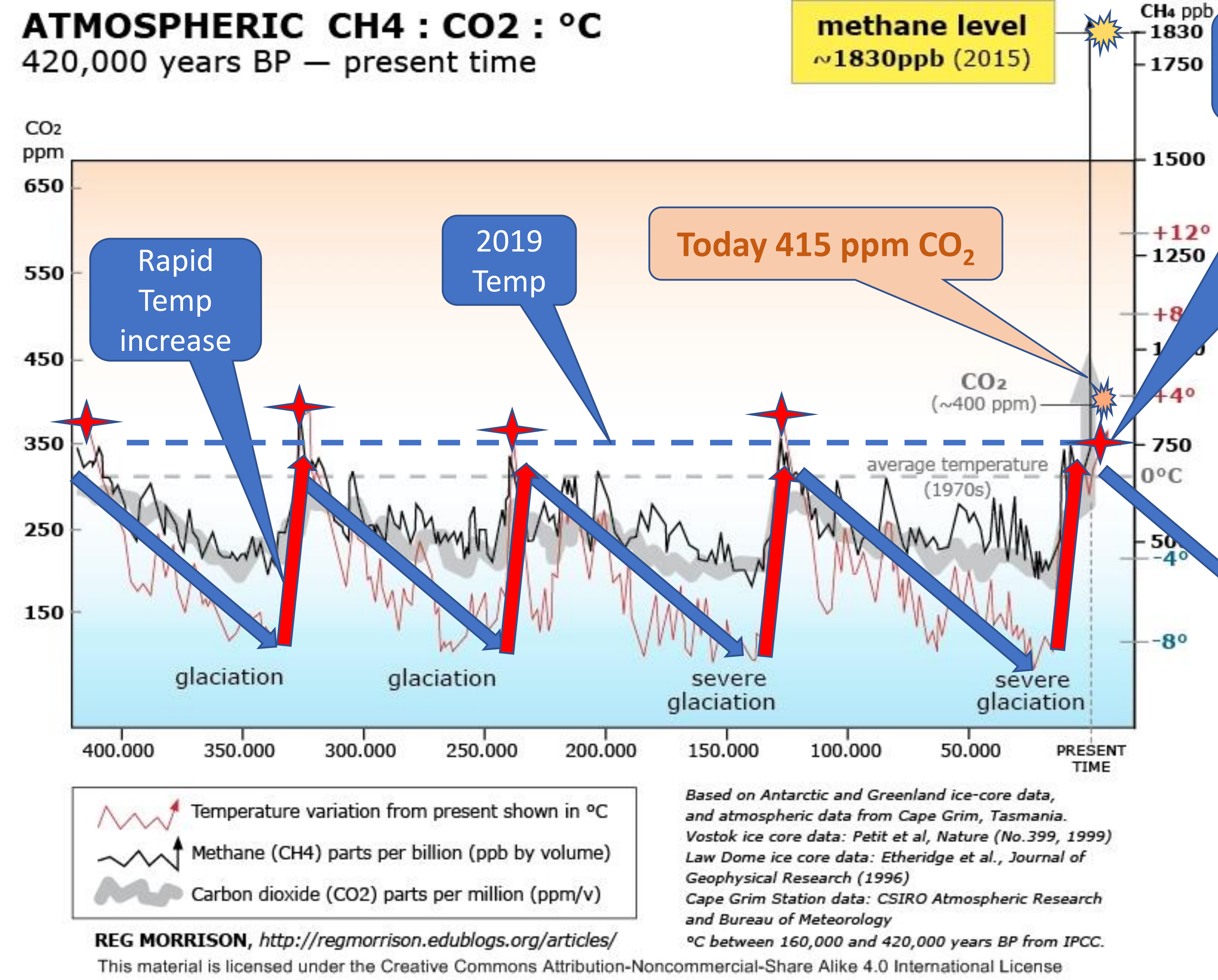
Climate Change linked to GHG Emissions

Anxiety created by this postulate is subject of May Climate Series

1. Proof of Global Warming
2. Greenhouse Gases – What are they?
3. Carbon Cycle
4. Sequestration

BREAK


Positive proof of global warming.
18th Century
1900
1950
1970
1980
1990
2006

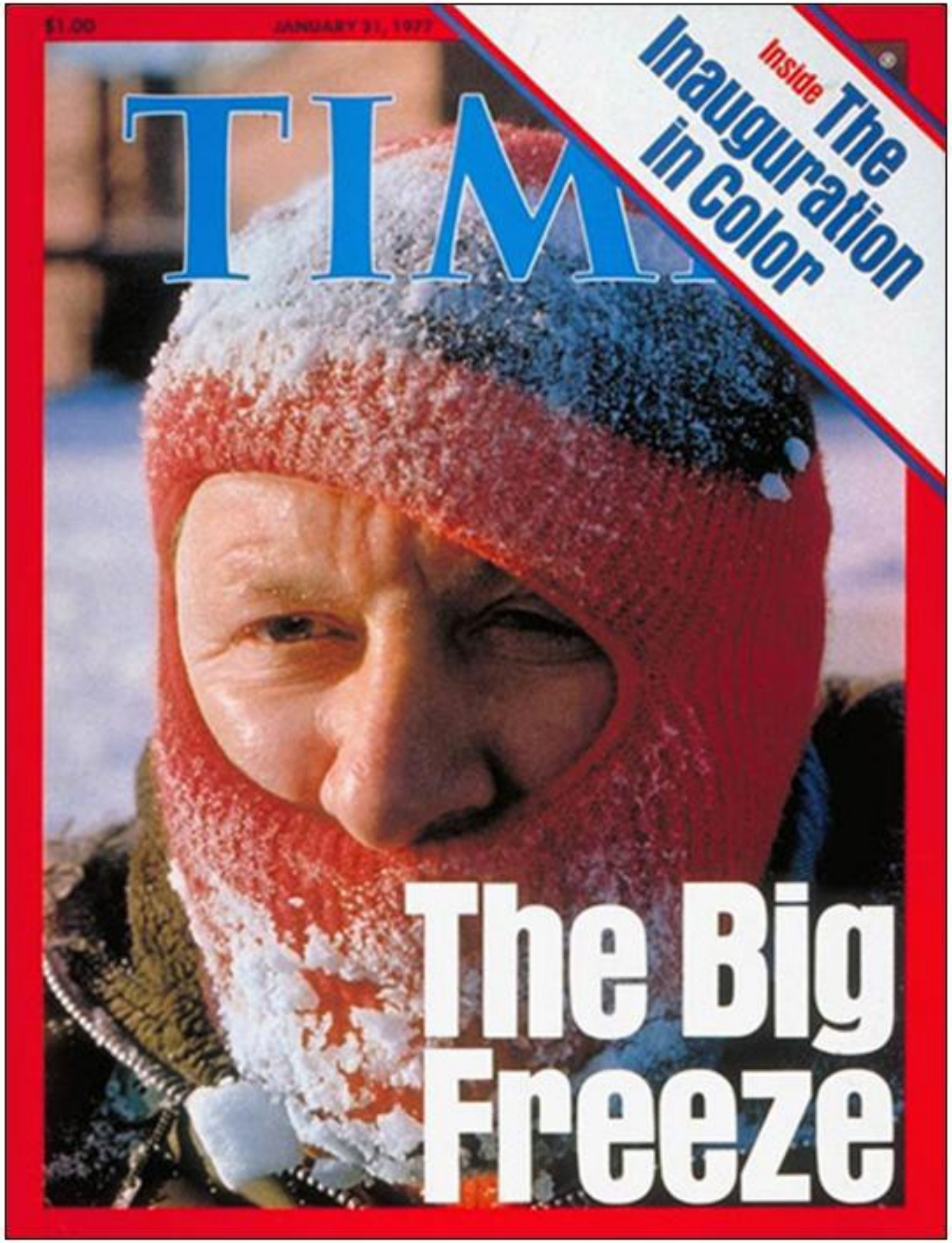


THE CLIMATE CHANGE IMPERATIVE

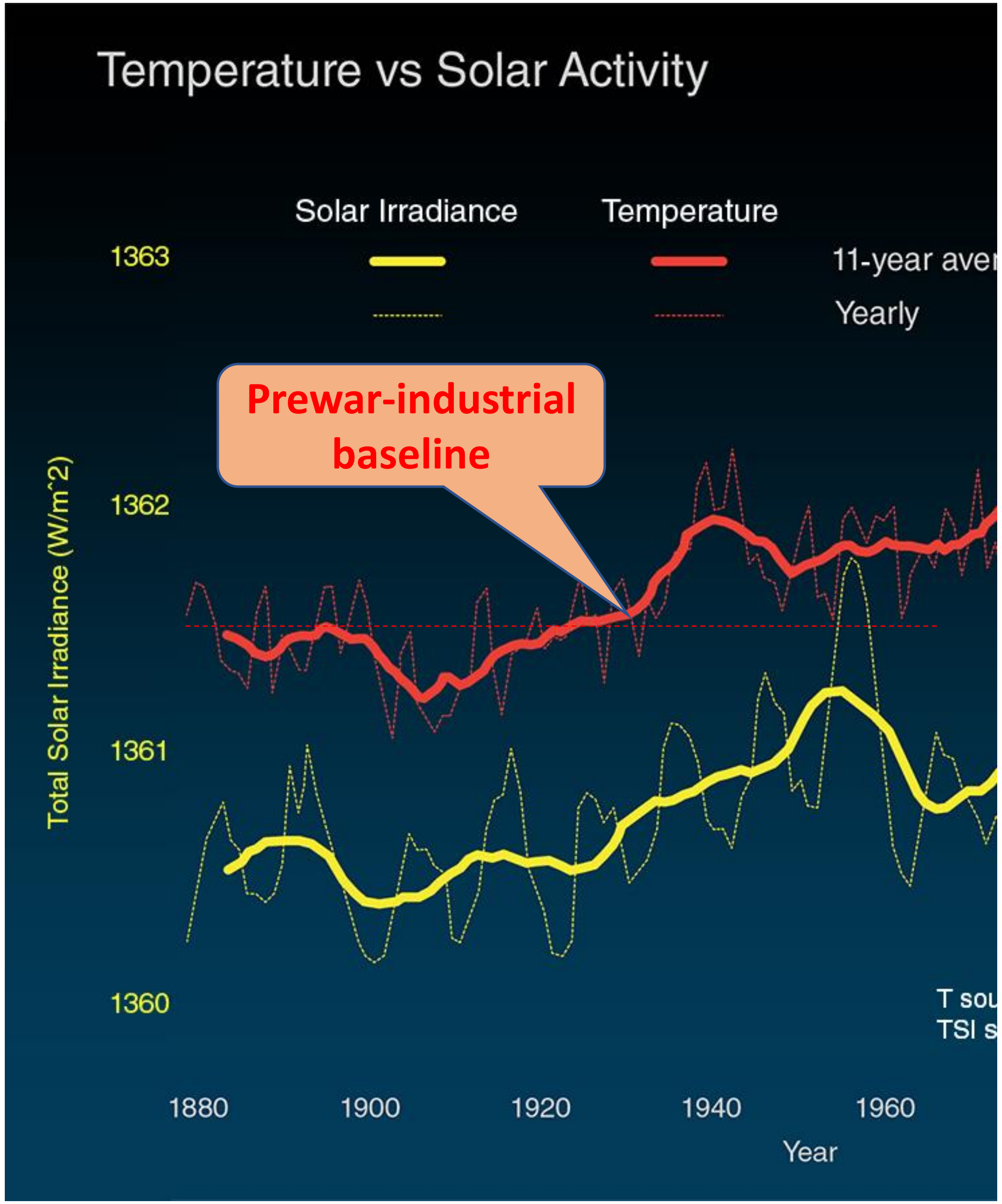
the second reason

Why we must "Live Without Oil"

JANUARY 31



1977

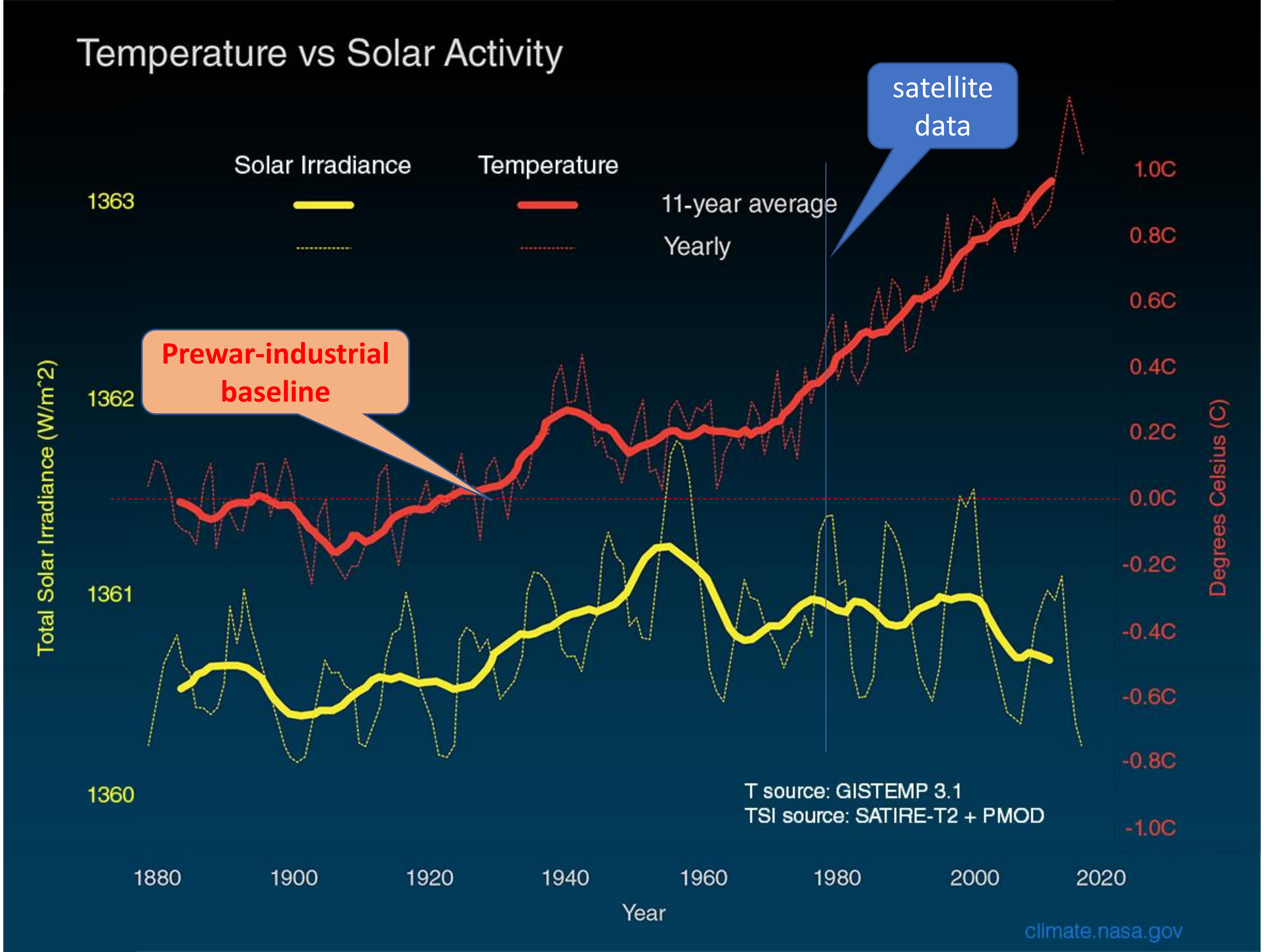


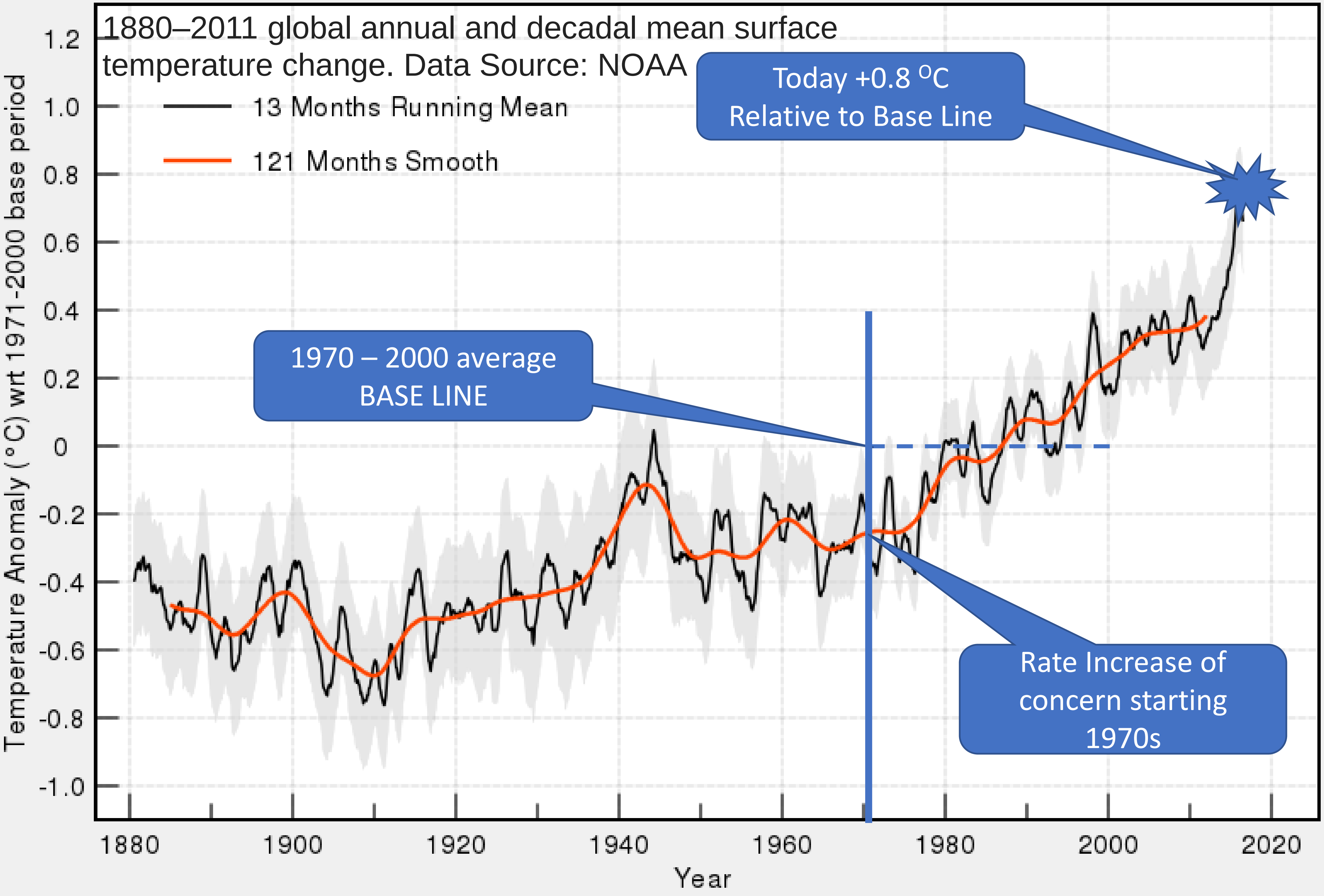
In the 1970s, the consensus was that temperature fluctuations were tied to solar irradiance as this NASA data shows.

Temperature data was collected from surface stations and radiosondes.

By 1979, satellite data added to the picture and it was then realized that the rate of temperature increase was significant.

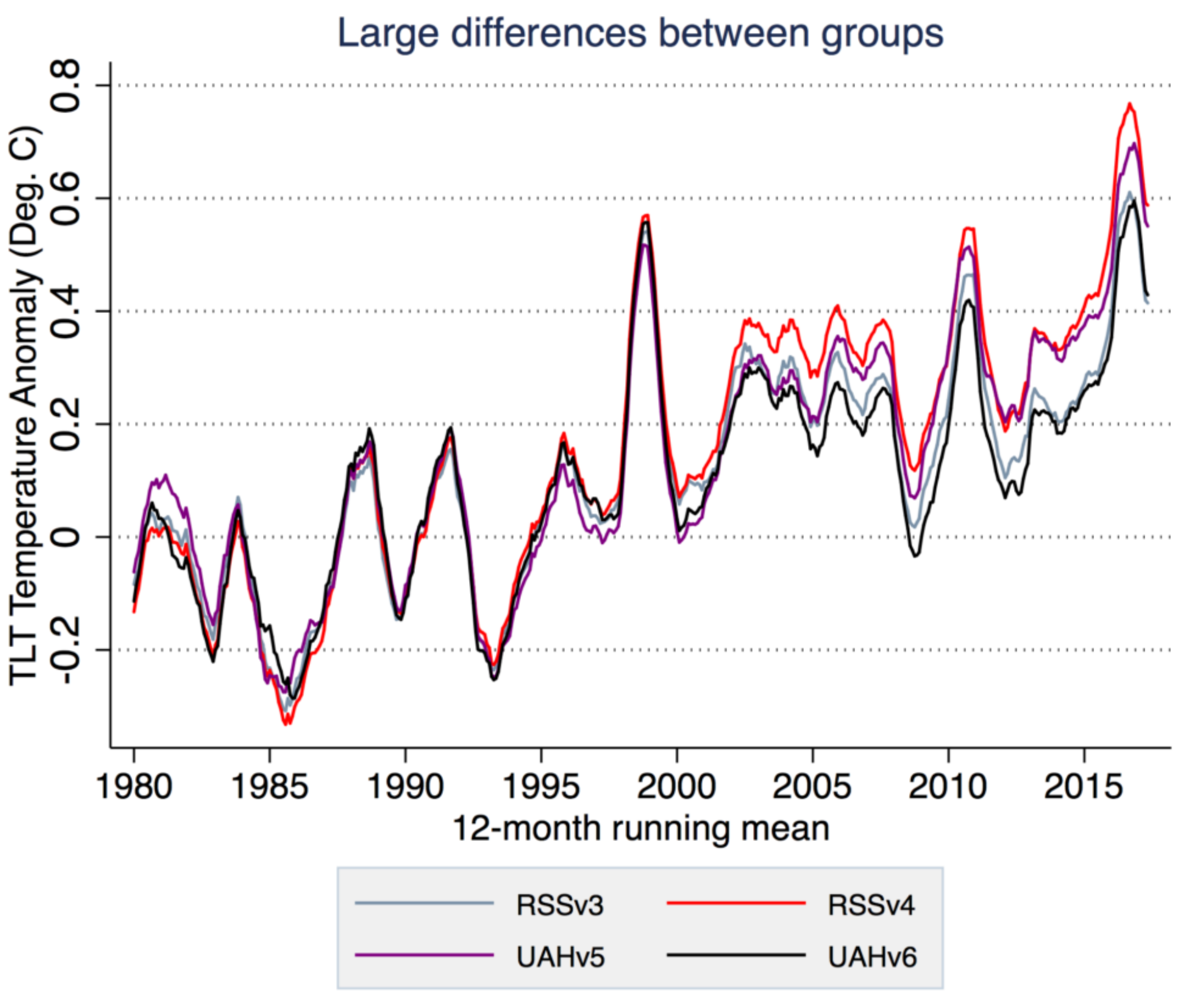
climate.nasa.gov


Temperature vs Solar Activity
satellite
data
Solar Irradiance
Temperature
11-year average
Yearly
Prewar-industrial
baseline
1363
1362
1361
1360
Total Solar Irradiance (W/m^2)
1.0C
0.8C
0.6C
0.4C
0.2C
0.0C
-0.2C
-0.4C
-0.6C
-0.8C
-1.0C
Degrees Celsius (C)
T source: GISTEMP 3.1
TSI source: SATIRE-T2 + PMOD
1880
1900
1920
1940
1960
1980
2000
2020
Year
climate.nasa.gov



1880–2011 global annual and decadal mean surface temperature change. Data Source: NOAA
13 Months Running Mean
121 Months Smooth
Today +0.8 ºC
Relative to Base Line
1970 – 2000 average
BASE LINE
Rate Increase of
concern starting
1970s
Temperature Anomaly (°C) wrt 1971-2000 base period
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
2020
Year

Adjustments Between Early and New Satellite Temperature Data



- Satellite measured troposphere temperature data
- Records since 1979.
- Satellite data collection has developed
- EG: Satellite orbits decay and data has to be adjusted
- 2 sources are:

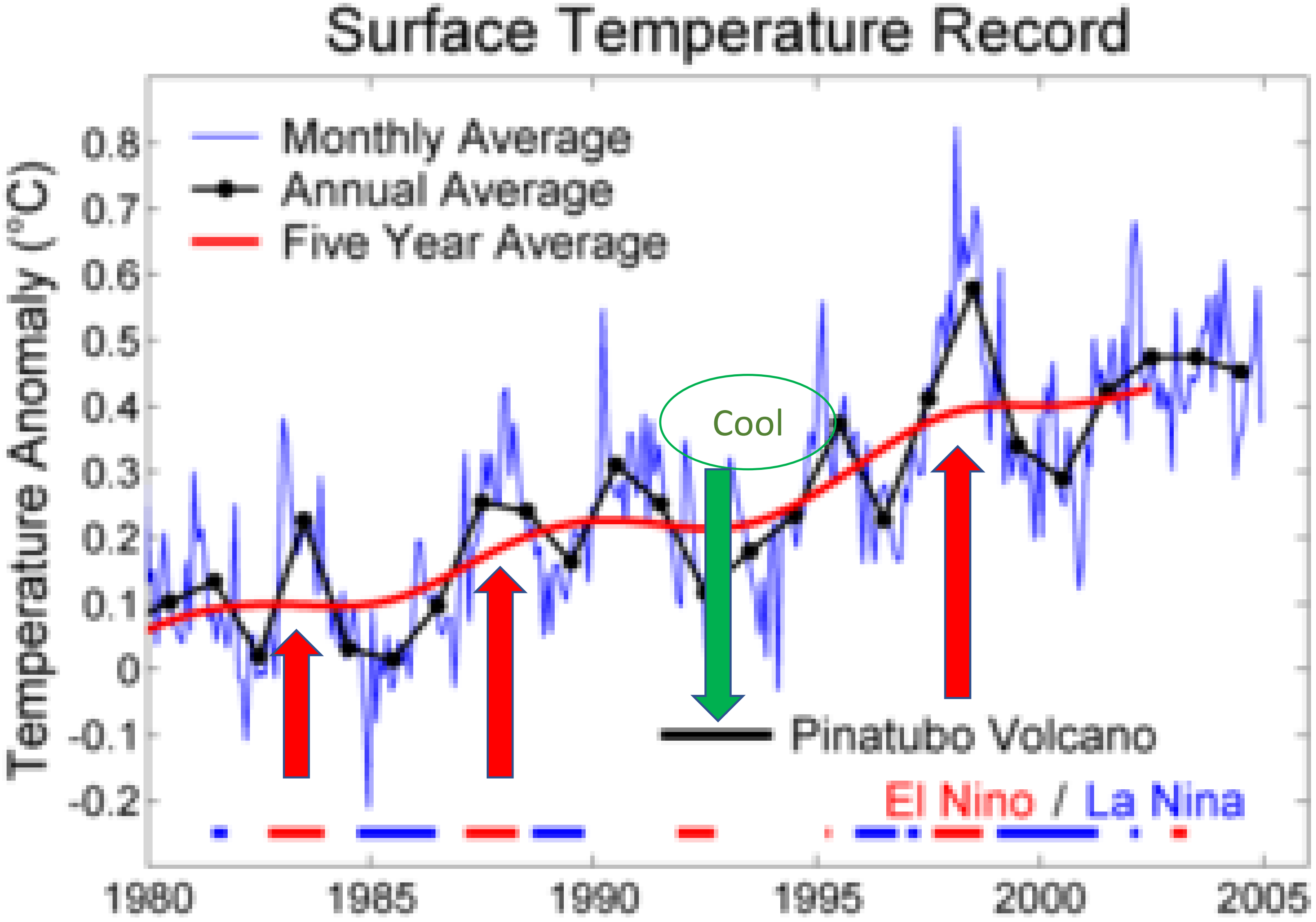
  RSS Remote Sensing Systems, Calif.

  UAH Univ. Alabama, Huntsville
- Comparison with data collected from surface (land) stations

https://www.carbonbrief.org/major-correction-to-satellite-data-shows-140-faster-warming-since-1998

Impact of El Nino, La Nina & Pinatubo 1992 Eruption on $T^{O}C$

June 1991 Eruption
Mt Pinatubo, Philippines
2nd largest eruption in 20th century
Emitted 42 million tonnes of CO_2
Human annual emissions 30+ billion tonnes
Greater impact from sulphate aerosols



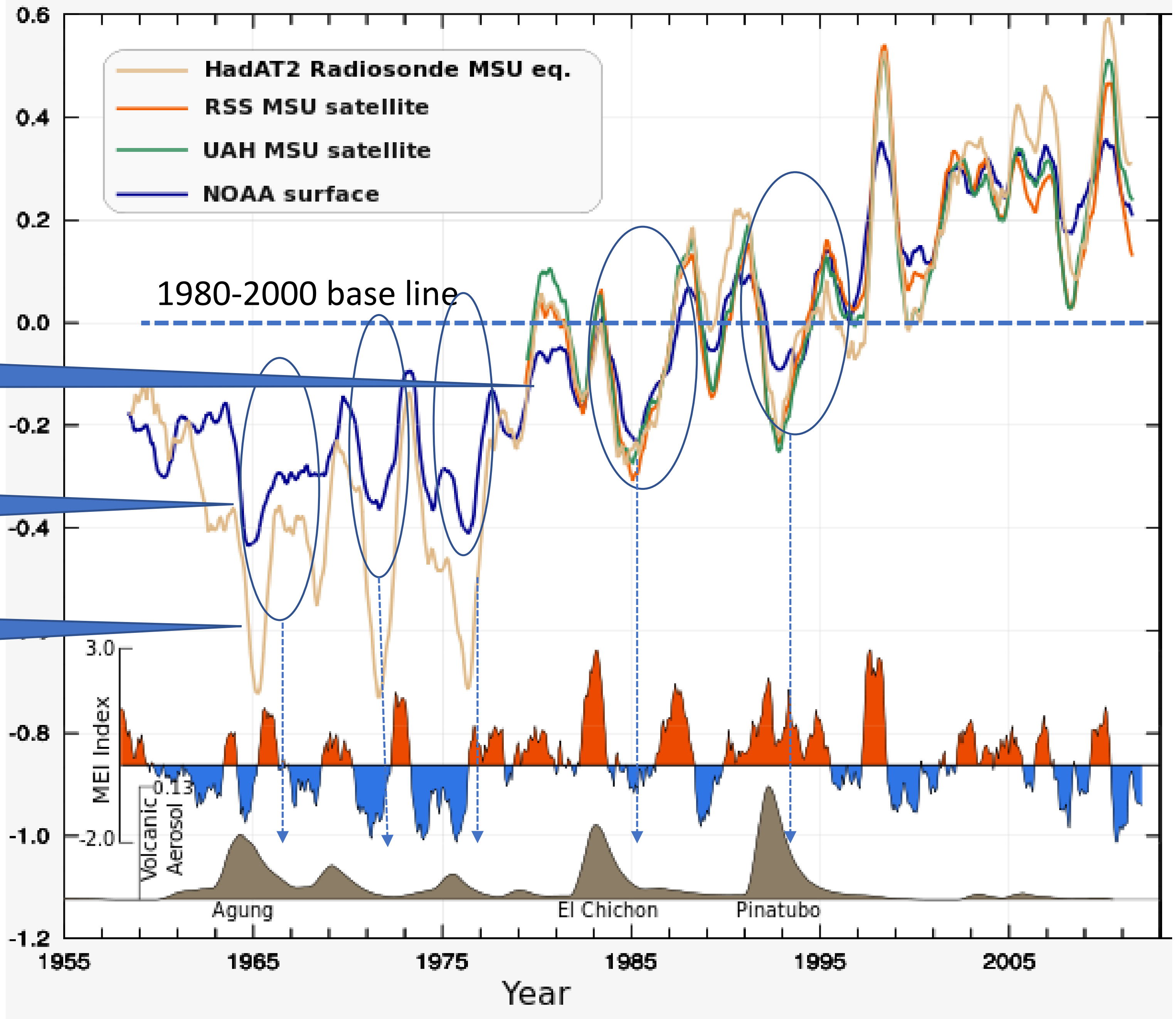
Impact of Volcanic Aerosols on $T^{O}C$

Cooling following eruption

Satellite data starts

Surface data

Radiosonde data discrepancy



SCIENCE AND CONSENSUS

Michael Crichton (2003)

"Let's be clear: the work of science has nothing whatever to do with consensus.

Consensus is the business of politics.

Science, on the contrary, requires only one investigator who happens to be right, which means that he or she has results that are verifiable by reference to the real world.

In science consensus is irrelevant.

What is relevant is reproducible results.

The greatest scientists in history are great precisely because they broke with the consensus…"

The Causes of Global Warming – Climate Change

Subject of the May Saturday Speaker Series

1. Can we model climate change?
2. What can we learn from history?
3. Can we control climate change?
   reduce the rate of temperature increase
   geoengineer the climate
4. How can we prepare for the impacts and bear the costs of “solutions”?

University of Victoria
Retirees Association

AN ELDER ACADEMY EVENT

May Saturday Speaker Series

Climate Change Anxiety:

Causes, Consequences, Solutions and Costs

TIME: 10:00am to noon
University of Victoria, David Turpin Building (DTB), A Wing,

May 2: “Climate Modelling”,

Presenter: Dr. Johannes Feddema, Professor U.Vic

May 9: “Climate Change a Geologist’s Perspective”,

Presenter: Tom Gallagher, Explorationist & Researcher.

May 16: “The Importance of Oceans to Climate Change”,

Presenter: Dwight Owens, ONC

May 23: “Is Geoengineering the Naloxone for our Fossil Fuel Addiction”

Presenter: Dr. HadI Dowlatabadi, Professor UBC

May 30: “Tackling the Adaptation Imperative: International Best Practices”

Presenter: Dr. Hannah Teicher, Researcher, PICS

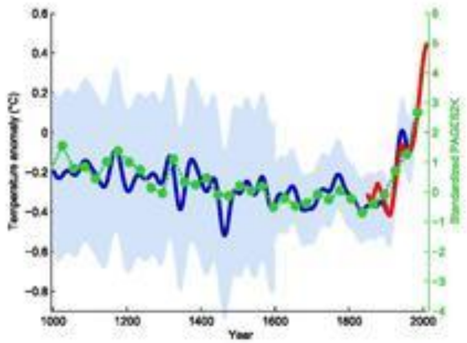
Evidence for (Anthropogenic Cause ?? of) Climate Change

- Global temp rise 2016 warmest on record (0.9^{o}C since late 19 Century)
- Shrinking Ice Sheets:
  - Antarctic loss tripled in last decade 1993 -2016, Antarctic lost 126 billion tonnes
  - Greenland lost 286 billion tonnes
  - Declining Arctic sea ice
- Increasing rate of Glacial Retreat
- Decreased snow cover
- Sea Level rise 8 inches last century
- Extreme weather
- Warming Oceans top 700 m warming 0.15^{o}C since 1969

Levitus, S.; Antonov, J.; Boyer, T.; Baranova, O.; Garcia, H.; Locarnini, R.; Mishonov, A.; Reagan, J.; Seidov, D.; Yarosh, E.; Zweng, M. (2017). NCEI ocean heat content, temperature anomalies, salinity anomalies, thermosteric sea level anomalies, halosteric sea level anomalies, and total steric sea level anomalies from 1955 to present calculated from in situ oceanographic subsurface profile data (NCEI Accession 0164586). Version 4.4. NOAA National Centers for Environmental Information. Dataset. doi:10.7289/V53F4MVP

Interpretation of Temperature Data
"Causes" of Climate Change

- Ocean Circulation changes: El Nino ENSO (1yr), PDO (30 yr), La Nina,
- Solar Irradiance changes:
- Earth's changing position relative to the sun: Milankovich Cycles (3)
- Data Source Variations & Manipulations:
  - surface vs satellites,
  - radiosonde (weather balloons) vs MSU microsonde unit conversion vs thermometers
  - accuracy and precision of old vs new instruments
  - thermometer placement (urban effects)
  - proxies vs historical data continuity
  - altitude effects
  - hemispheric effects
  - Statistical distortions – Mann's Hockey Stick Curve (1999)



- Greenhouse Gas Effects: Water Vapour, CO_2, CH_4 Other (aerosols, black carbon, particulates)

Contributors to Greenhouse Gas Effect (GHGs)

United States Environmental Protection Agency. 27 June 2016. Retrieved 20 Jan. 2017.

Compound	Formula	Concentration in atmosphere (ppm)	Contribution (%)
Water vapor and clouds	H_2O	10–50,000[A] (1 – 5%)	36–72%
Carbon dioxide	CO_2	~400 (0.04%)	9–26%
Methane	CH_4	~1.8	4–9%
Ozone	O_3	2–8[B]	3–7%

Why is little attention paid to water vapour (clouds), aerosols?

[A] Water vapor strongly varies locally
[B] The concentration in stratosphere. About 90% of the ozone in Earth's atmosphere is contained in the stratosphere.

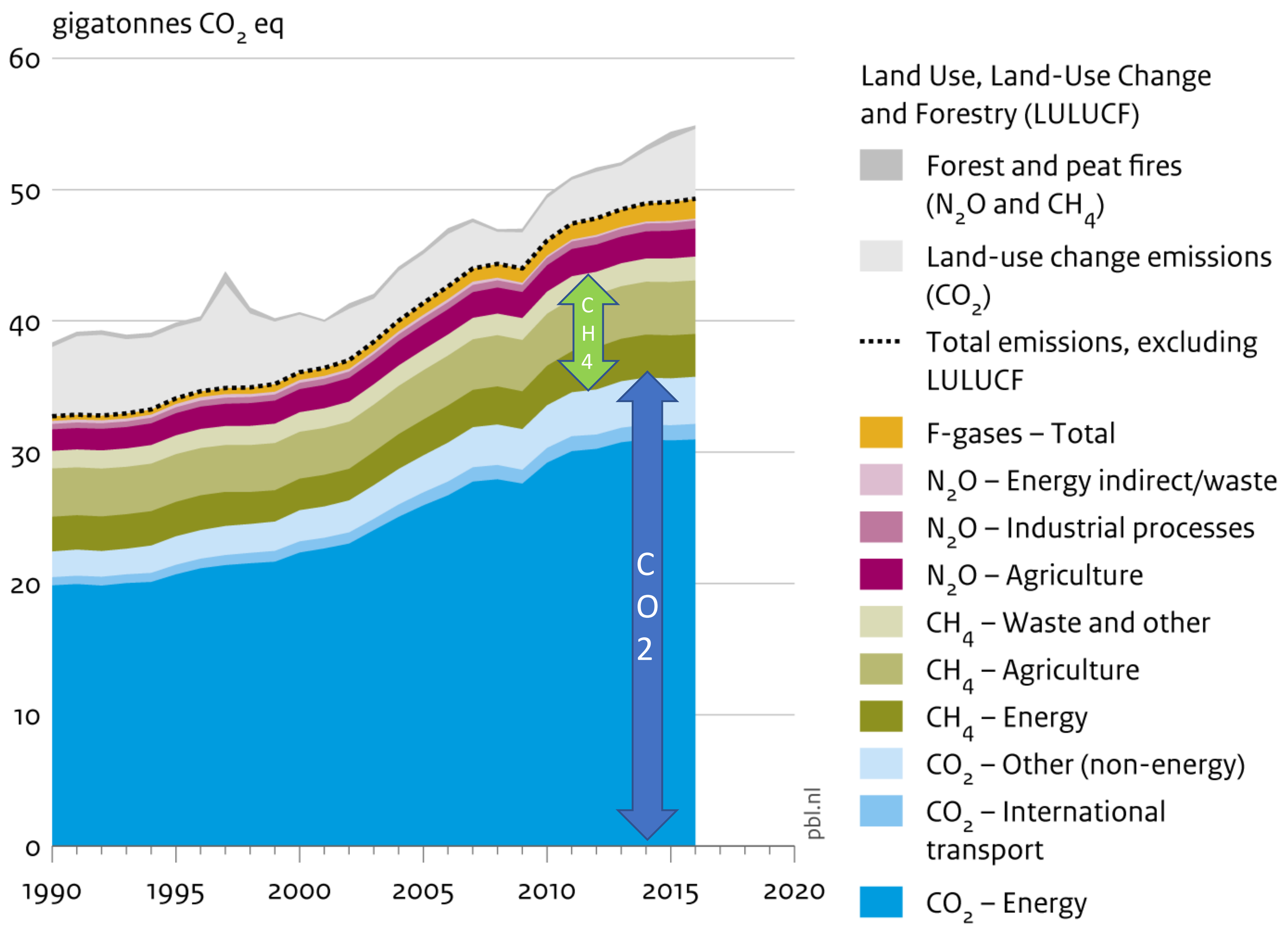
1 molecule CO_2 in 2500 molecules of air (N_2 & O_2)

1 molecule CH_4 in 555,000 molecules of air (N_2 & O_2)

Water Vapor & Aerosols

- Clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth’s changing energy budget.
- The quantification of cloud and convective effects in models, and of aerosol–cloud interactions, continues to be a challenge. Climate models are incorporating more of the relevant processes than at the time of AR4, but confidence in the representation of these processes remains weak
- Clouds are known to affect temperature and rainfall distribution both spatially and temporarily:
  - condensation nuclei/ice crystals
- Aerosols have a similar major impact on radiative forcing:
  - black carbon & sulphate (Volcanos)

Global greenhouse gas emissions, per type of gas and source, including LULUCF



Source: EDGAR v4.3.2 (EC-JRC/PBL 2017); Houghton and Nassikas (2017); GFED 4.1s (2017)

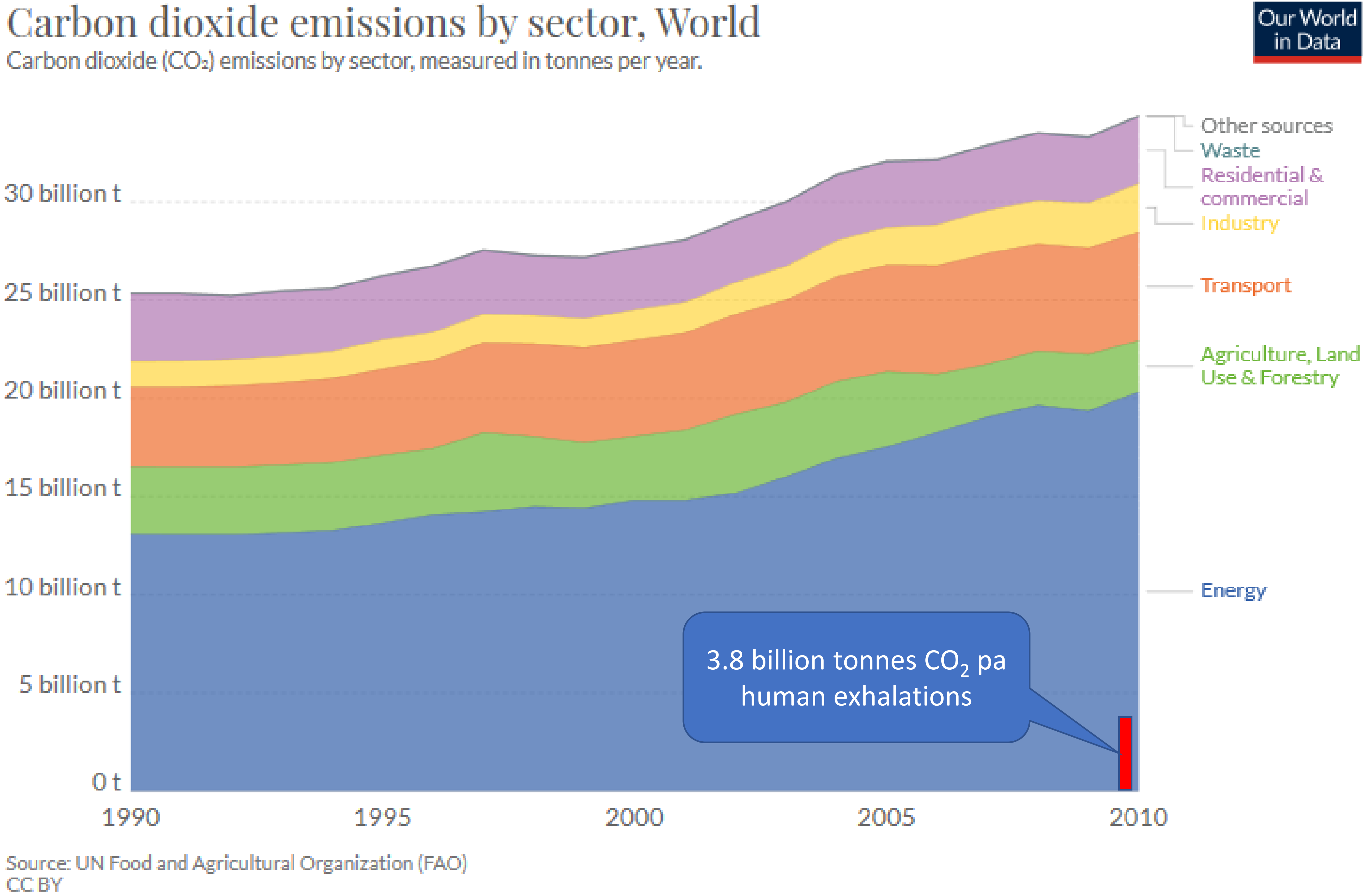
CO_2 vs Population

- Breathing (exhalation) 4% is CO_2 (ref: Biotopics)
- Annual contribution is 1000 lbs CO_2/person
- Population (ref: Geohive)
- 1 tonne C=3.67 tonnes CO_2
- 1.04 x 3.67 = 3.8 billion tonnes CO_2 pa

YR	Pop Billions	HC emissions GtC/yr	Breath emissions GtC/yr
1950	2.56		0.35
1980	4.45	4.05	0.61
1990	5.29	5.07	0.72
2000	6.08	6.80	0.83
2010	6.85	8.56	0.93
2020	7.60	9.5	1.04
2050	9.54		1.30

Conclusion

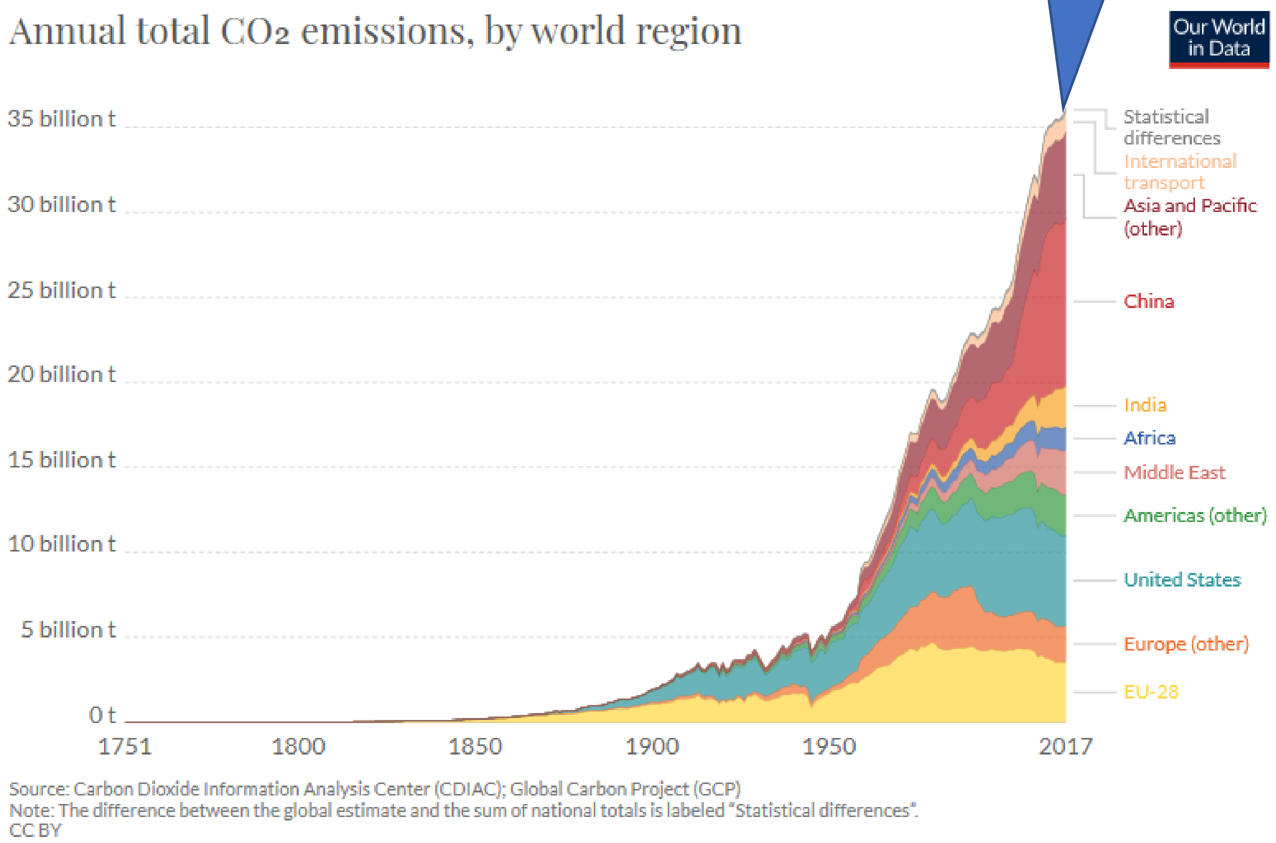
Breath from global population contains >10% of carbon dioxide emitted each year & growing as population increases.

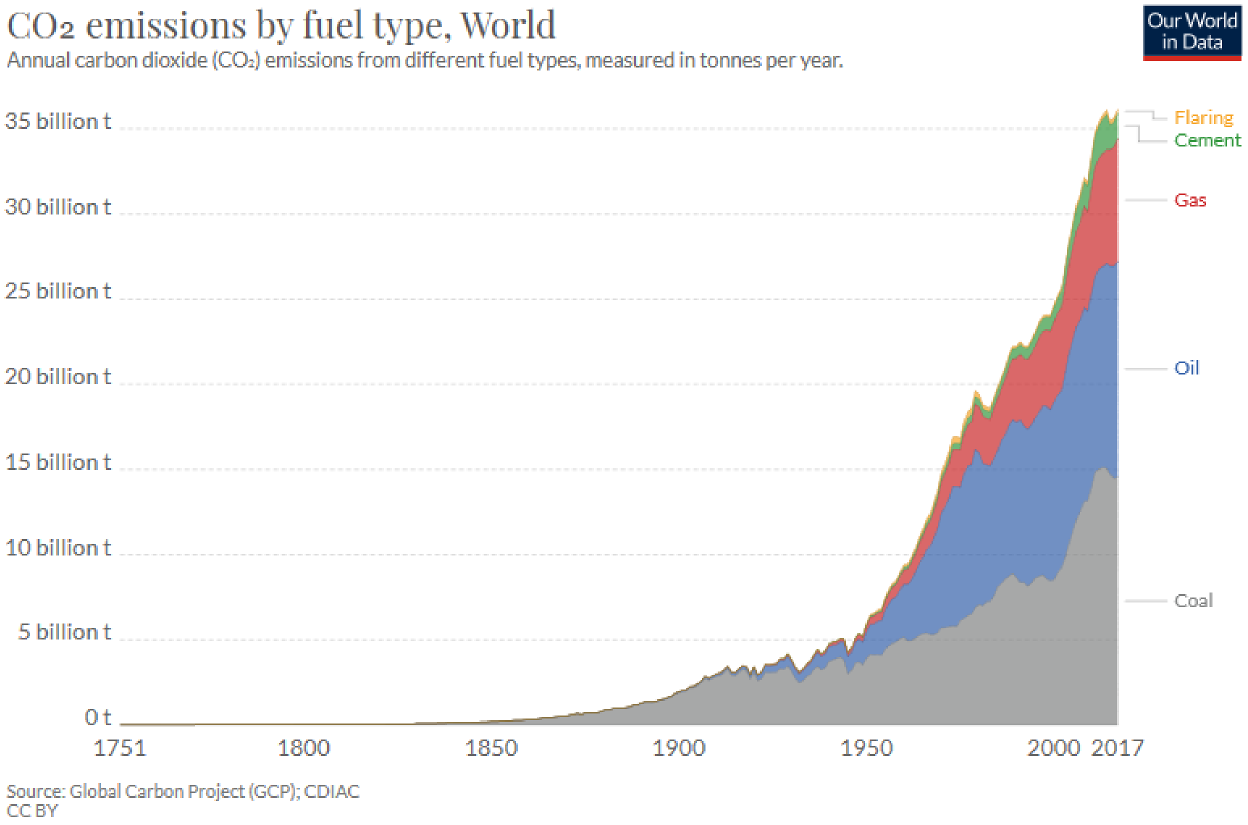

Carbon dioxide emissions by sector, World
Carbon dioxide (CO_2) emissions by sector, measured in tonnes per year.
Our World in Data
30 billion t
25 billion t
20 billion t
15 billion t
10 billion t
5 billion t
0 t
1990
1995
2000
2005
2010
Other sources
Waste
Residential & commercial
Industry
Transport
Agriculture, Land Use & Forestry
Energy
3.8 billion tonnes CO_2 pa human exhalations
Source: UN Food and Agricultural Organization (FAO)
CC BY

Carbon Dioxide Emission by Region and by fuel Type

https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

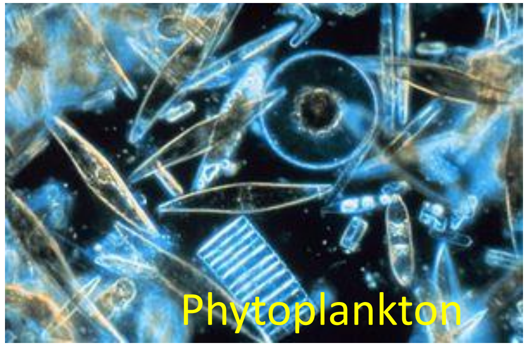
35+ billion tonnes CO_2 pa





Carbon

- Carbon is the foundation of life
- Produces 85 - 90% of the energy we consume
- 4th most abundant element in universe
- From diamonds to graphite (hardest to softest)
- Carbon cycle
- Earth's Carbon stores (in billions tonnes)
    - Kerogen 15,000,000, Source of Fossil Fuels including **hydrates** (4,500 in known FF reserves)
        - Type 2 (lipids - plankton, animal), liquid & gas source rocks through thermogenic decay: Marine
        - Type 3 (cellulose, lignins, humic – plant), gas producing source rocks through bacteriogenic & thermogenic decay
    - Rocks 65,000,000 EG. limestones, dolomites, marble, carbonatites : Ca/MgCO_3
    - Soil Humus 1,600
    - Biota 570
    - Ocean in solution 38,000 (HCO_3^-) + (Ca^{2+})
    - Ocean in reefs 6,000
    - Atmosphere 875 (3,210 billion tonnes as CO_2 or 410 ppm: 1 ppm = 7.2 billion tonnes CO_2



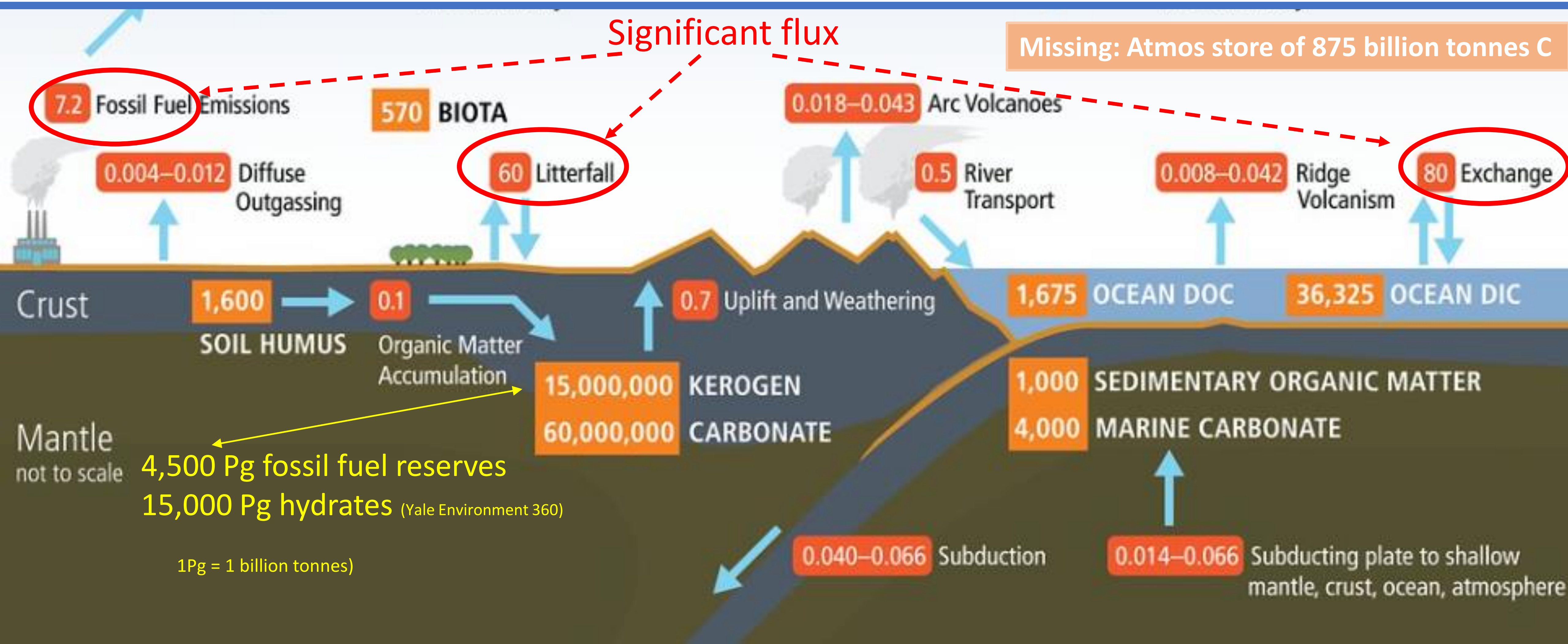
Coccolithophore Phytoplankton
photosynthesis CO_2 + Ca^{2+} = Chalk
Kilometre thick ocean floor ooze
covers 35% of ocean

- Earth Carbon Flux (annually in billions tonnes)
    - Volcanos emit 0.084 (0.38 billion tonnes CO_2) not well established
    - Litterfall - atmosphere 60 (220 billion tonnes CO_2)
    - Ocean- atmosphere 80 (293 billion tonnes CO_2)
    - Anthropogenic 9.5 (35+ billion tonnes CO_2)

These are the BIG 3
Note relatively small anthropogenic contribution

Carbon Stores (orange) & Annual Flux (red) in Petagrams

DEEP CARBON OBSERVATORY

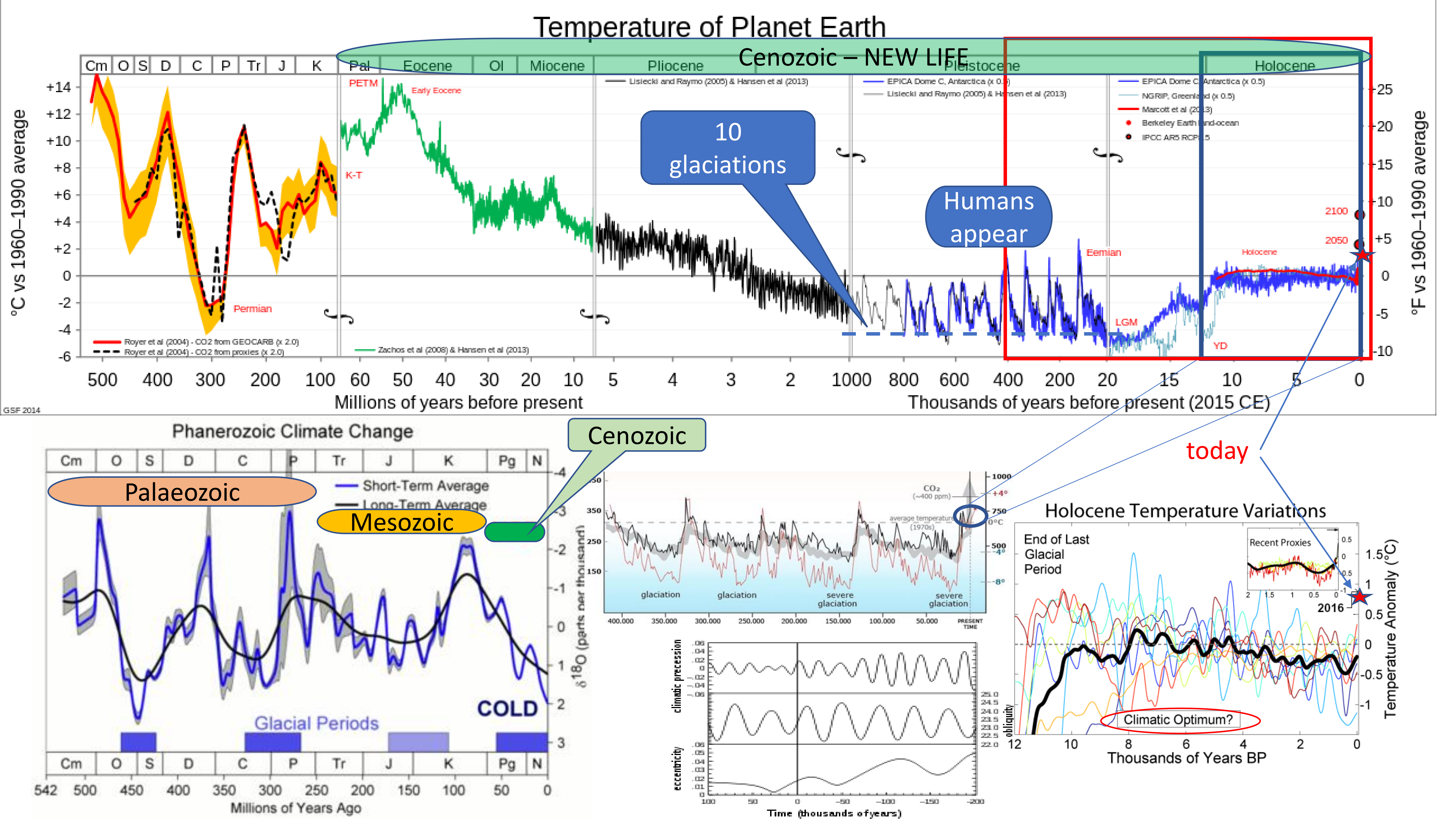


CO_2

- Colorless, odorless but NOT a pollutant
- Essential to life
- 50 –100 tonnes of CO_2 per lifetime of auto
- If unchecked by 2050 would be >2x pre-industry level
- Avge American generates (20 tonnes per yr) 2x CO_2 produced by Japanese & Europeans
- Is there a saturation level (cap) between atmosphere and hydrosphere and biosphere?

Impact of Burning Fossil Fuels on CO_2 Content of Atmosphere

- Atmosphere holds 875 billion tons of Carbon as CO_2 (410 ppm)
- Oceans hold 39,000+ billion tons of Carbon as dissolved CO_2
- Burning fossil fuels adds ~9 billion tons per year of Carbon as CO_2 (~1% atmos)
- Approx 1 billion tons of Carbon exhaled annually by world population
- Can human emission of 9.5+ billion tons per year of Carbon be recycled by natural processes or will it increase the atmospheric content and lead to unstoppable global warming?
- Are there other causes of global warming?
- Could it be that we are about to cool to another period of glaciation?
- Does warming promote plant/tree growth and to an CO_2 increase? Which comes first?



Temperature of Planet Earth
Cenozoic – NEW LIFE
Cm O S D C P Tr J K Pal Eocene Ol Miocene Pliocene Pleistocene Holocene
10 glaciations
Humans appear
PETM
Early Eocene
K-T
Permian
Eemian
LGM
YD
Holocene
2100
2050
°C vs 1960–1990 average
°F vs 1960–1990 average
Millions of years before present
Thousands of years before present (2015 CE)
GSF 2014
Phanerozoic Climate Change
Palaeozoic
Mesozoic
Cenozoic
Short-Term Average
Long-Term Average
COLD
Glacial Periods
Millions of Years Ago
glaciation
severe glaciation
average temperature (1970s)
PRESENT TIME
today
Time (thousands of years)
climatic precession
obliquity
eccentricity
Holocene Temperature Variations
End of Last Glacial Period
Recent Proxies
2016
Climatic Optimum?
Temperature Anomaly (°C)
Thousands of Years BP

Various researchers: references available on request

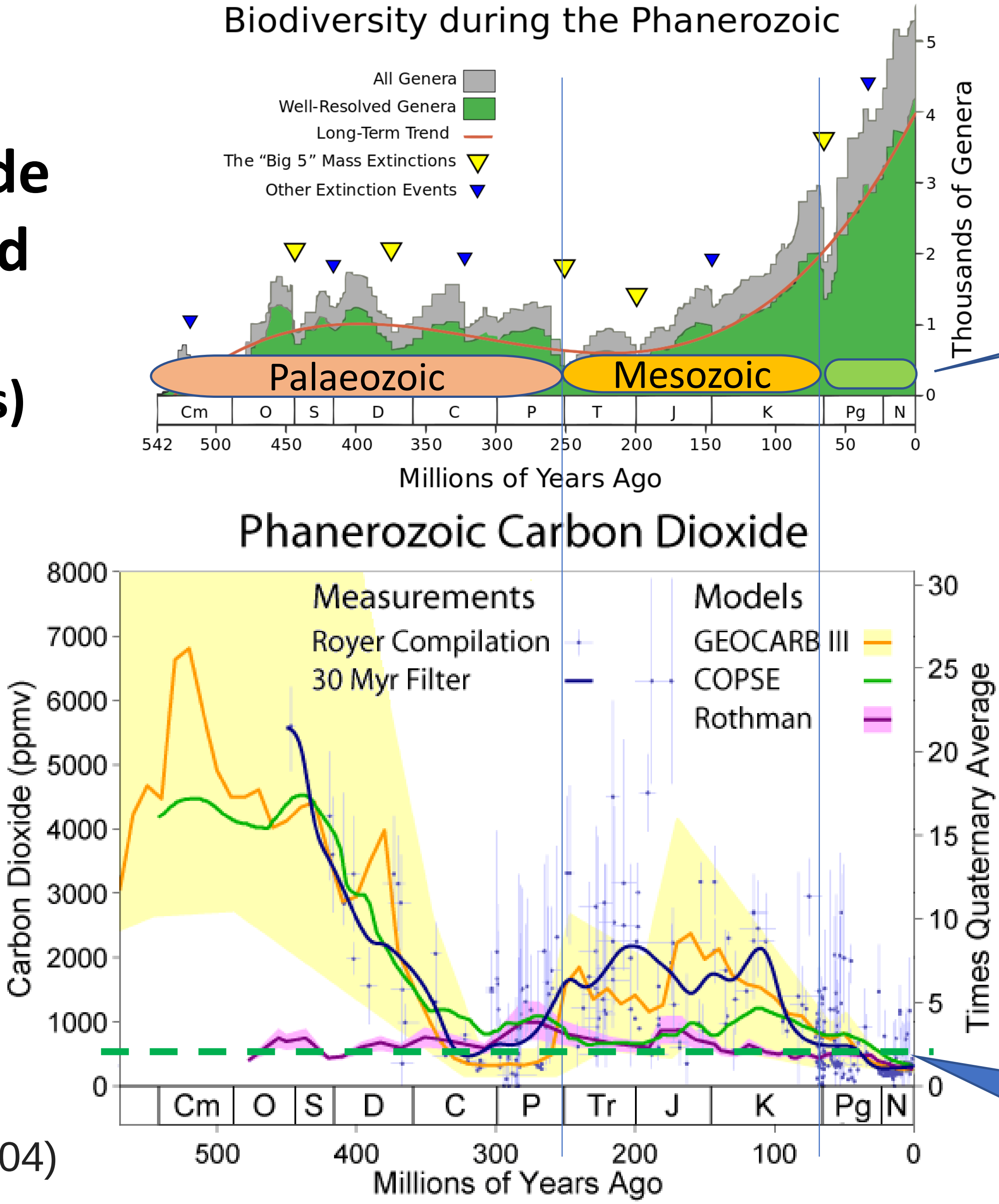
Holocene Climate Optimum – warm period 12,000 – 2000 BP

- Global average temperatures were probably warmer than now. While temperatures in the Northern Hemisphere were warmer than average during the summers, the Tropics and parts of the Southern Hemisphere were colder than average
- North Pole increases of up to 4 °C (in one study, winter warming of 3 to 9 °C and summer of 2 to 6 °C in northern central Siberia).
- Western Arctic show clear evidence for conditions warmer than now. At 16 sites, quantitative estimates show local temperatures were on average 1.6±0.8 °C higher than now. Research indicates the Arctic had less sea ice than the present. Arctic Coastal Plain in Alaska, there are indications of summer temperatures 2–3 °C warmer than present.
- Northwestern Europe experienced warming, but there was cooling in Southern Europe. The average temperature change declined rapidly with latitude. No change in mean temperature is reported at low and middle latitudes.
- Northwestern North America had peak warmth from 11,000 to 9,000 years ago, and the Laurentide Ice Sheet still chilled the continent.
- Northeastern North America experienced peak warming 4,000 years later.
- Central Asia current desert regions were extensively forested due to higher rainfall and the warm temperate forest belts in China and Japan were extended northwards.
- Tropical reefs show temperature increases of less than 1 °C; the tropical ocean surface at the Great Barrier Reef about 5350 years ago was 1 °C warmer and enriched in ^{18}O by 0.5 per mil relative to modern seawater.
- African Humid Period, 12,000 and 6,000 years BP, Africa was much wetter. This was caused by a strengthening of the African monsoon by changes in summer radiation, resulting from long-term variations in the Earth's orbit around the Sun. "Green Sahara" was dotted with numerous lakes, containing typical African lake crocodile and hippopotamus fauna. Humans played a role in altering the vegetation structure of North Africa at some point after 8,000 years ago, when they introduced domesticated animals. Leading to the rapid transition to the arid conditions found in many locations in the Sahara. Transitions into and out of the wet period occurred within decades, not the previously-thought extended periods.
- Southern Hemisphere (New Zealand and Antarctica), the warmest period during the Holocene appears to have been roughly 10,500 to 8,000 years ago, immediately following the end of the last ice age. By 6,000 years ago, the time normally associated with the Holocene Climatic Optimum in the Northern Hemisphere, they had reached temperatures similar to present ones, and they did not participate in the temperature changes of the north.

The History of Biodiversity & Atmospheric Carbon Dioxide from the start of Preserved Life on Earth

(Phanerozoic 542 million years)

Direct determination of past carbon dioxide levels relies primarily on the interpretation of carbon isotopic ratios in fossilized soils (paleosols) or the shells of phytoplankton and through interpretation of stomatal density in fossil plants. Each of these is subject to substantial systematic uncertainty.
(Robert A Rohde)



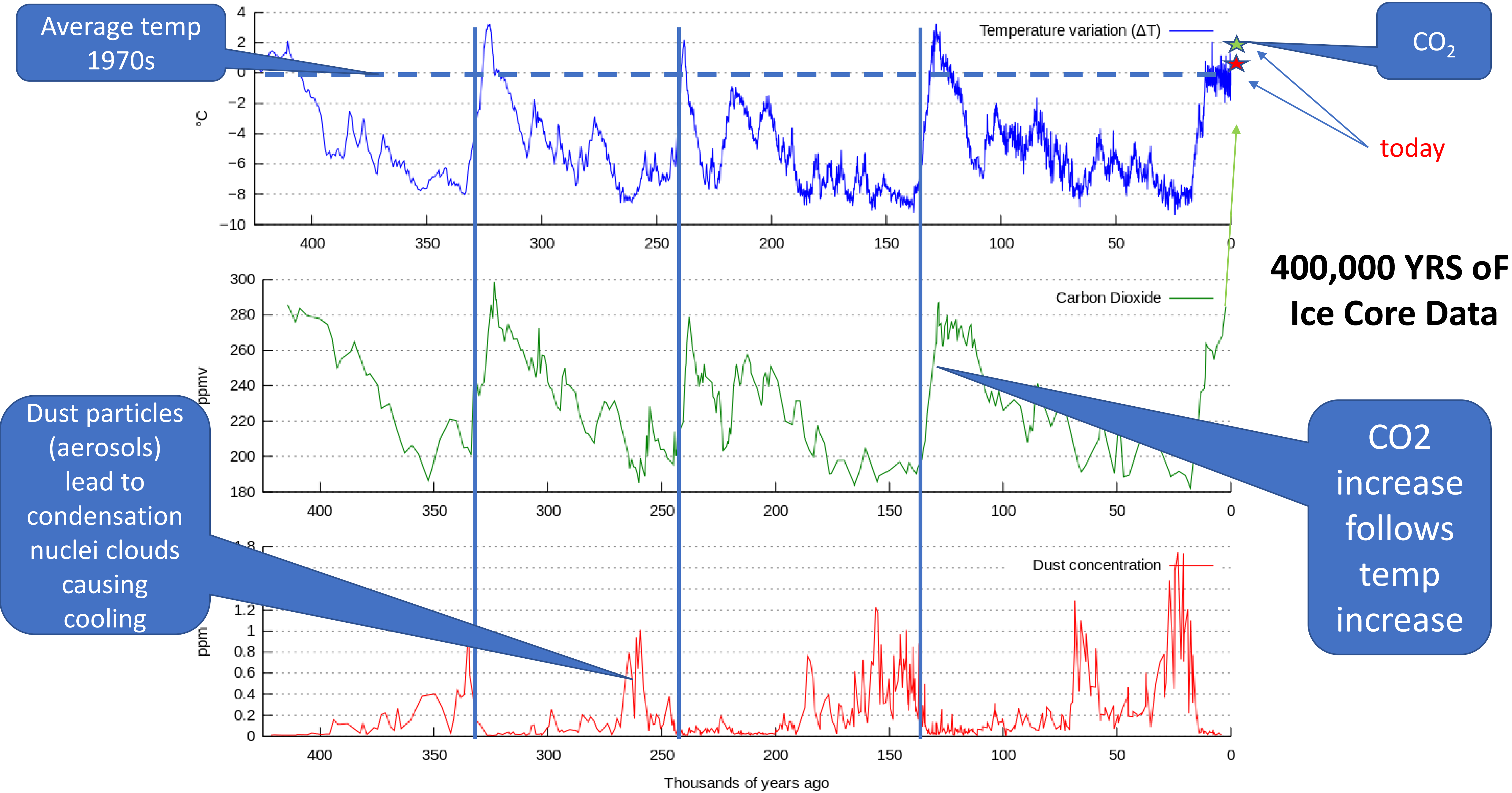
Royer et al. (2004)

Cenozoic

Low atmospheric CO_2 corresponds to an increase in biodiversity & abundance

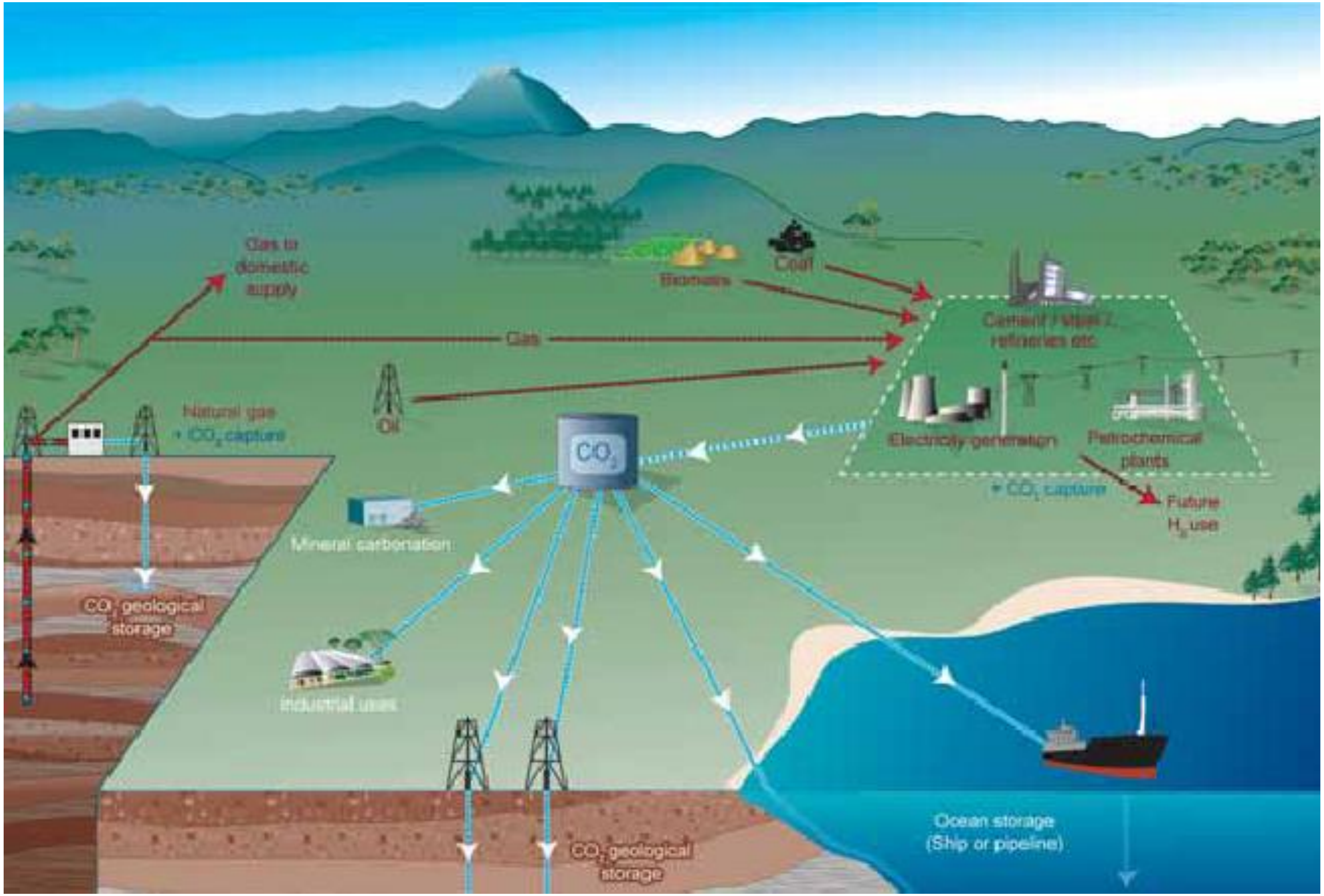
Atmospheric CO_2 stimulates biogenic growth leading to sequestering of CO_2

415 ppm CO_2



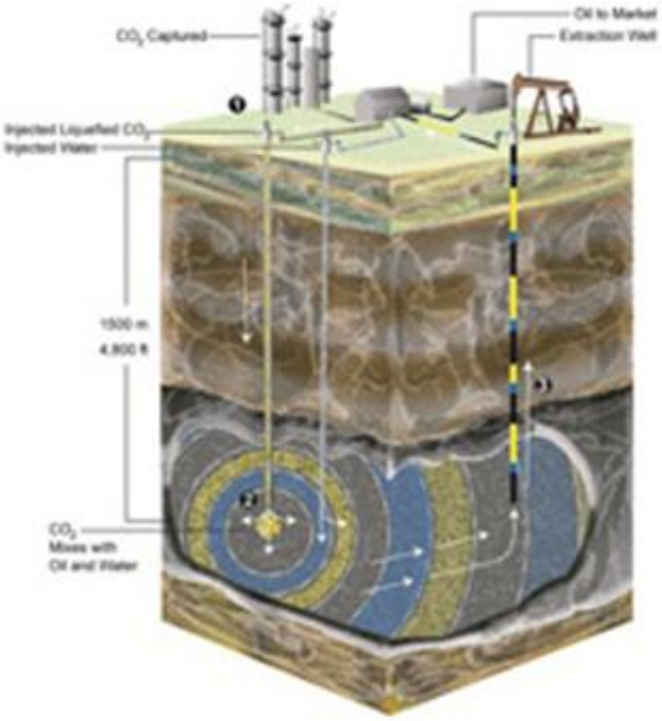
(Graphs by Robert Simmon, using data from Lüthi et al., 2008, and Jouzel et al., 2007.

CO_2 CCS
(Carbon Capture Sequestration)



Weyburn – Midale CO_2 Storage, Saskatchewan

- Launched 2000
- CO_2 from Beulah, North Dakota (Dakota Gasification Company - coal)
- 8500 tonnes per day CO_2, compressed, liquified pipelined 320kms to Weyburn
- Injected with water 1500 m underground:
- 2000 tonnes per day Midale
- 6500 tonnes per day Weyburn
- Enhanced Oil Recovery (EOR)
- 8,000 cu. Ft of CO_2 increases oil production by 2 to 3 barrels
- All injected and recycled CO_2 will remain safely stored underground



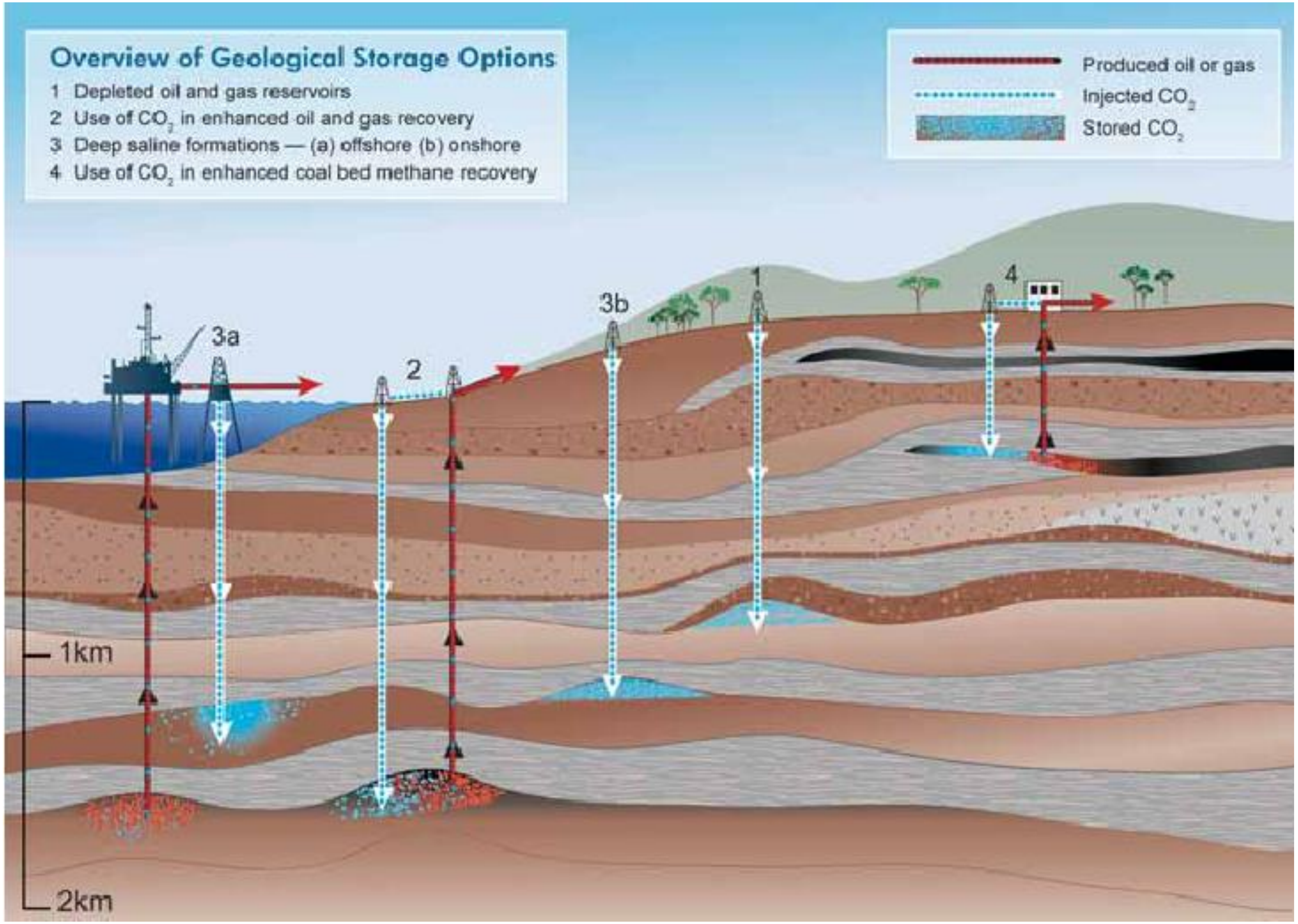
CO_2 Sequestration - Geology

Storage Option Global Capacity

Estimate of # Sites Required

Depleted gas fields
690
Depleted oil fields/CO_2-EOR
120*
Deep saline aquifers
400 - 10 000
Unmineable coal seams
40

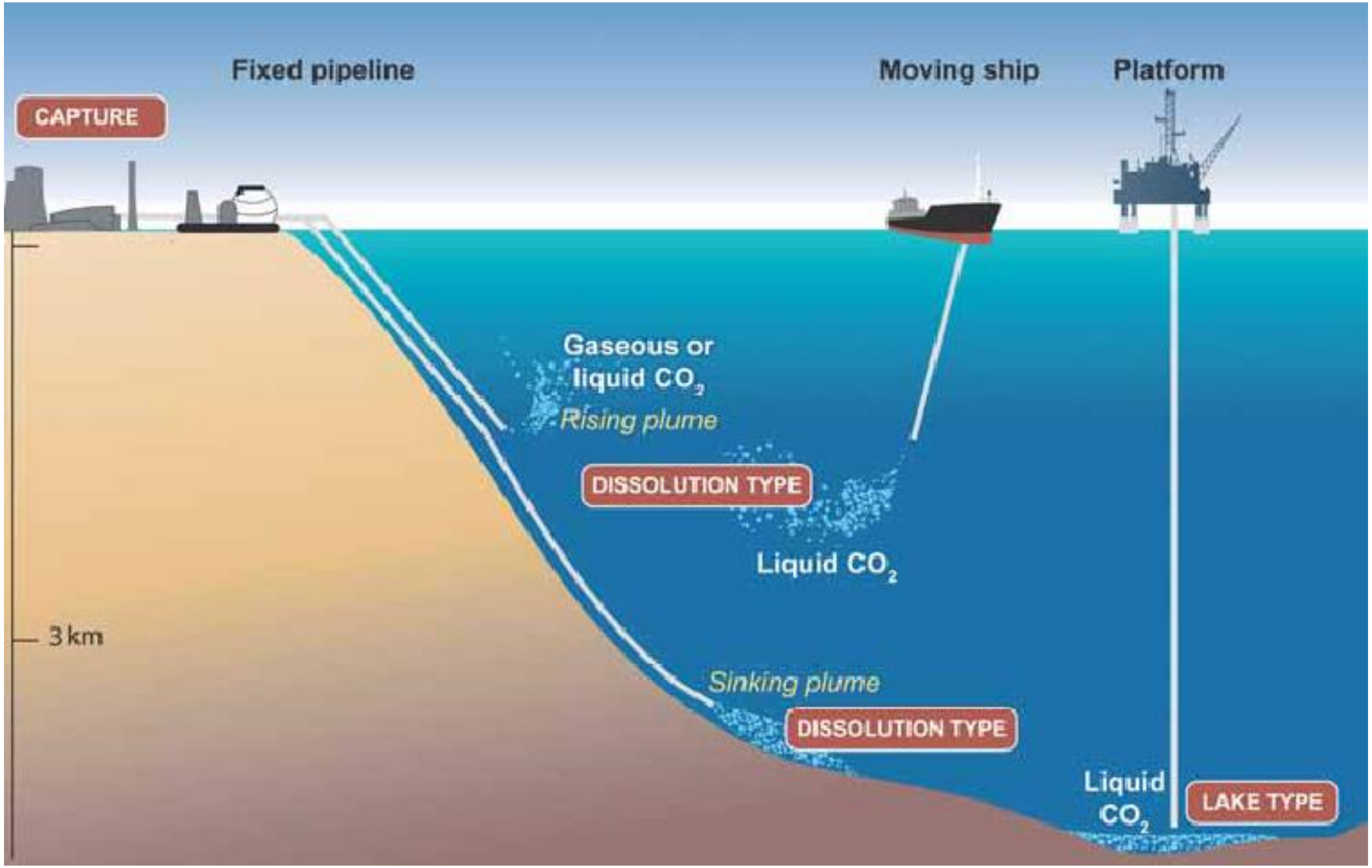
*= 4000 Weyburn/Midale projects (10yr life)



CO_2 Sequestration - Ocean

Storage Option
Global Capacity
Gt CO_2 ??

- Unknown capacity
- What are risks?



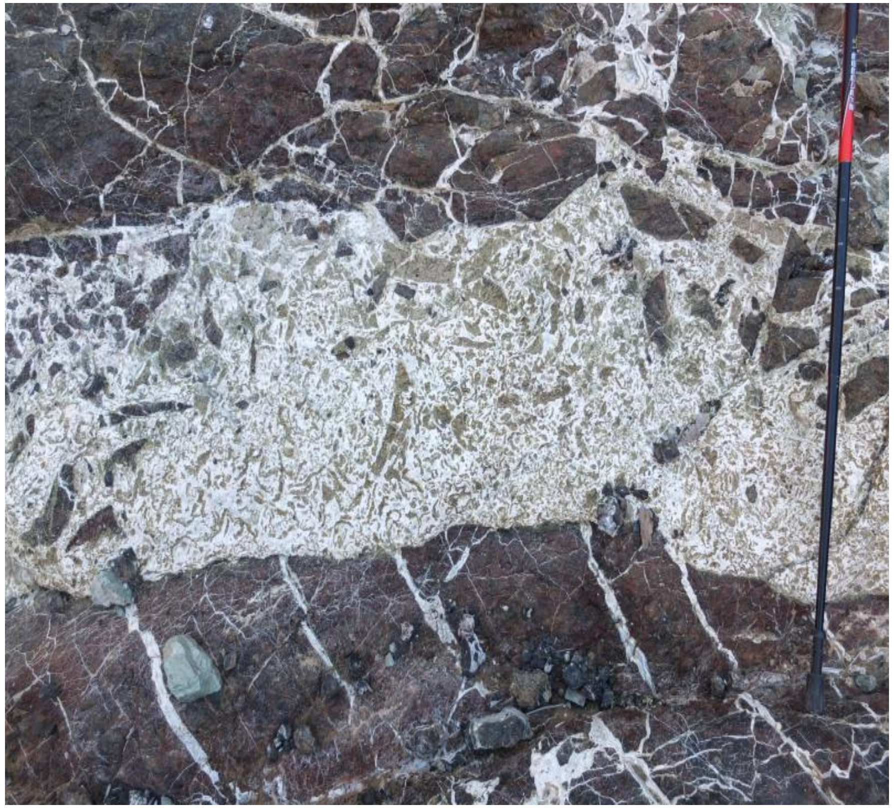
oman drilling project

omandrillingproject@southampton.ac.uk

Scientific Drilling in the Samail Ophiolite, Sultanate of Oman

Started December 1, 2016
15 holes at 6 sites
Core samples of oceanic crust & mantle peridotite

Olivine – rich rocks commonly found in ocean floor assemblages, are known to chemically combine CO_2 and form the mineral magnesite $MgCO_3$
Considered a possible means of CO_2 sequestration.
Under evaluation offshore BC…. Dwight Owens, ONC.



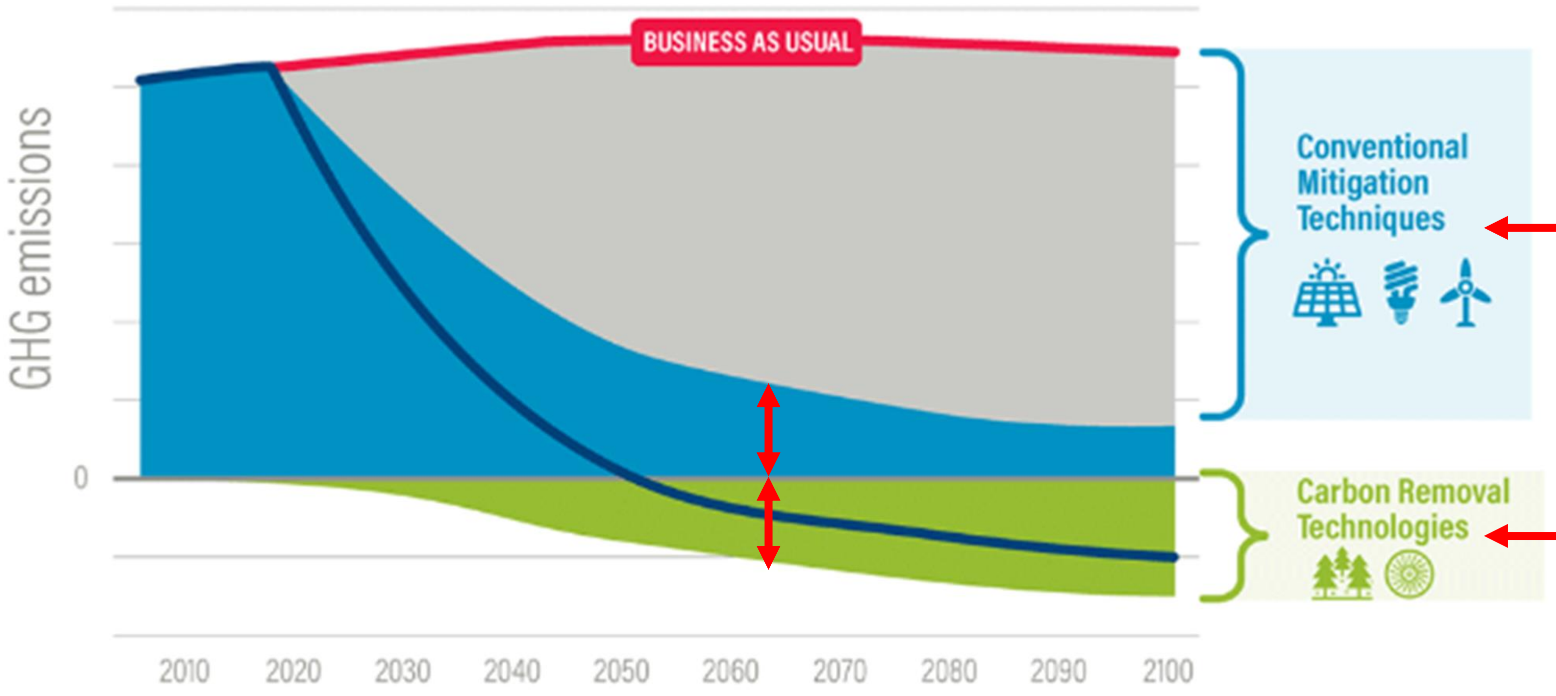
Plastics: Sequestering Carbon

- ✓ Plastics and other goods produced from oil and gas by-products a means of sequestering carbon.
- ✓ Feel good about buying and using these products.

REVIEW: The 2 Imperatives

FIRST: The planet is running out of Oil (Hydrocarbons)

SECOND: Burning Hydrocarbons at the current rate is causing runaway global warming



What can we do?

Substitution & Reduction in Consumption

Sequestration

BREAK

• **Oil Pre –1950s**	**100 +**
• **Oil 1950 –1970**	**40**
• **Oil (average)**	**8 - 11**
• **Coal**	**30**
• **Gas**	**28**
• **Biomass – Biofuels**	**1 - 4**
• **Wind**	**4 - 16**
• **Solar PV**	**4 – 2**
• **Solar CSP**	**28**
• **Hydro**	**35 - 49**
• **Wave**	**??**
• **Tidal**	**??**
• **Nuclear**	**75 – 106**
• **Geothermal**	**<2 – 6**
• **Hydrogen**	**??**

Shale oil Increasingly costly

$$EROEI = \frac{\text{Energy Delivered}}{\text{Energy Required to Deliver that Energy}}$$

(Source of data varies)

Ratio = 1 Breakeven

Ratio = 5+ is considered worthwhile given uncertainty in calculation

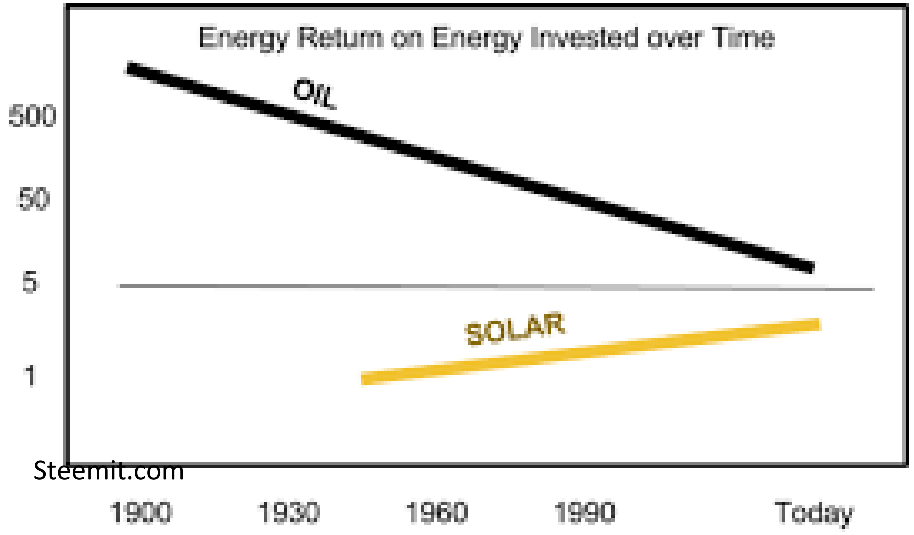
EROEI is energy returned on energy invested

$$EROEI = \frac{\text{Energy Delivered}}{\text{Energy Required to Deliver that Energy}}$$

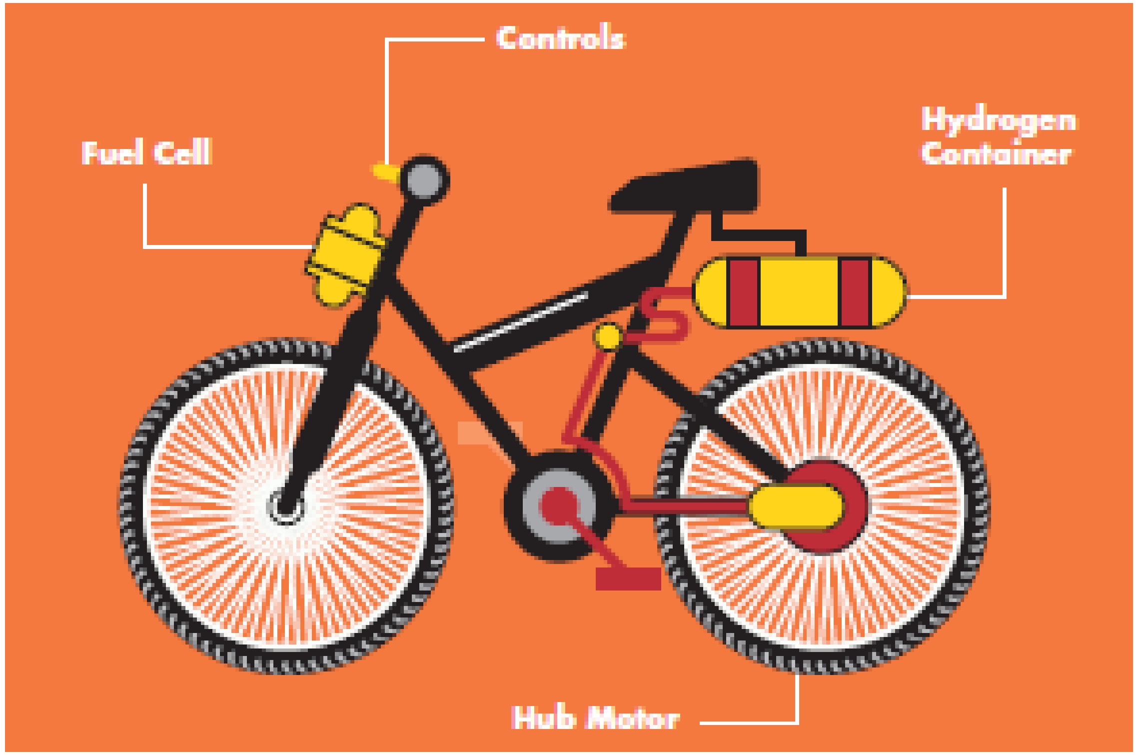
Points to Consider

EROEI declines over time (eg. Oil is increasingly more difficult to produce)
EROEI increases over time (eg. Solar, efficiencies in scale and production technologies)
EROEI needs to consider amortization where capital infrastructure is required, (refining, pipelining)
EROEI needs to consider life of service and replacement costs
EROEI needs to consider full cost of materials and processes required:

- Biofuels – fertilizer, fuel for tractors fuel for refining, addition of denurants (pentanes plus)
- Solar – mining, shipping and processing of materials…silica, rare earths, metals
- Hydrogen - mining, shipping and processing of membrane materials & availability of electricity
- Wind – carbon fibre, steel & turbine construction
- Hydro – dam construction



Nicolas Pocard from Ballard Power looks at Hydrogen and the Fuel Cell on Feb 8



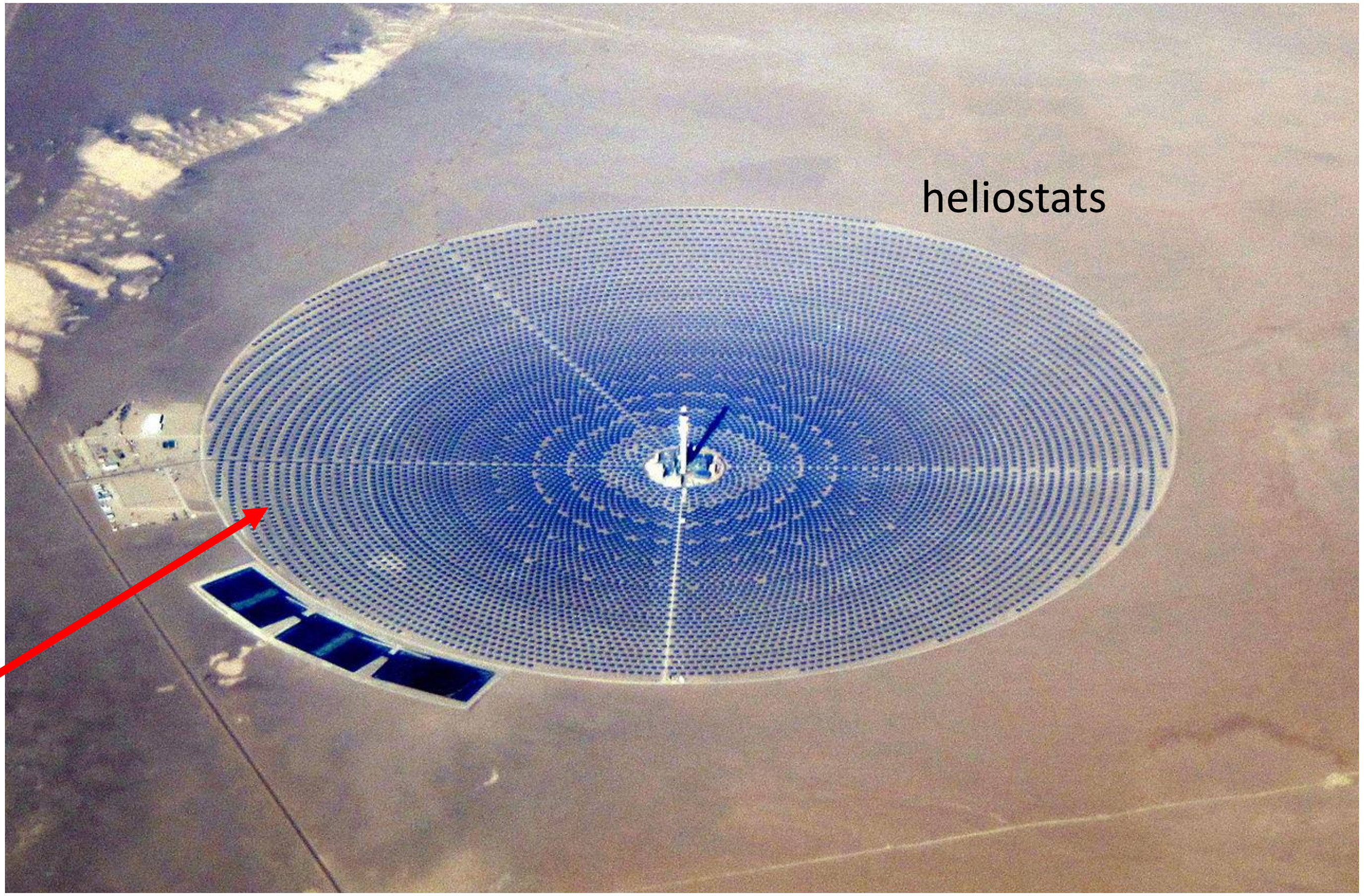
Challenges

- A 1999 University of California study revealed that more than 3,000 gallons of gaseous hydrogen is necessary to produce the same energy as a gallon of gasoline. (http://darwin.bio.uci.edu/~sustain/global/sensem/Forrest98.htm).
- Compressed gaseous hydrogen is highly explosive.
- Liquid hydrogen comes close to equaling gasoline's energy but it is so cold, it fractures the metals used in fuel systems.
- Hydrogen production is problematic

Tom Tiedje of IESVIC talks about Solar Panels on February 15th

354 MW San Bernardino Cty Cal

photovoltaics vs solar thermal



Crescent Dune 110 MW, Tonopah, Las Vegas Nevada
Focus sun energy to melt salt. Completed in 2015
but mothballed in 2019

Curran Crawford of IESVIC will address
Wind Energy Opportunities on February 22nd

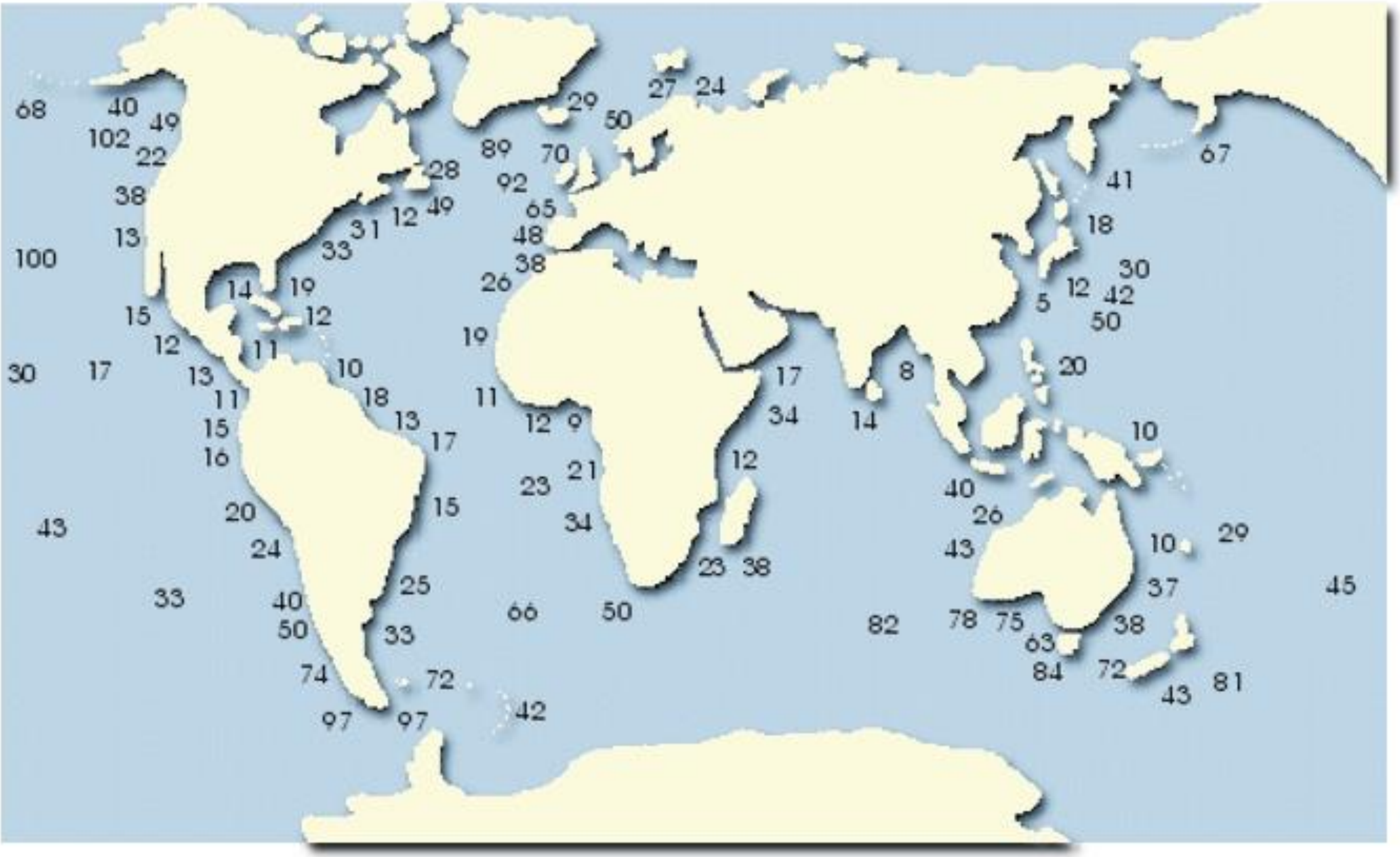







Brad Buckham of IESVIC will discuss Wave Supplied power on February 29th

Annual average wave power in kW per metre of crest width



PART 2 in MARCH

- Heather Matthews of BC Hydro will talk about hydro supplied power meeting BC's demand for electricity
- John Stewart of the Canadian Nuclear Association will fly in from Ottawa to introduce developments in nuclear energy
- Andrew Rowe of IESVic will talk about batteries and storage
- We will conclude with a panel discussion on March 28th with experts from UVic. moderated by Chris Kennedy, Chair of Civil Engineering.

We do not have a presenter on the two remaining renewable energy sources

Geothermal or Biomass/Biofuels

so I will say a few words now

Geothermal Summary

2 Types

- Electrical power generation from steam/binary is:
  - expensive,
  - unpredictable,
  - unreliable &
  - very site specific
  - EROEI <6

HIGH Geothermal gradient required

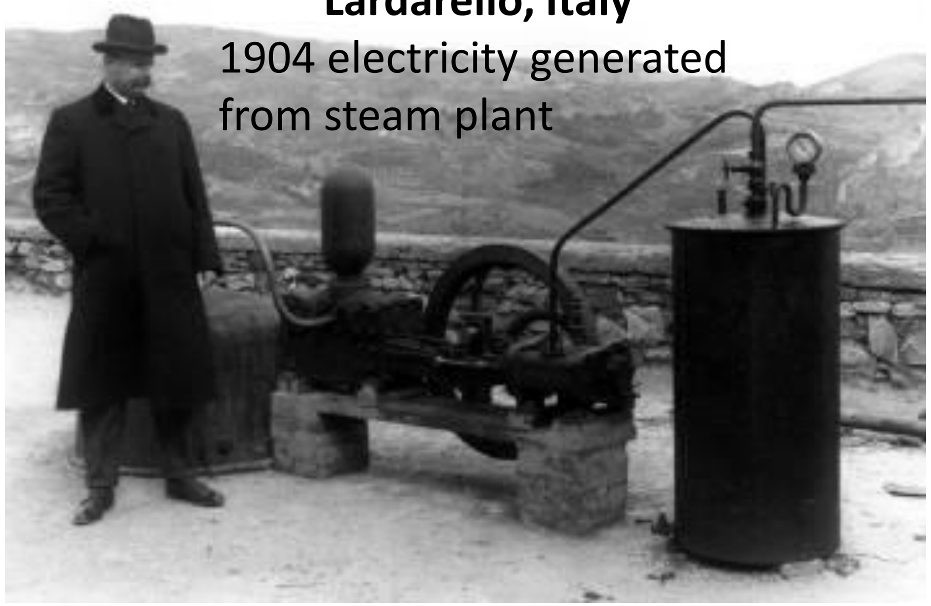
- "Ground-Source": does not produce electricity
  - Heat exchangers to extract heat from circulating warm water
  - Individual home vs community projects
  - EG: 3 projects
    - Finland
    - Idaho
    - Okotoks

NORMAL Geothermal gradient required

Geothermal Energy

Lardarello, Italy

1904 electricity generated from steam plant



- **Water hot enough to boil to produce steam & drive turbine to produce electricity**
- **3 high grade fields**
  - **Lardarello Italy**
    - **1st electricity 1904, 127 MWe by 1942: still operating**
  - **Geysers, California, dry steam**
    - **wells drilled by 1921, now installed capacity 1517 MW. 20+ plants**
  - **Wairakei, NZ**
    - **plant opened 1958**
- **Medium grade "deposits" water will boil but reservoir cools**
- **Reservoir depletes unpredictably over time declining in pressure and temperature**
- **Minerals precipitate and clog pipes**

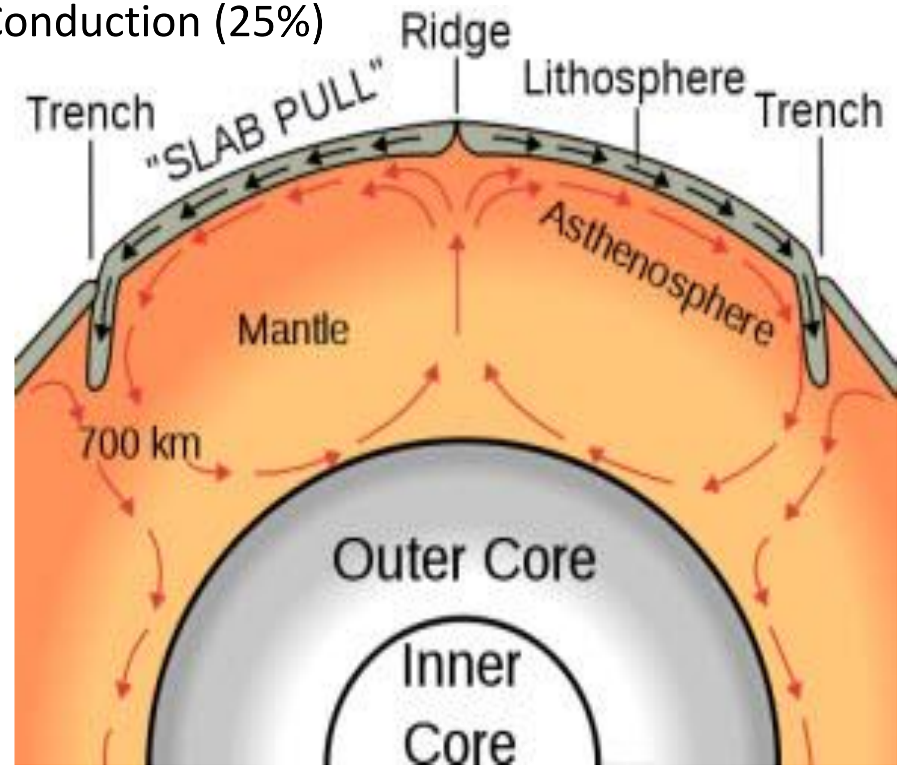
The total heat flow for the Earth to Atmosphere is
47 TW +/- 2TW
Equivalent to 0.09Wm^{-2} (90mWm^{-2}).

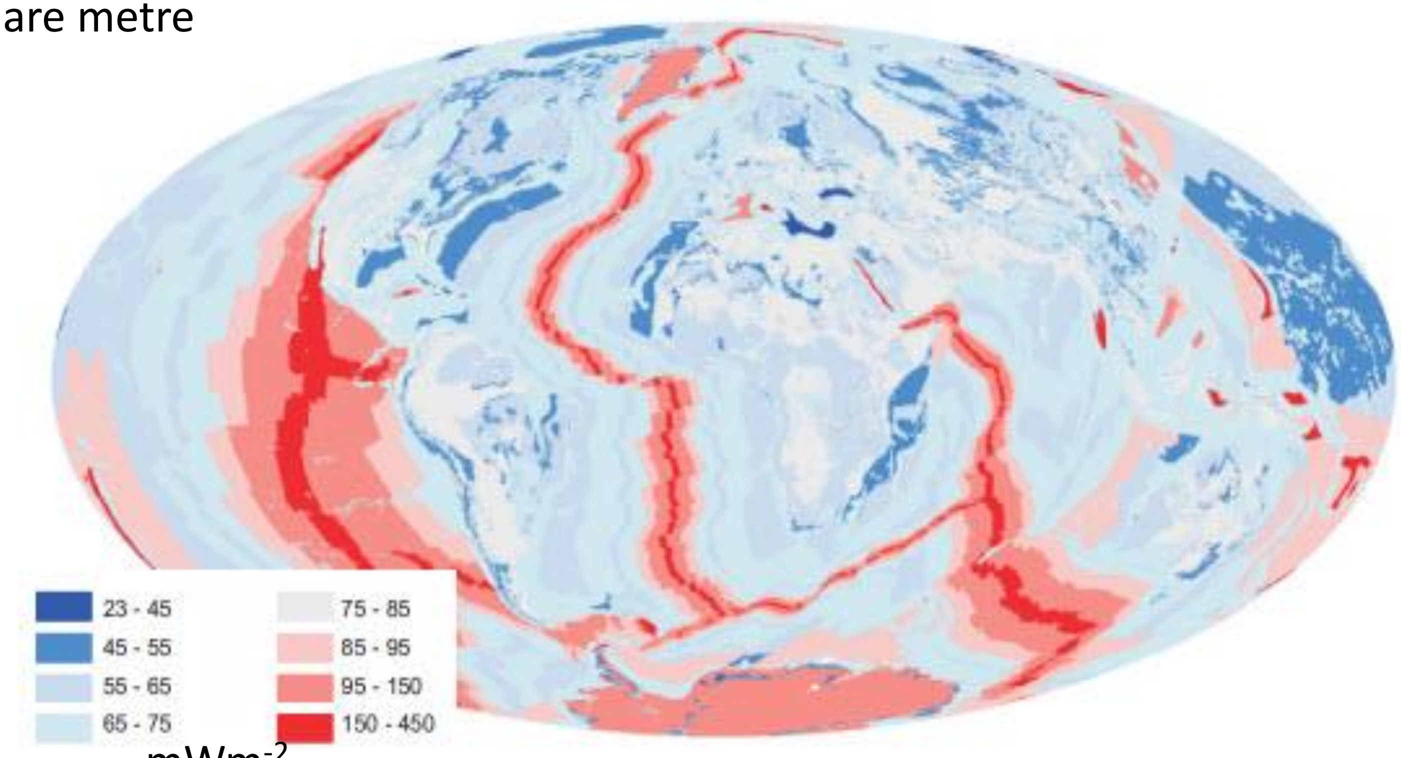
milliwatt per square metre

GEOTHERMAL ENERGY

Heat Flux

Energy released by
the cooling of planet earth by
Convection (75%)
Conduction (25%)





CONVECTION 75%

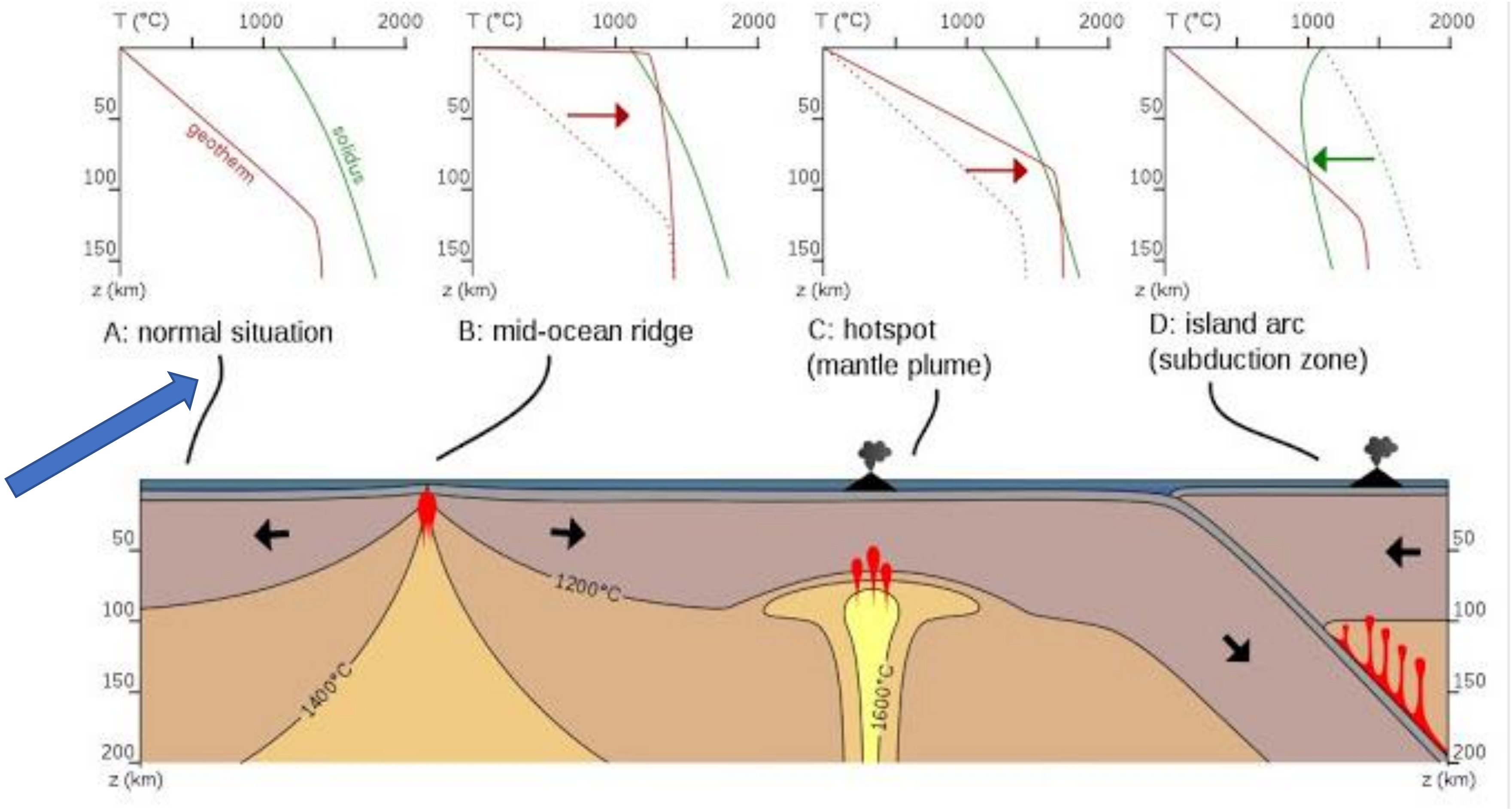
Ridges & Trenches 70%

Plumes or Hot Spots 5%

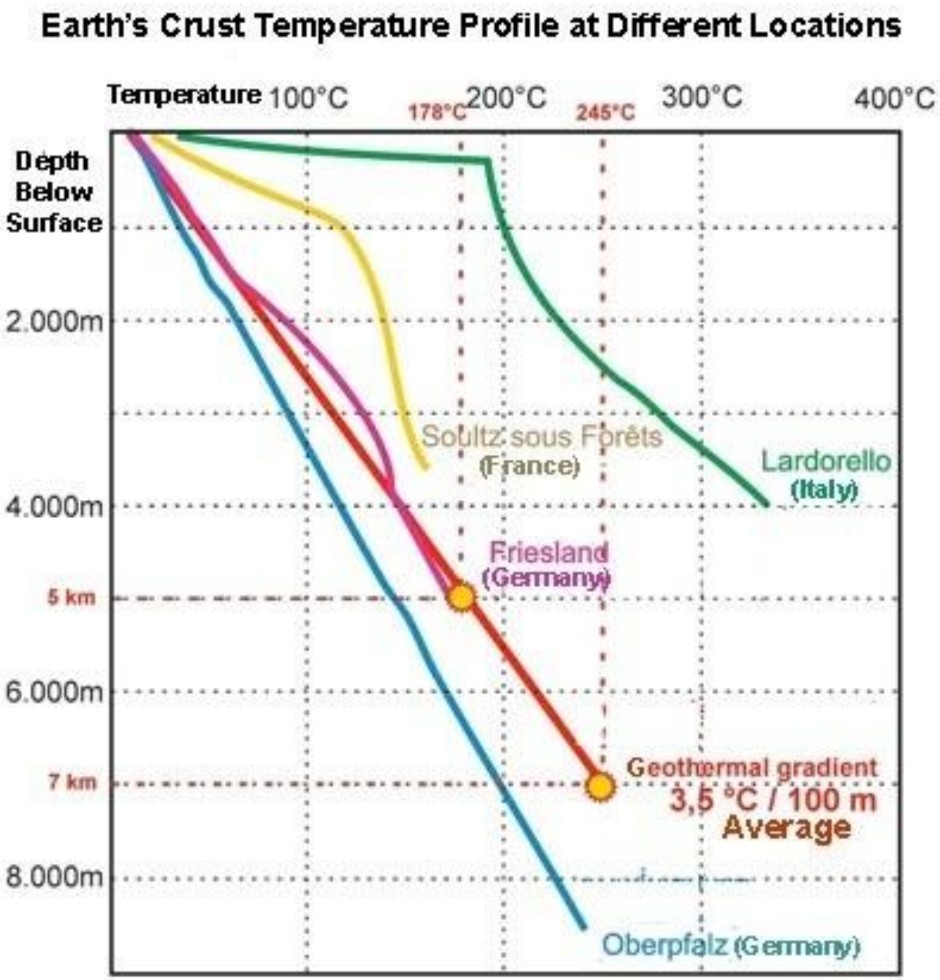
GEOTHERMAL GRADIENT

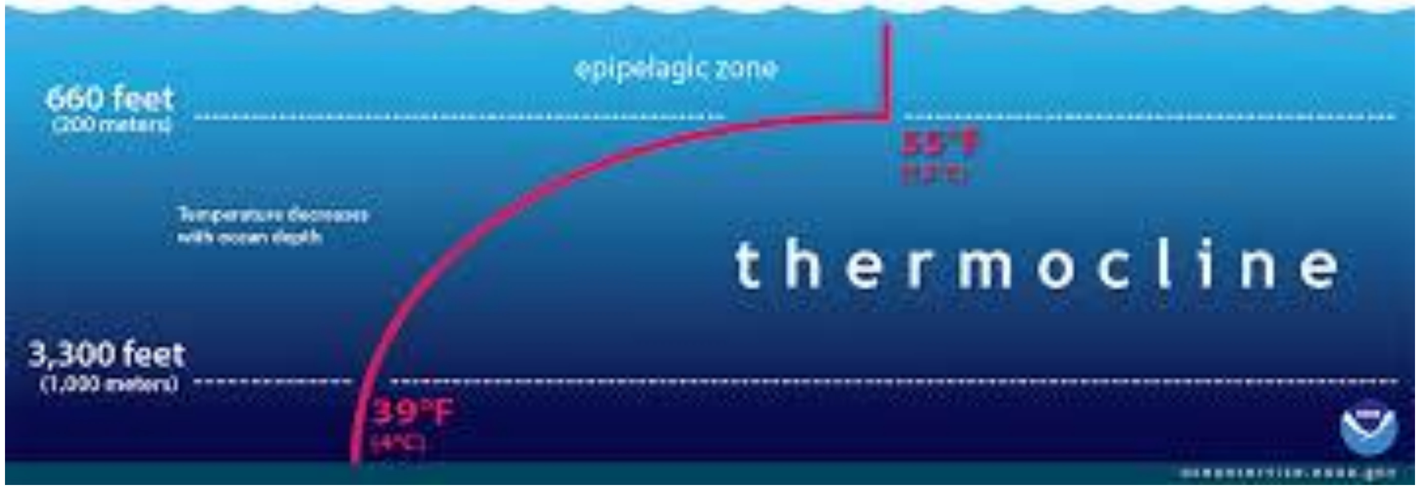
Geothermal gradient is the rate of increasing temperature with respect to increasing depth in the Earth's interior.

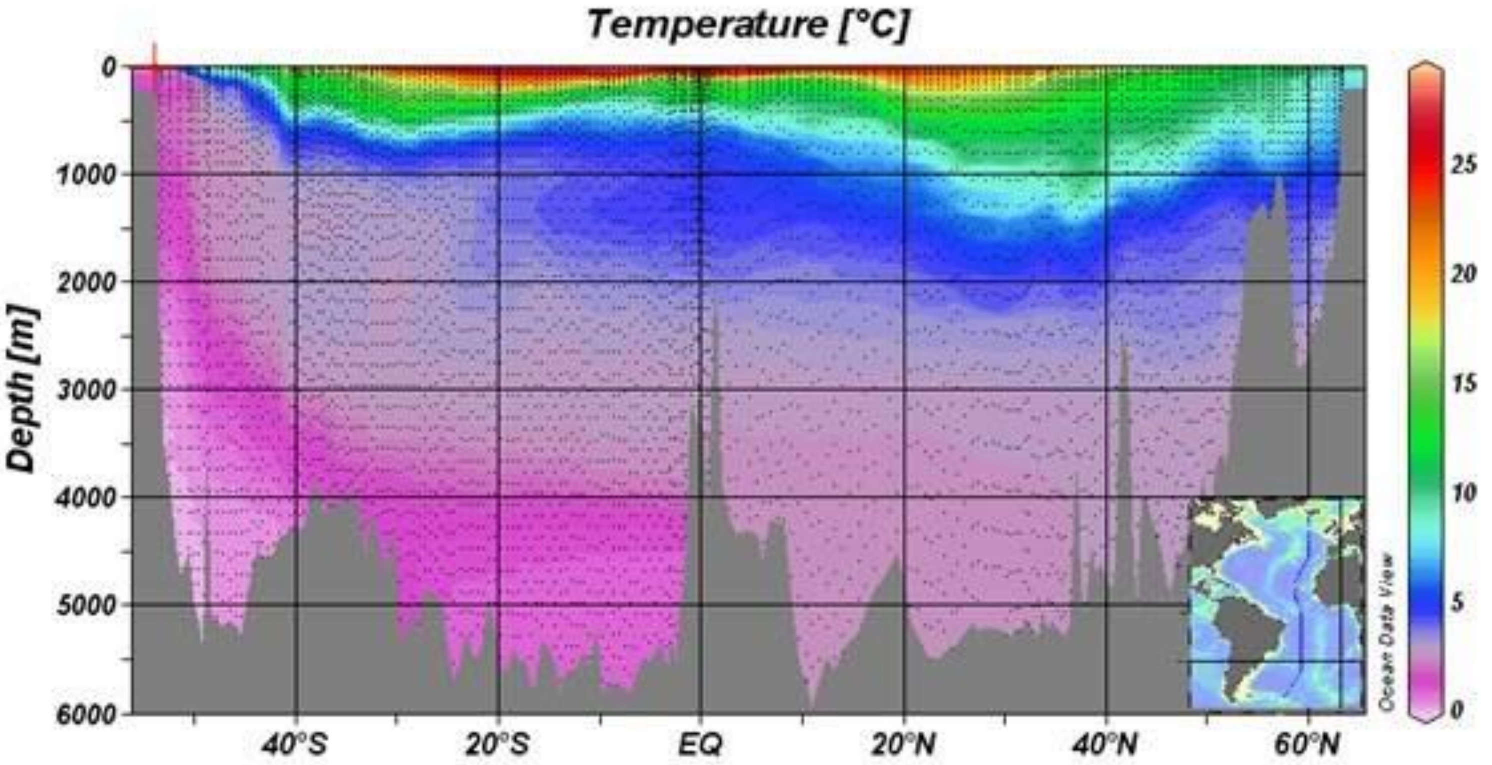
Away from tectonic plate boundaries, it is about **25 °C per km** of depth in most of the world.



http://www.geologyin.com/2014/12/geothermal-gradient.html#PL1vr6OIP1uqv3e3.99


Earth's Crust Temperature Profile at Different Locations
Temperature 100°C 200°C 300°C 400°C
178°C
245°C
Depth Below Surface
2.000m
4.000m
5 km
6.000m
7 km
8.000m
Soultz sous Forêts (France)
Lardorello (Italy)
Friesland (Germany)
Geothermal gradient 3,5 °C / 100 m Average
Oberpfalz (Germany)


epipelagic zone
660 feet (200 meters)
thermocline
3,300 feet (1,000 meters)
39°F (4°C)


Temperature [°C]
Depth [m]
0
1000
2000
3000
4000
5000
6000
40°S
20°S
EQ
20°N
40°N
60°N
25
20
15
10
5
0
Ocean Data View

Installed Geothermal Electrical Capacity

(source: various)

Country	Capacity (MW) 2007	Capacity (MW) 2013	Capacity (MW) 2018	Share of national generation(%)
USA	2687	3389	3591	0.3
Philippines	1969.7	1894	1868	27.0
Indonesia	992	1333	1948	3.7
Mexico	953	980	951	3.0
	471.6	895	1005	14.5
	810.5	901	944	1.5
	421.2	664	755	30.0
Kenya	128.8	215	676	51.0
Japan	535.2	537	542	0.1
Turkey	38	163	1200	0.3
Costa Rica	162.5	208		14.0
El Salvador	204.4	204		25.0
Nicaragua	79	97		9.9
Total	9,731.9	11,765	14,369	–

Current capacity is insignificant
14.3 GW geothermal vs 4700 GW fossil fuel

IPCC capacity expectations 35 GW to 2000 GW

Currently, 6.9% of global potential tapped

IGA

Geothermal
Energy
Advocacy
Group

Members

Australia,
France,
Germany,
Iceland,
Italy,
Japan,
Mexico,
New Zealand,
Norway,
Republic of Korea,
Switzerland,
United Kingdom
United States
European Commission

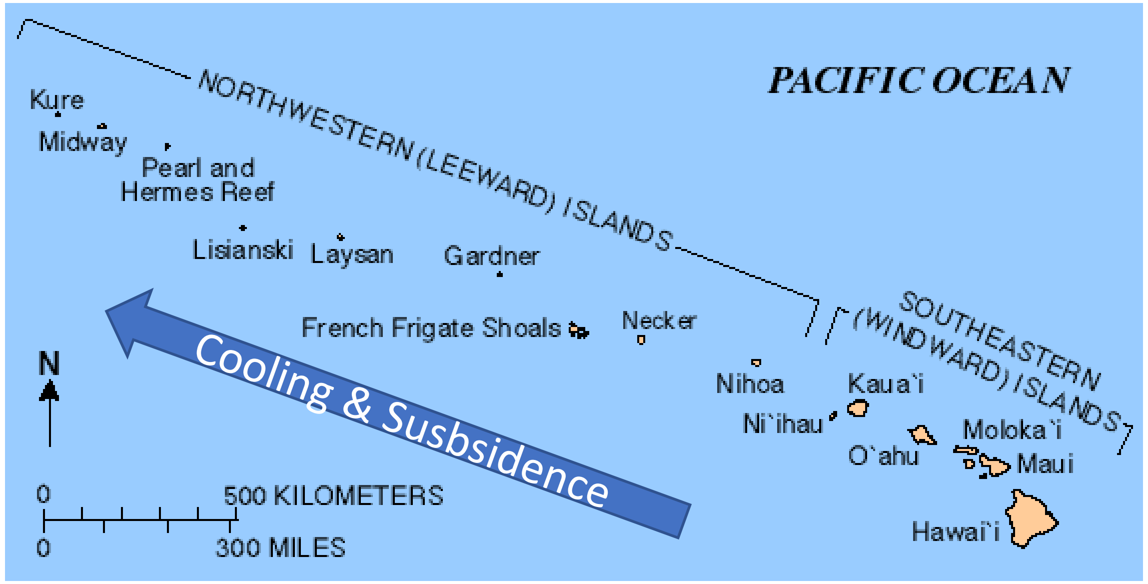
IEA GEOTHERMAL ADVOCACY GROUP

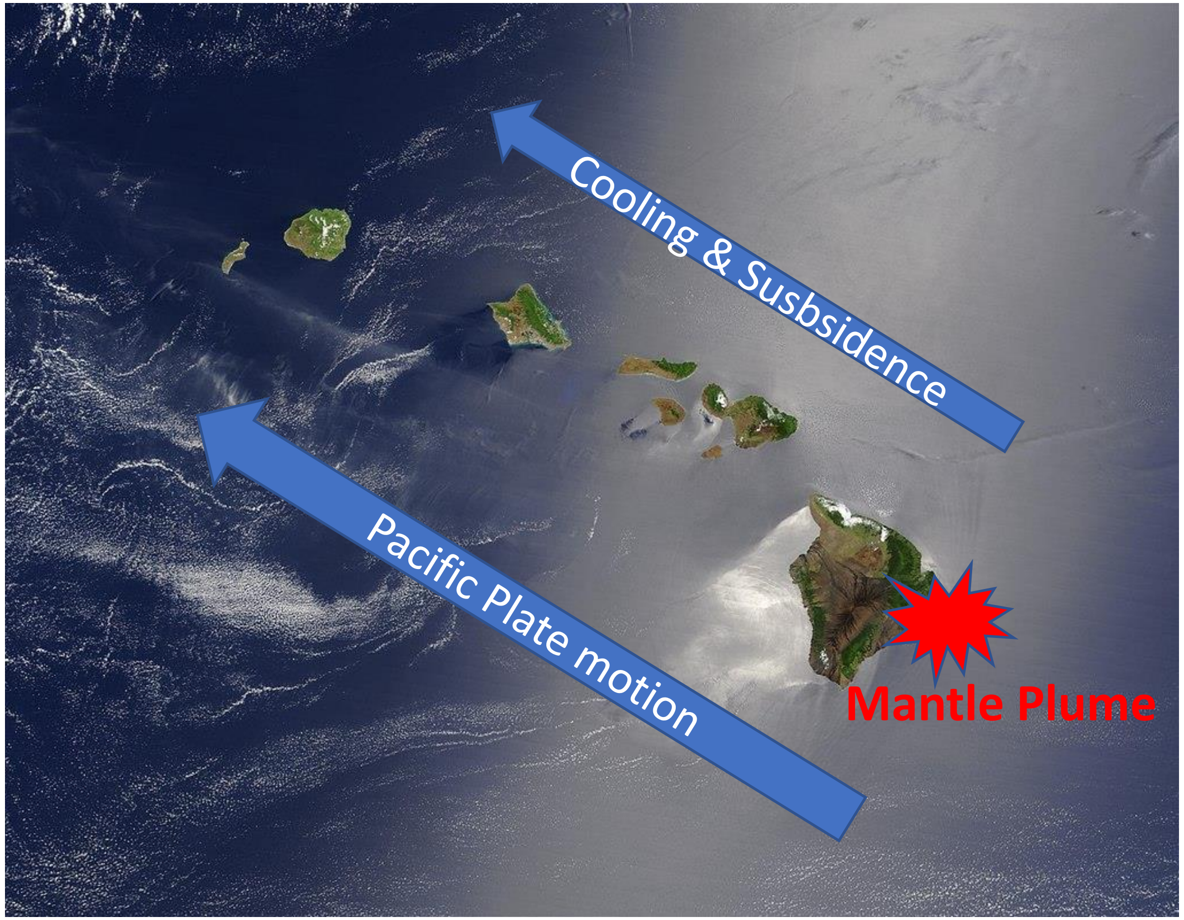
IEA Geothermal

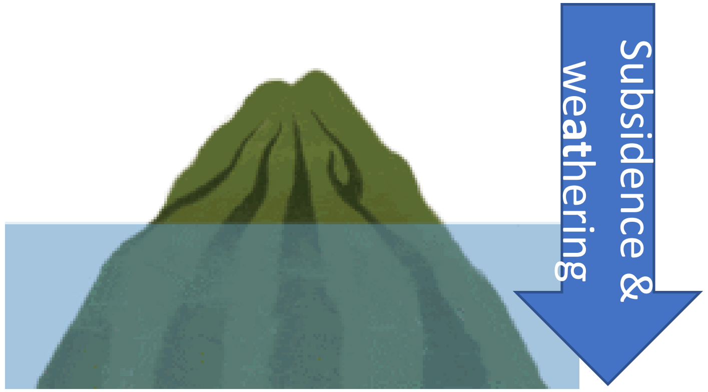
Executive Committee Secretary GNS Science
Wairakei Research Centre
Private Bag 2000, Taupo, New Zealand
Ph: +64-7-374 8211
E-mail: iea-giasec@gns.cri.nz

Sponsors:
Ormat Technologies and the
Spanish Geothermal Technology Platform (Geoplat).

HAWAIIAN HOTSPOT

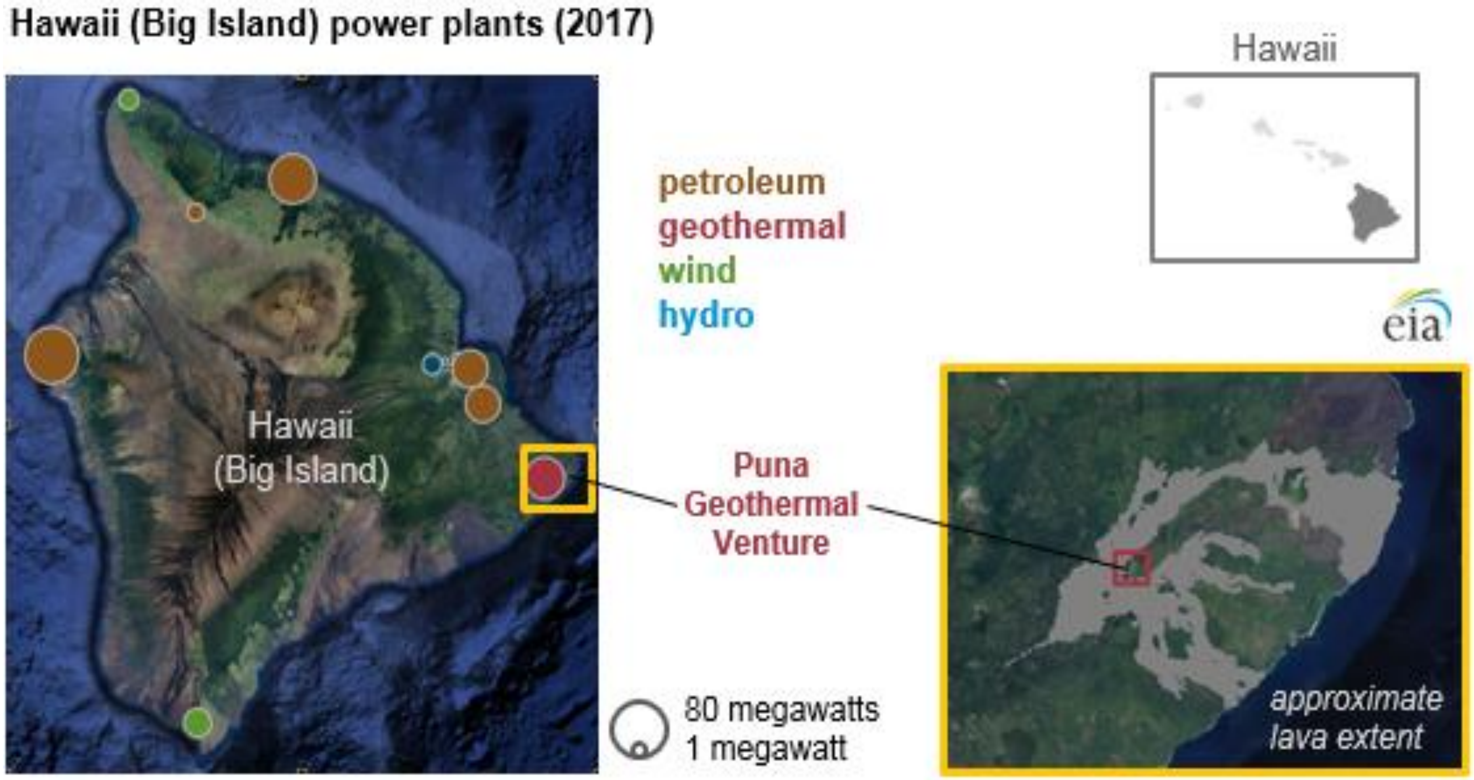




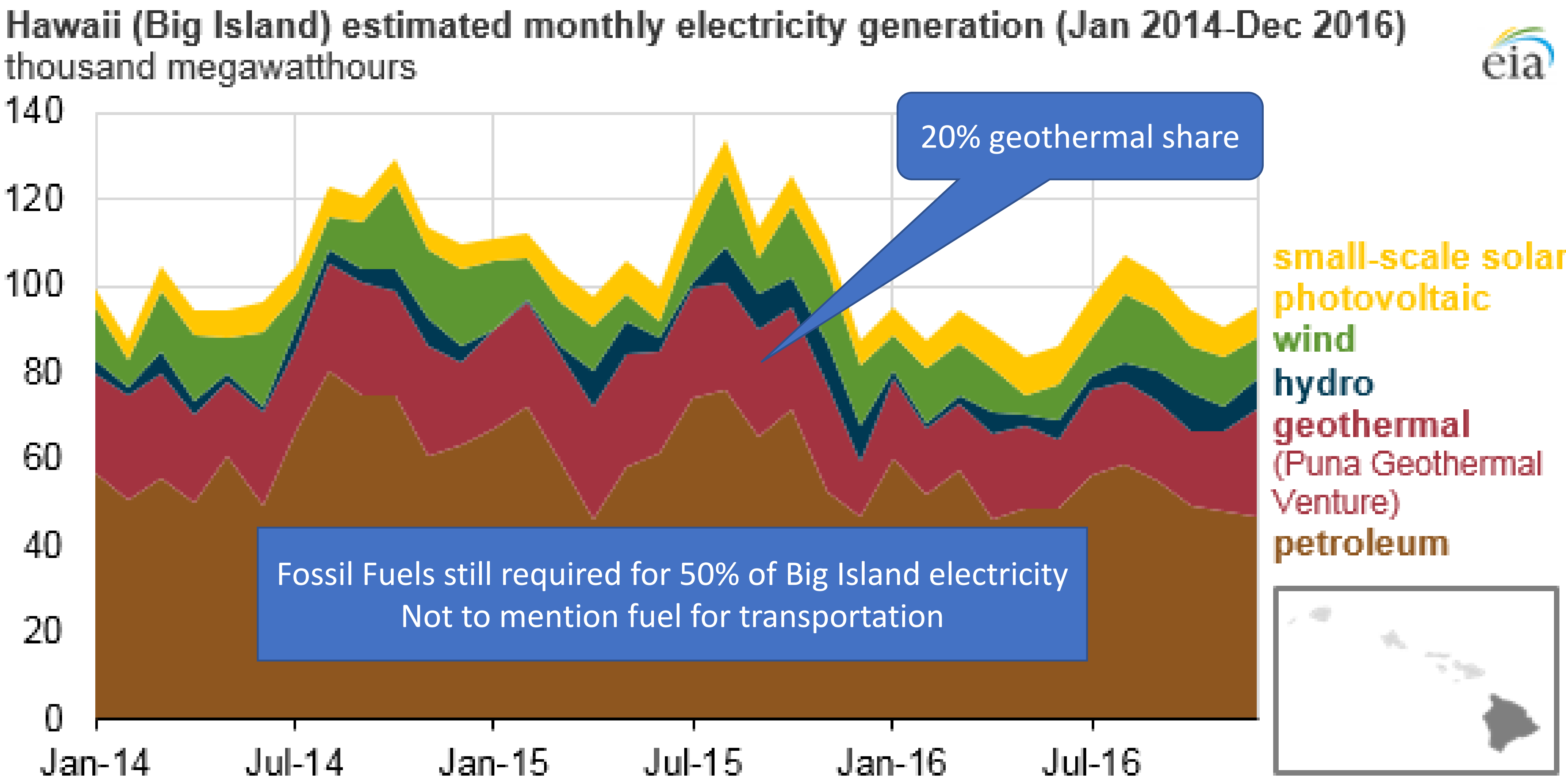


Puna Geothermal Ventures (subsidiary of Ormat), Hawaii
38 MW electrical plant – opened 1993

- Plans to replace ten older units with two new ones.
- Increase the capacity of the plant by 8 MW to total of 46 MW,
- Currently shut down since the volcanic eruption.
- Full capacity expected by the end of the 2nd Qtr 2020.
- 11 wells 2 – 3,000 m deep

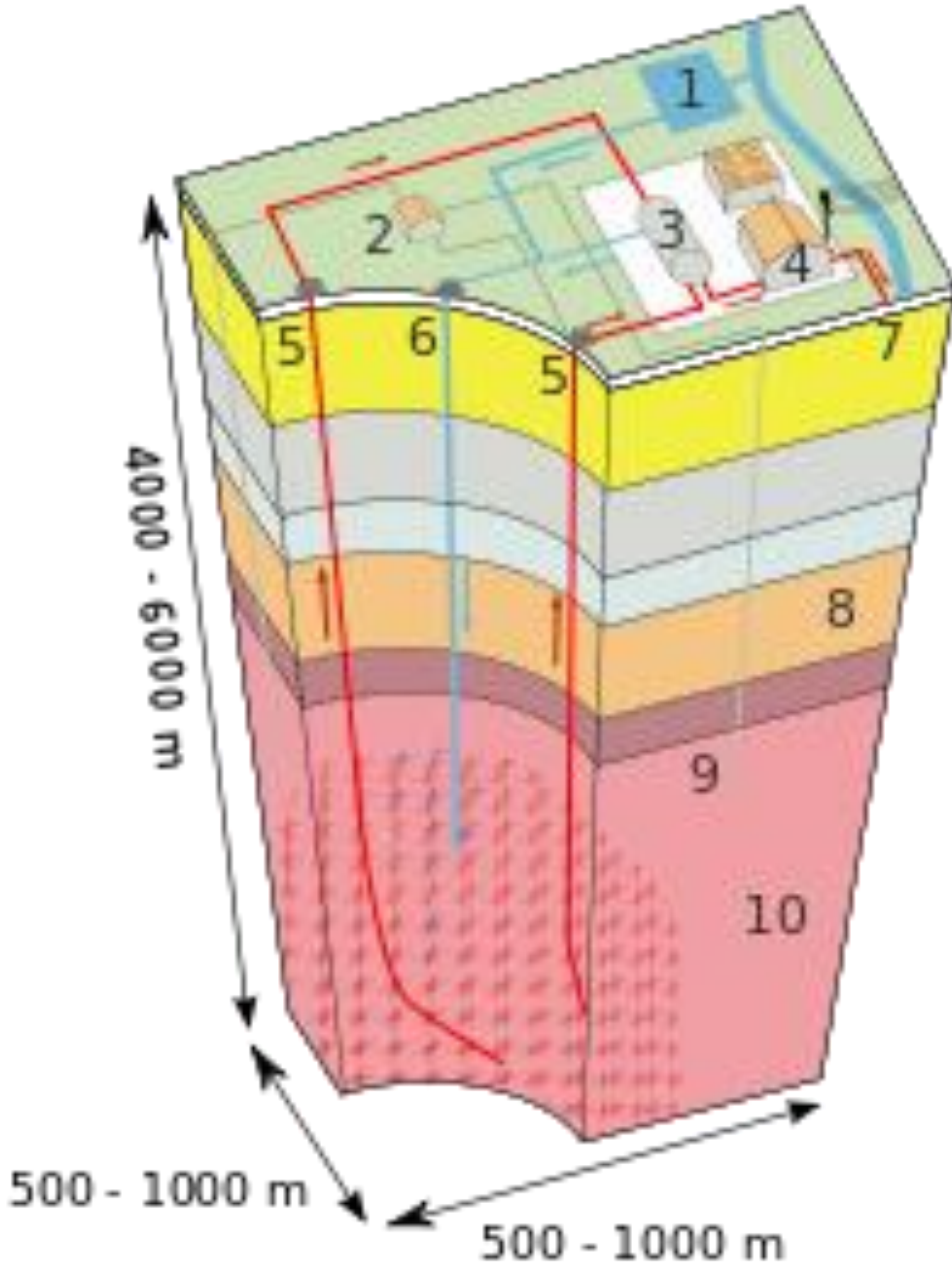


Source of Electrical Power Hawaii – Big island



Binary Geothermal

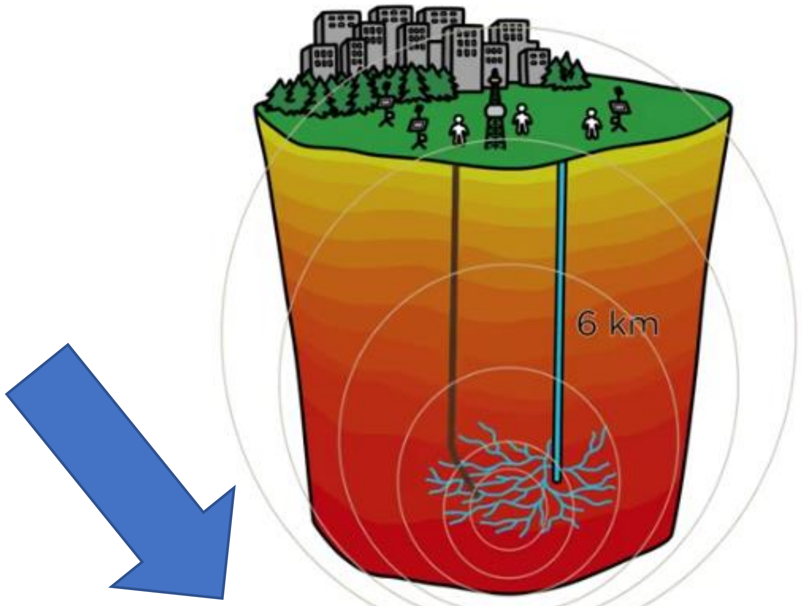
- Water "boils" fluid with lower boiling point, drives turbine
- Isobutane boils at 11^{o}F
- Mammoth Lake plant, California
- Produces equivalent of 3 million Bbls of oil over its life
- Equivalent of the amount of oil US imports in a morning!
- 15 MW Binary Plant (by Ormat or Mitsubishi) requires 75^{o}C (examples in Nevada, USA)



GROUND SOURCE HEAT
Finnish energy company, St1 Otaniemi, Espoo, Finland

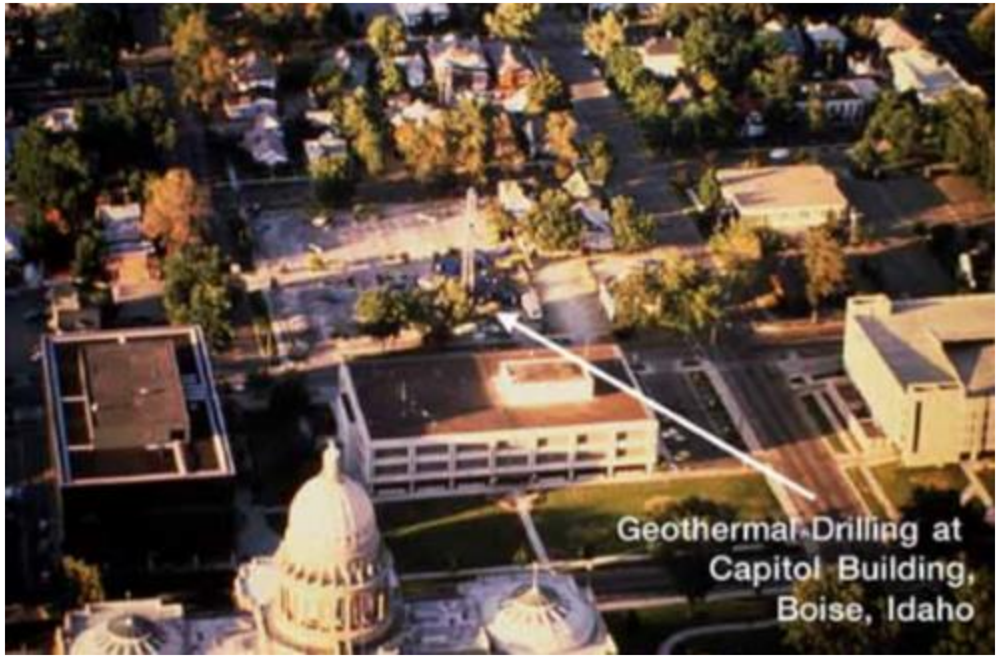
https://www.st1.eu/

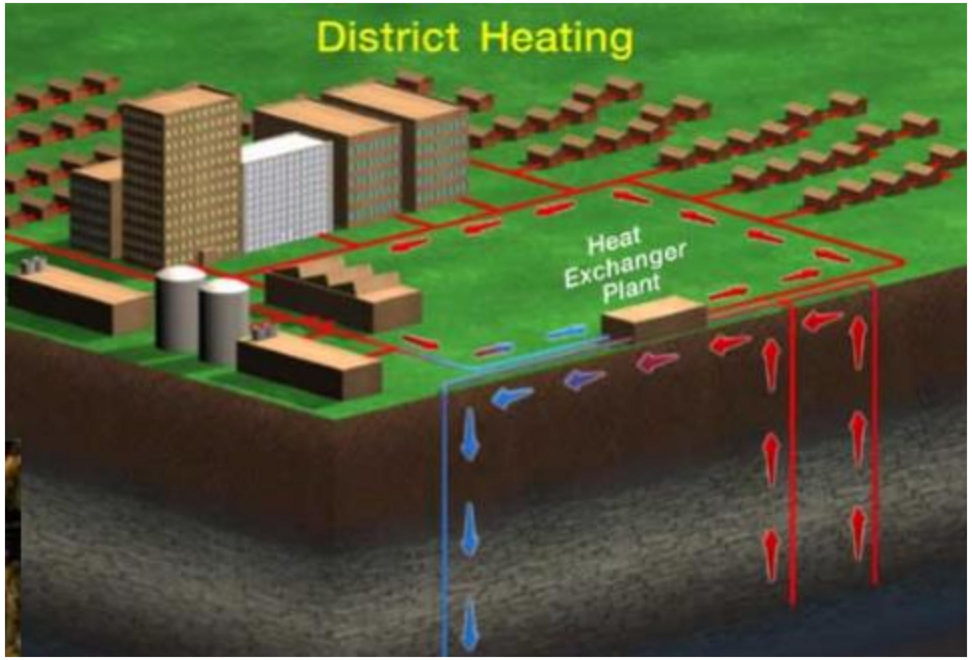
- The plant will be the world's deepest geothermal heat production plant, which will produce heat completely without emissions.
- The first 6.4 kilometre-deep geothermal heat well was completed last year.
- The second well drilled to a depth of 3.3 kilometres is awaiting the results of water stimulation modelling. The drilling plan for the remaining part of the second well has been determined according to modelling and the actual drilling will be completed in 2020,



District Heat: Not Electricity generation

Ground Source District Heating:
First in USA
Boise Idaho Capitol Building





Drake Landing, Okotoks, Alberta

The first of its kind in North America, DLSC is heated by a district system designed to **store abundant solar energy underground during the summer months and distribute the energy to each home for space heating needs during winter months**. The system is unprecedented in the World, fulfilling 95% of each home's space heating requirements from solar energy and resulting in less dependency on limited fossil fuels.

Is BIOMASS part of the solution?

- **3 products, burn for heat, methane from decay, liquids biofuels**
- **Sinks or Stores: Sequestering carbon: planting – harvesting vs preservation**
- **Sources include – wood, animal waste, seaweed, peat, agricultural crops & waste, garbage**
- **Deforestation in Bangladesh & Haiti where trees used for fuel**
- **India burns 200 million tonnes cow dung per year**
- **2.4 billion rely on biomass for cooking and heating, with an expected increase to 2.6 billion by 2030.**
- **Biomass provides 13% of world energy needs – how sustainable is this vis a vis wood supply in areas where it is used and pollution from inefficient burning**

BIOFUELS: Ethanol C_2H_6O & Biodiesel

FEEDSTOCK:

Liquids can be produced from any organic matter:

coal, gas, grain (corn), sugar, soy beans, animal waste

Fischer-Tropsch a chemical refining process developed in 1926 in Germany: other related distillation – refining processes

ETHANOL (Corn)

- Ethanol EROEI=0.84 – 1.65. 1 acre of corn = 328 gals ethanol (subtract: tractor fuel, fertilizer, distillation fuel use).
- Ethanol contains approx. 34% less energy per unit volume than gasoline, and therefore in theory, burning pure ethanol (80,000 BTUs per gallon) in a vehicle reduces miles per US gallon 34%, given the same fuel economy, compared to burning pure gasoline (124,000 BTUs per gallon)
- Would require all continental US to grow the corn to meet the needs of US autos.
- Unlike gasoline, pure ethanol is nontoxic and biodegradable, and it quickly breaks down into harmless substances if spilled.
- Chemical denaturants are added to ethanol to make fuel ethanol, and many of the denaturants are toxic (pentanes plus)

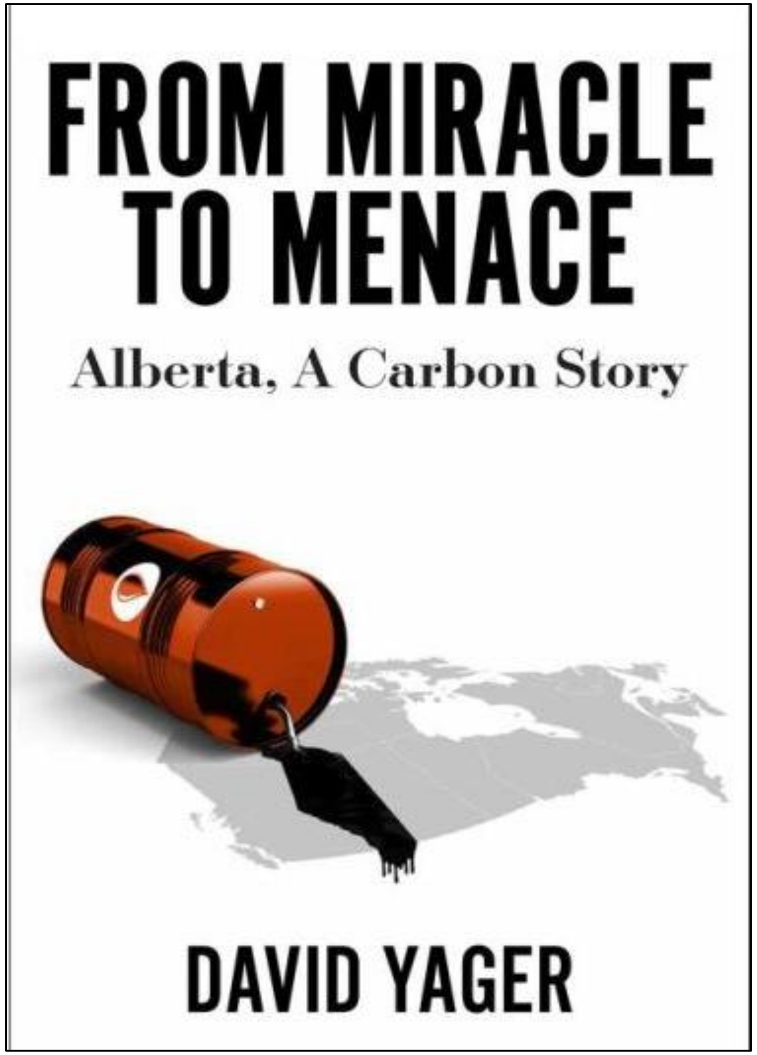
BIODIESEL (Soy & Canola)

- Biodiesel is produced from soy beans, canola, animal fats and palm tree oil
- on combustion produces more NOX than petroleum diesel
- World's major consumer of SOY beans is China (as feedstock for animals – pigs): Liquids are a bi-product
- Does replacing petroleum-based fuel with biodiesel cut greenhouse emissions?

CONTROVERSIAL

  - Land clearing
  - Significant subsidies provided to farmers
  - At the end of the day, combustion of any liquid biofuel produces CO_2.
  - Planting crops (Soy, Canola, Corn) will temporarily sequester CO_2
  - Are we any further ahead?

Alberta's massive carbon resources have supported Alberta and Canada financially

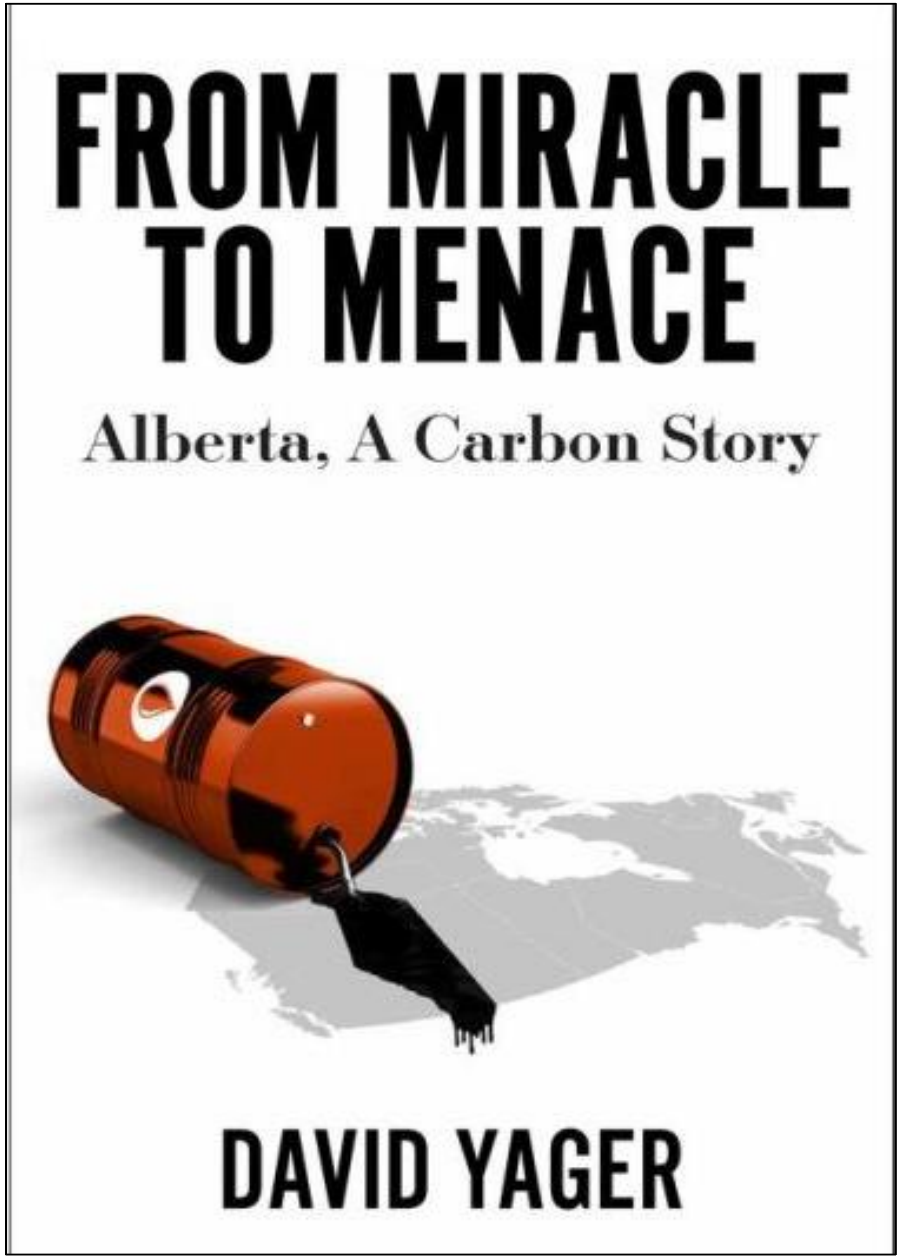


Friesen Press, 2019

"Decarbonizing the industrial and energy complex will require the largest financial disruption in history, affecting everyone and everything."

Last 8 years NET TRANSFERS

Alberta has paid	$180 billion: the most of all provinces
Ontario has paid	$45 billion with 3.5 X population of Alberta
BC has paid	$18 billion
Quebec received	$476 billion,
Nova Scotia received	$306 billion,
NB received	$203 billion
Manitoba received	$175 billion,
Newf & Lab received	$172 billion



Friesen Press, 2019

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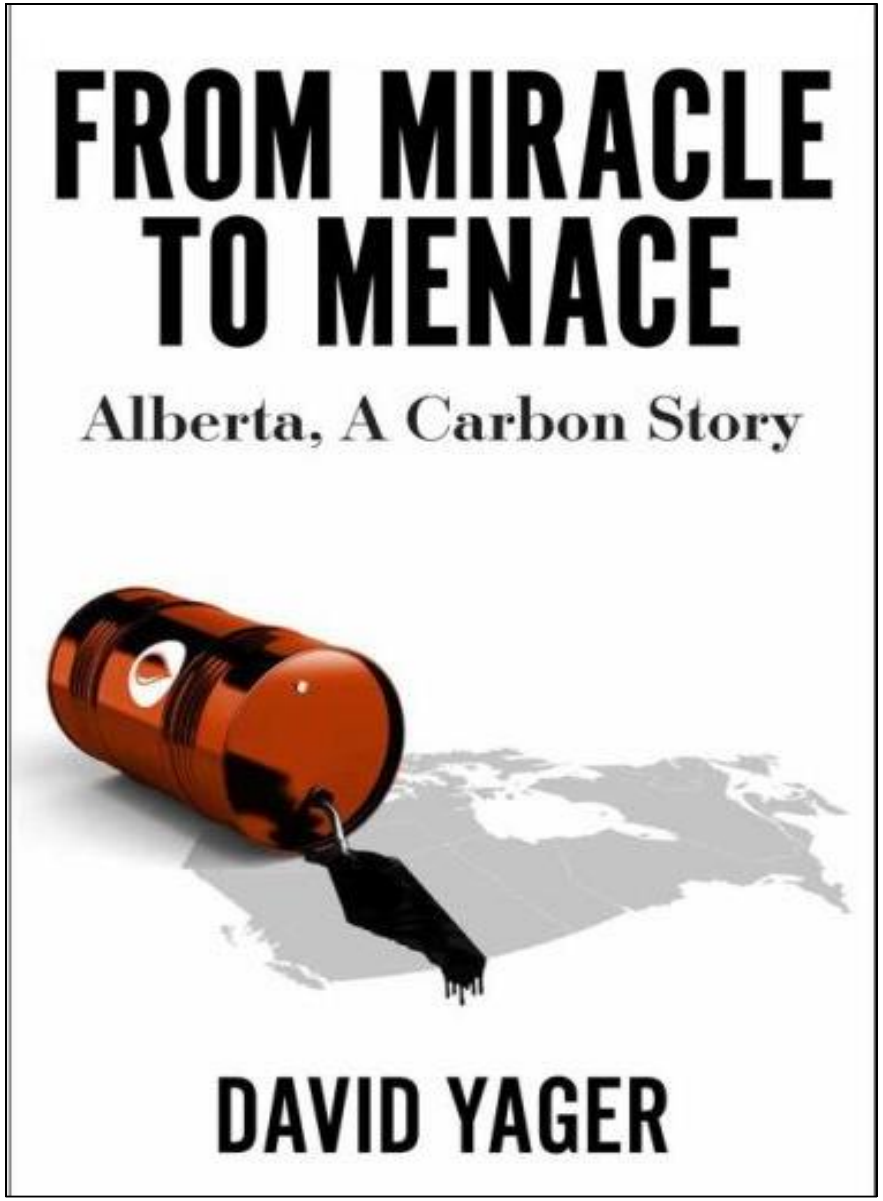
GDP Contribution (Stats Can 2017)

O & G Extraction	**$101 billion**
Mining	$22.2 billion
Vehicle parts	$8.8 billion
Vehicle manufacturing	$6.5 billion
Aerospace	$7.6 billion
Pulp Paper	$4.7 billion

Direct Jobs CERI 2022 est.

650,000 providing $40 billion in taxes



Friesen Press, 2019

Alberta's Industrial (petrochemical) and Energy Complex – Carbon-based Products

- Alberta creates 47% of Canada's chemicals (Chem. Ind. Assoc. Can)
- 45,000 direct and indirect jobs
- Exports valued at $8.4 billion in 2017

A refined barrel of oil yields

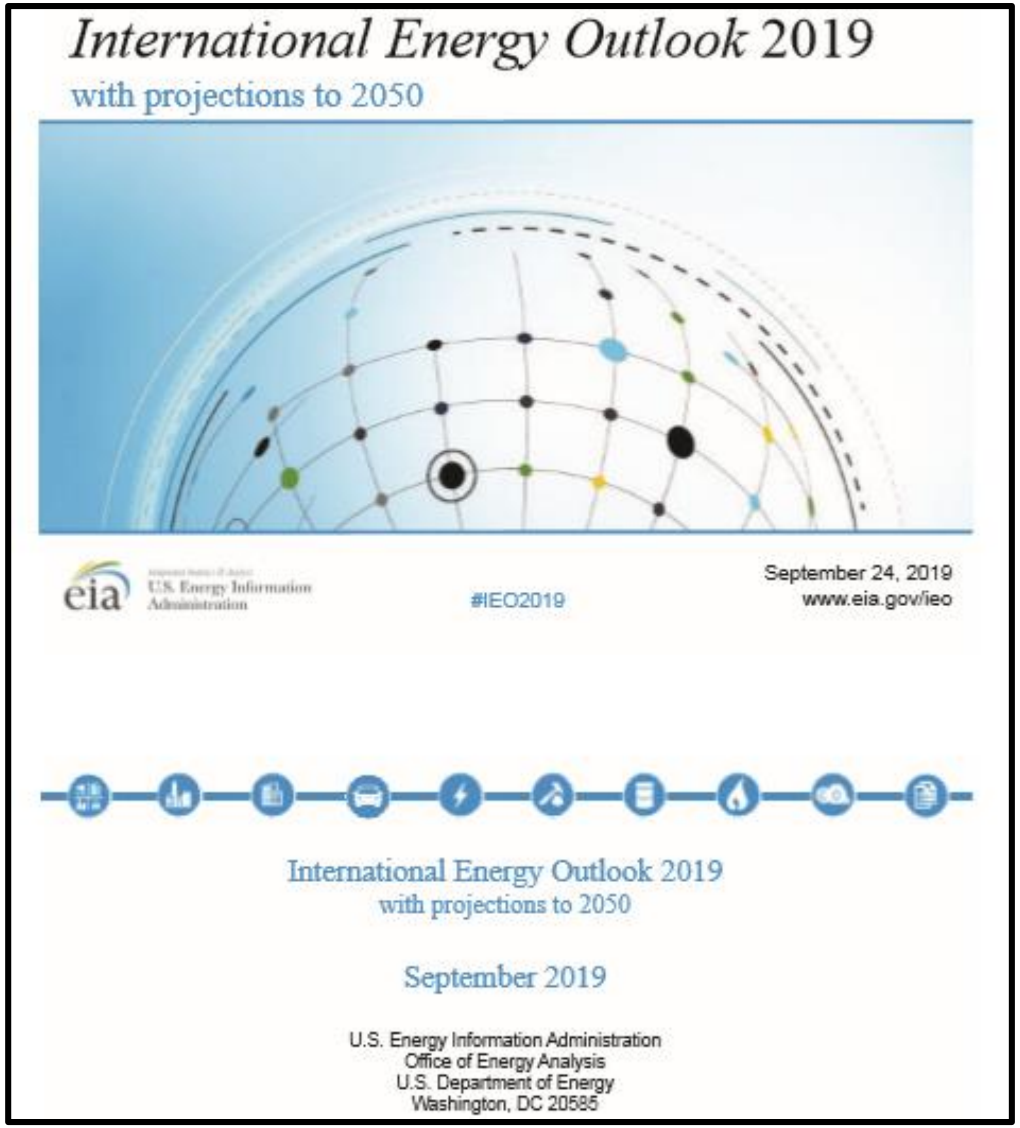
20 gals gasoline
11 gals diesel
4 gals jet fuel
2 gals bunker fuel
6 gals asphalt, lubricant, waxes
petrochemical feedstock + natural gas liquids

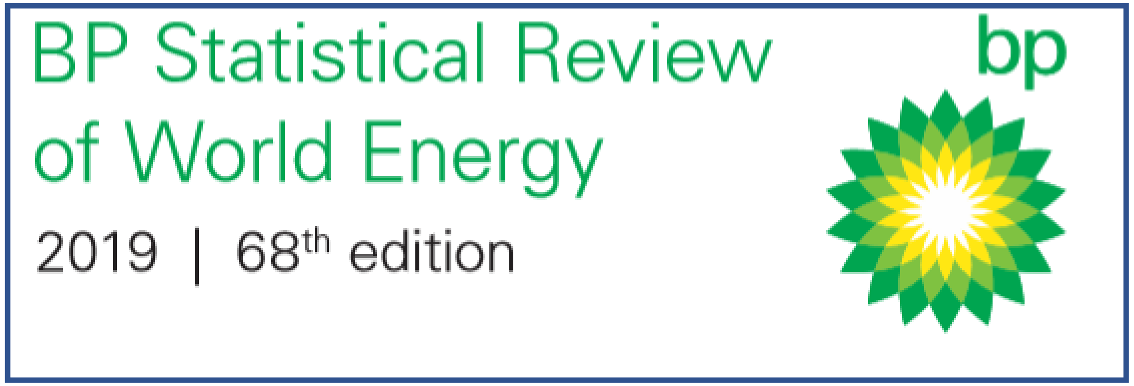
Fabrics: nylon, rayon, polyester, Orlon, Kevlar, carbon fibre, "rubber tires"
Ammonia from NG: fertilizer, explosives, mineral processing
Sulphur from NG: fertilizer, acid, cellulose (paper/pulp)
Polyethylene and plastics:
Pigments, pharmaceuticals/cosmetics

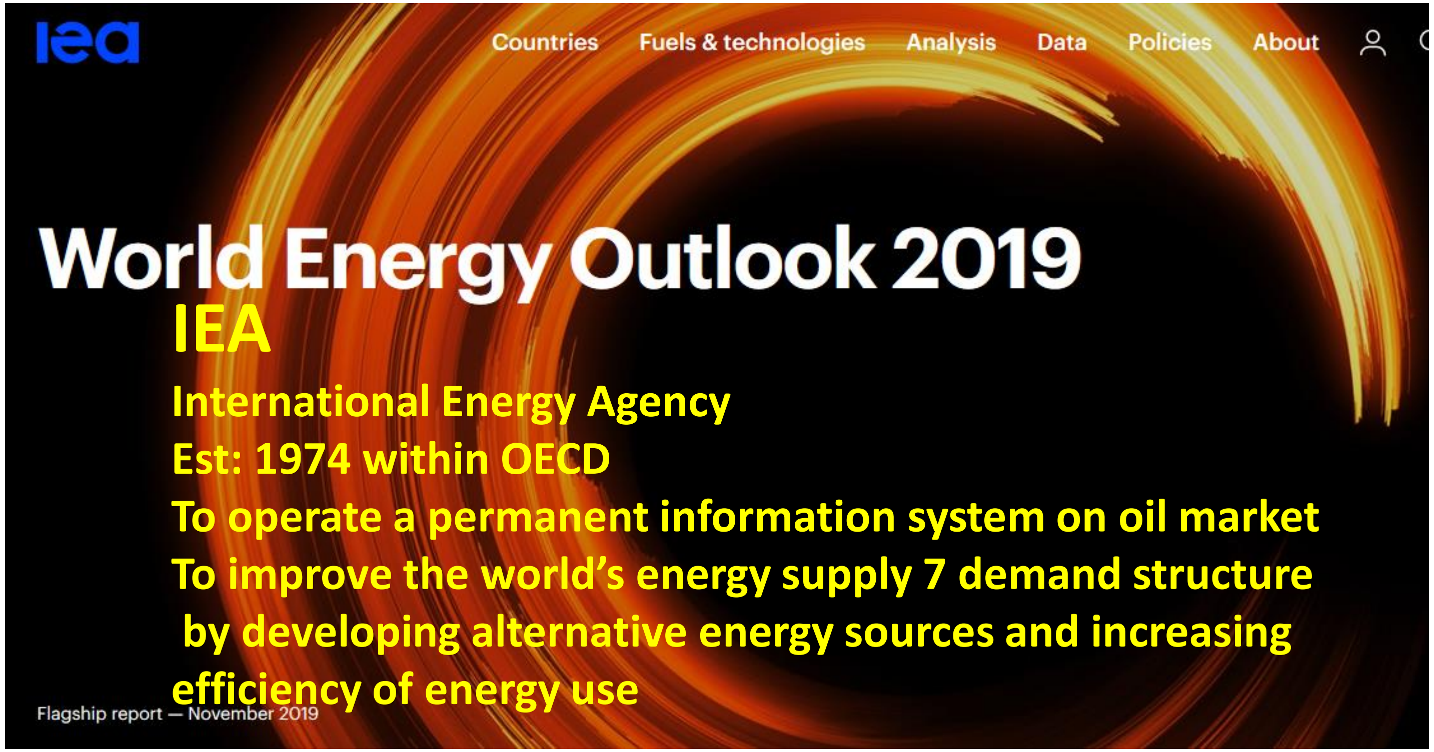
Forecasting and Data Sources

IPCC	Intergovernmental Panel on Climate Change (UN)
	Paris Climate Accord 2015
	33 climate conferences 6 major agreements. Eg. Kyoto, Copenhagen, Paris
EIA	Energy Information Administration (US)
IEA	International Energy Agency (OECD) 38 countries
IRENA	International Renewable Energy Agency
BP	Worldwide annual statistics on energy consumption and production
SHELL	Worldwide independent forecaster and modeler of consumption patterns

Sources of Data: IEA, EIA, BP







IEA

International Energy Agency

Est: 1974 within OECD

To operate a permanent information system on oil market

To improve the world's energy supply 7 demand structure by developing alternative energy sources and increasing efficiency of energy use

Conclusion

At a time when society is increasing its demands for an accelerated transition to a low carbon energy system, the energy data for 2018 paint a worrying picture, with both energy demand and carbon emissions growing at the fastest rates seen for years.

As I explained, in a statistical sense, it's possible to explain this acceleration in terms of a combination of weather-related effects and an unwinding of cyclical movements in China's pattern of growth. What is less clear is how much comfort we can take from this explanation.

What does seem fairly clear is that the underlying picture is one in which the actual pace of progress is falling well short of the accelerated transition envisaged by the Paris climate goals.

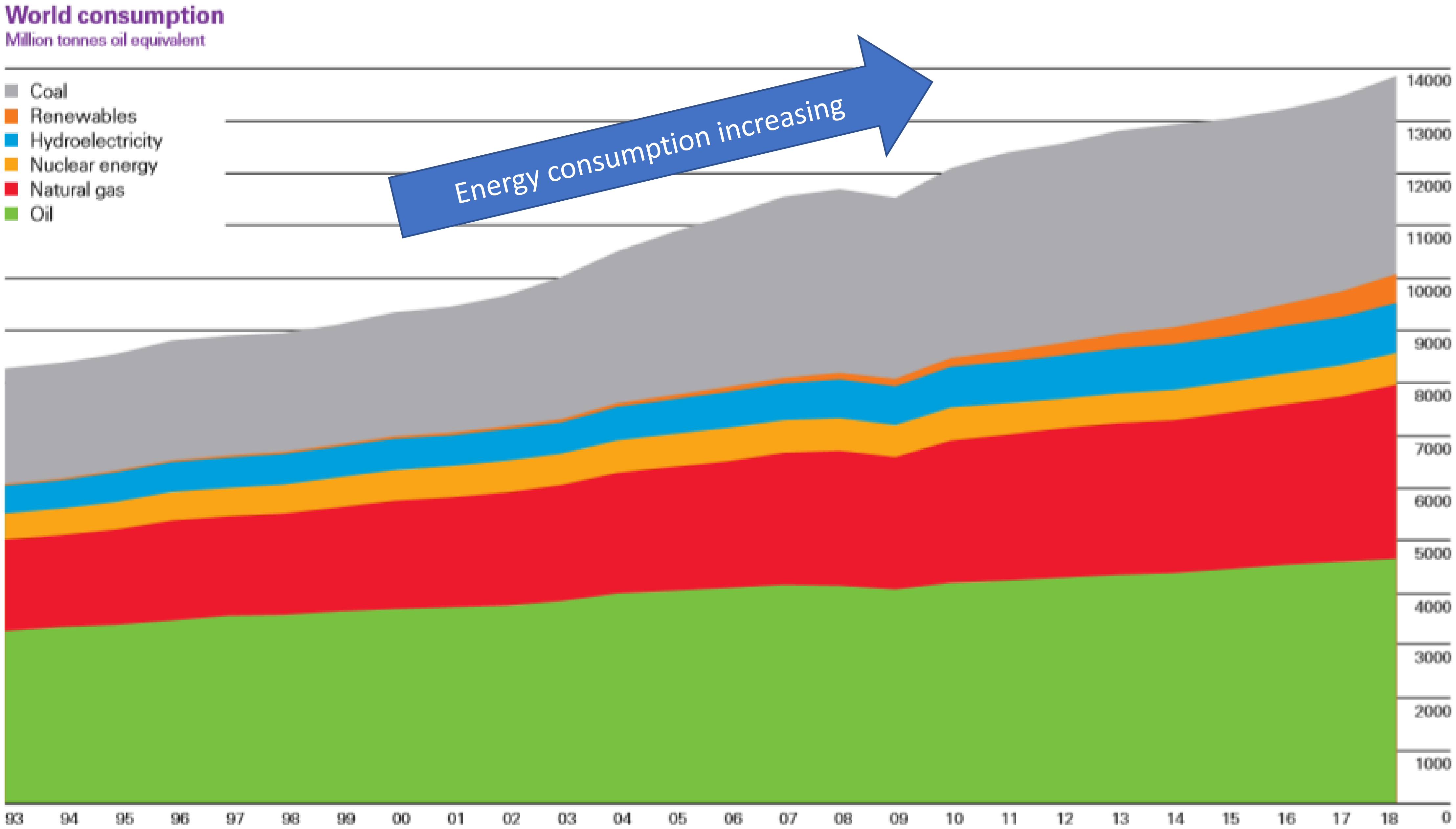
Last year's developments sound yet another warning alarm that the world is on an unsustainable path.

Spencer Dale

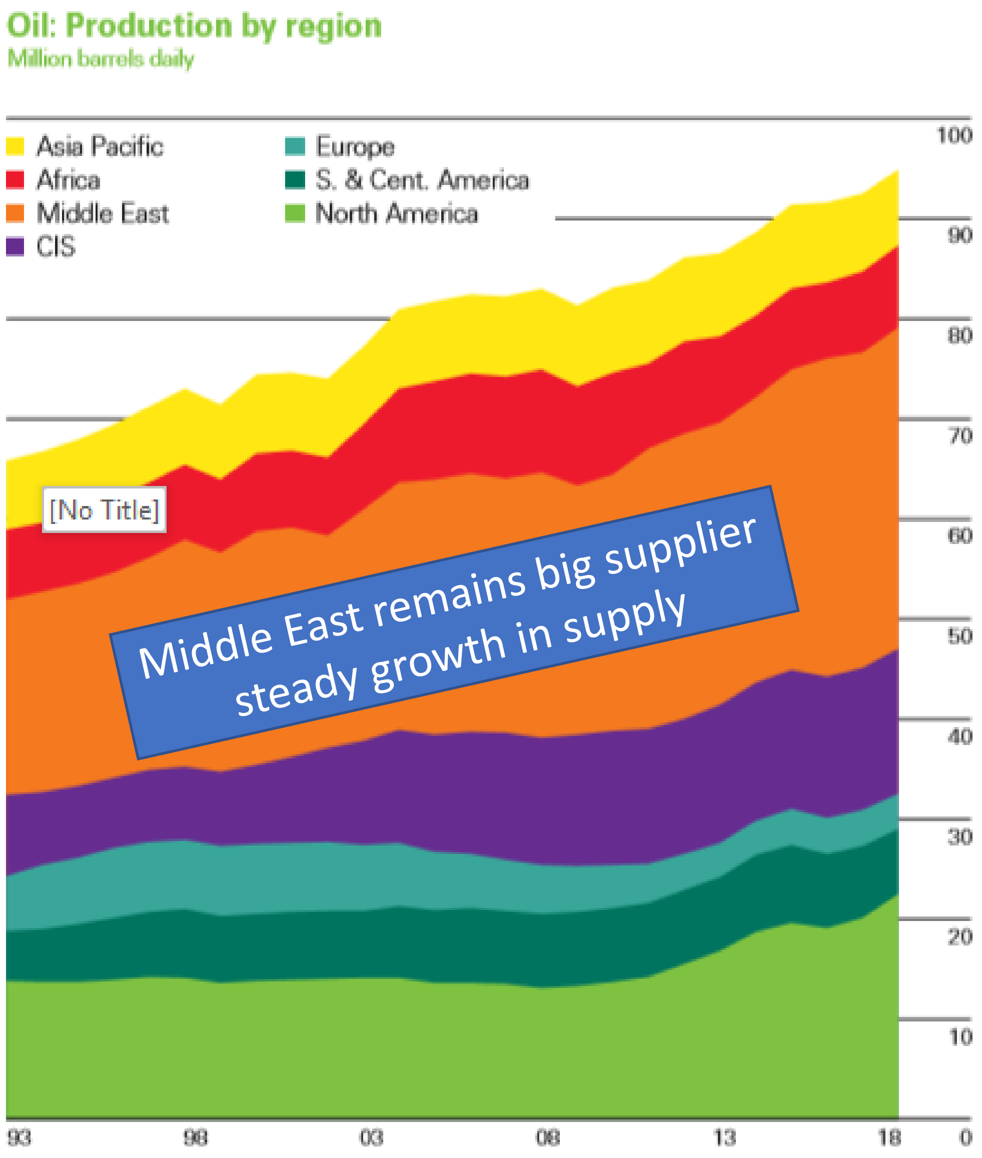
BP Statistical Review of World Energy

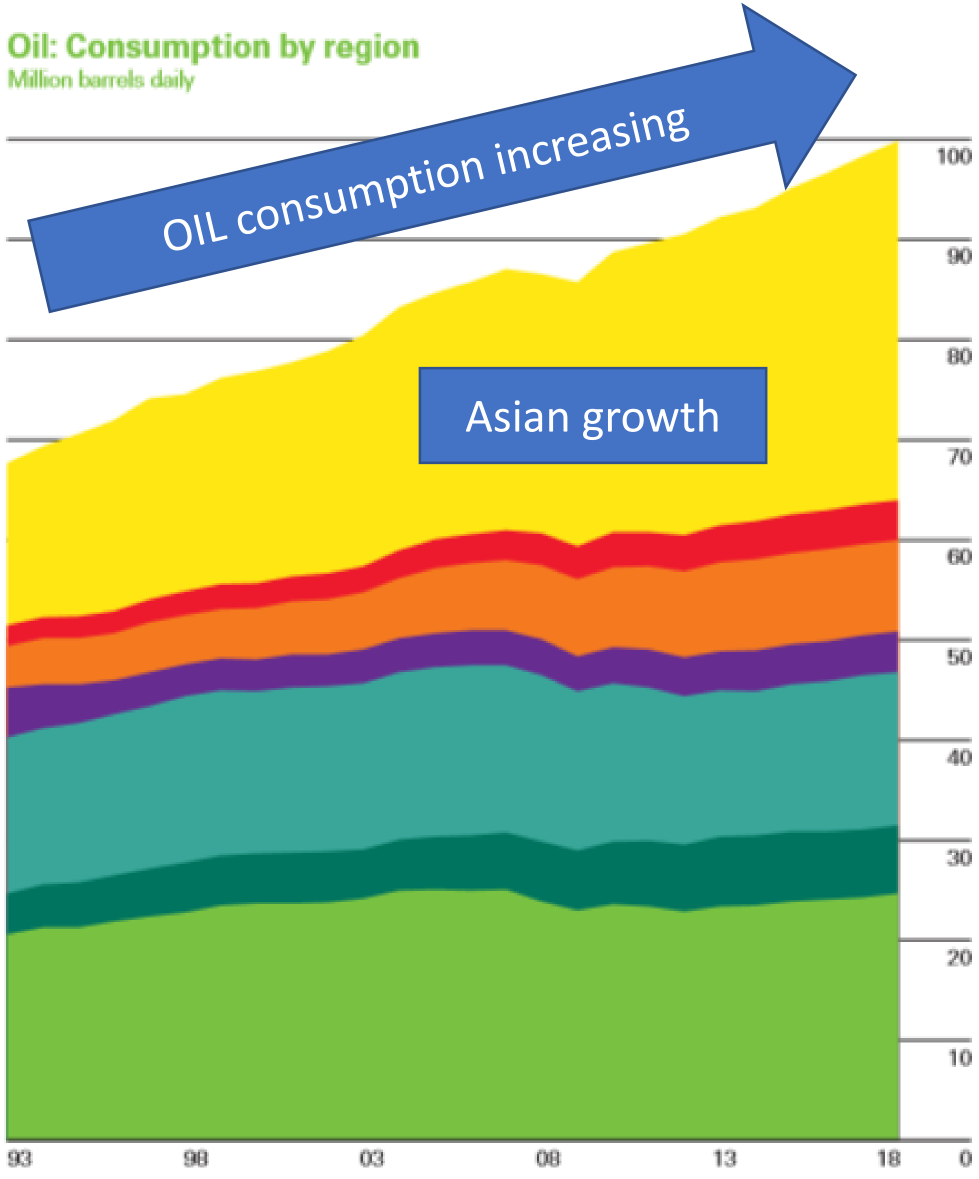
2019 | 68th edition

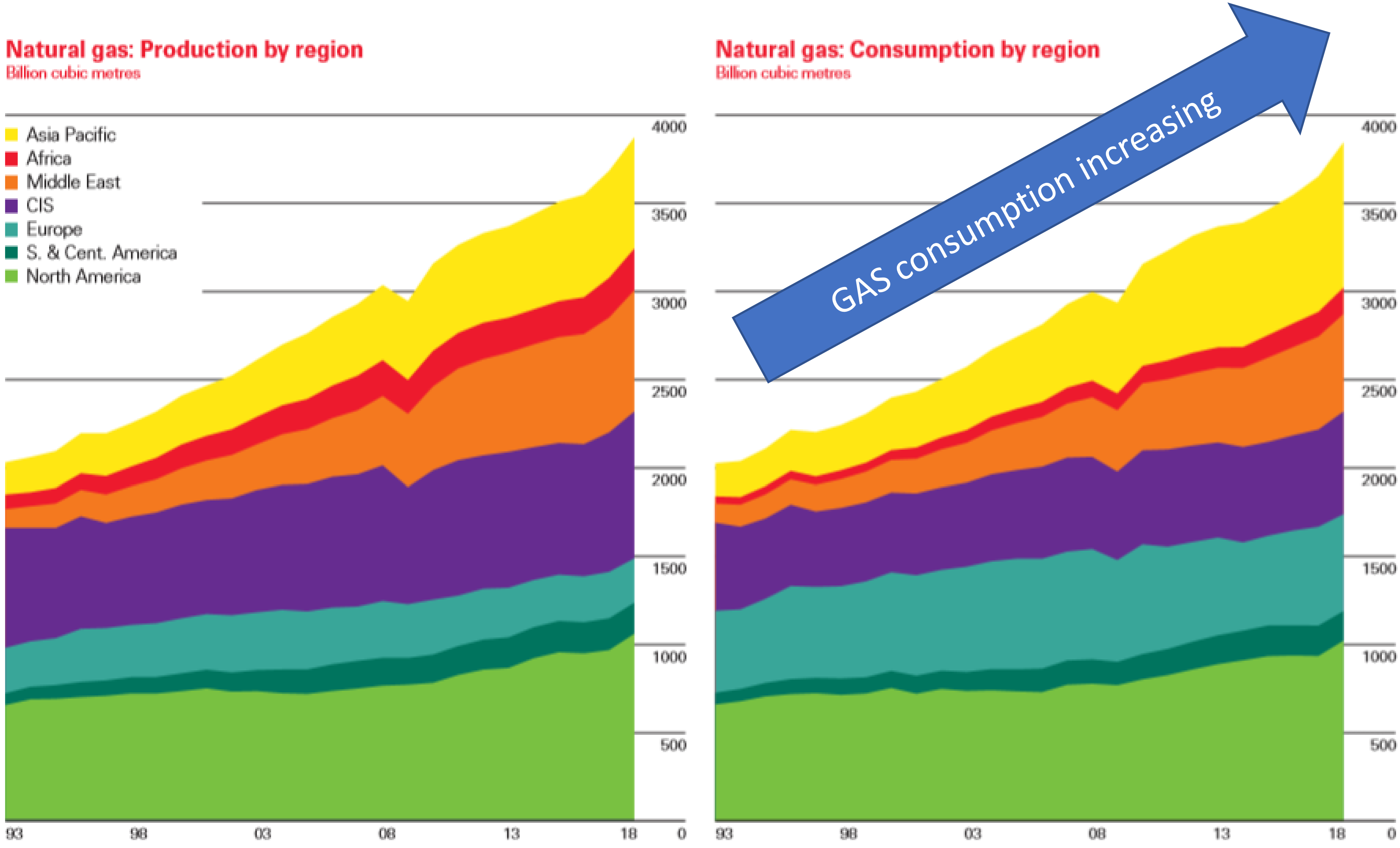
bp



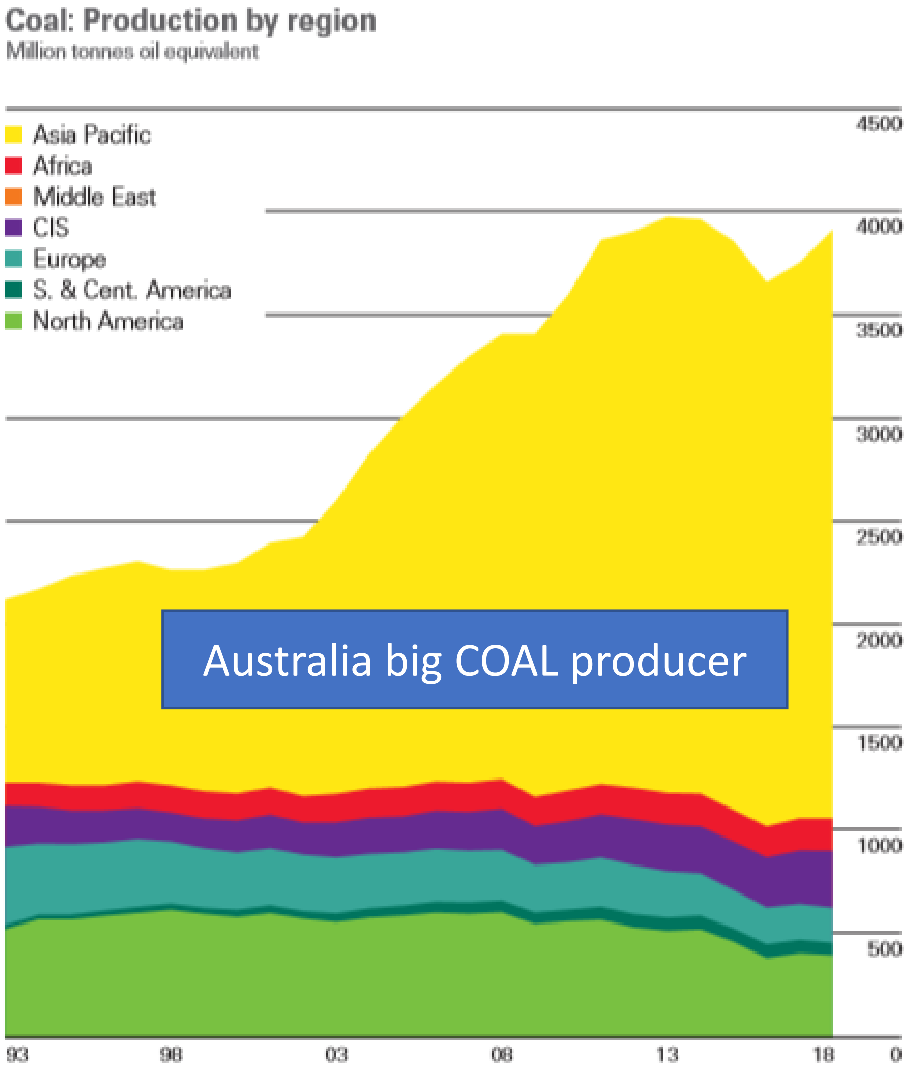
Global energy consumption increased by 2.9% in 2018. Growth was the strongest since 2010 and almost double the 10-year average. The demand for all fuels increased but growth was particularly strong in the case of gas (168 mtoe, accounting for 43% of the global increase) and renewables (71 mtoe, 18% of the global increase). In the OECD, energy demand increased by 82 mtoe on the back of strong gas demand growth (70 mtoe). In the non-OECD, energy demand growth (308 mtoe) was more evenly distributed with gas (98 mtoe), coal (85 mtoe) and oil (47 mtoe) accounting for most of the growth.

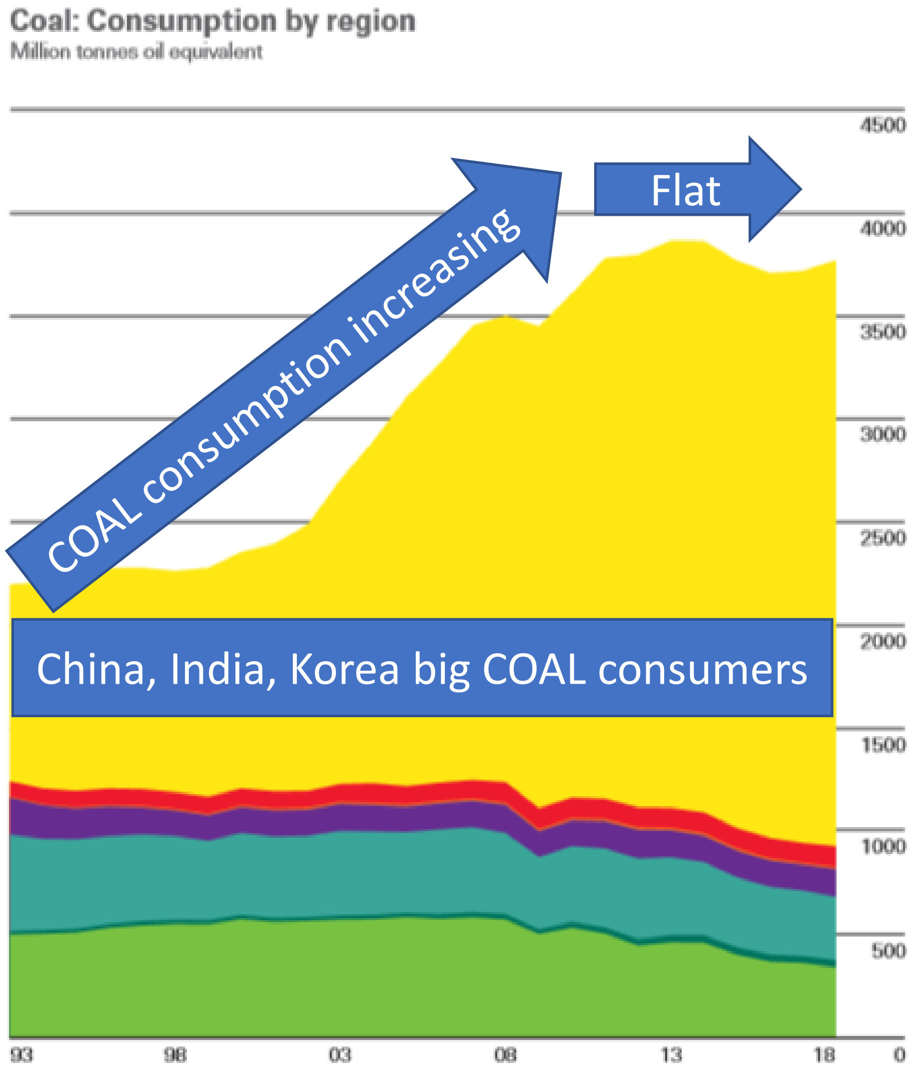

Oil: Production by region
Million barrels daily
Asia Pacific
Africa
Middle East
CIS
Europe
S. & Cent. America
North America
[No Title]
Middle East remains big supplier steady growth in supply
100
90
80
70
60
50
40
30
20
10
0
93
98
03
08
13
18


Oil: Consumption by region
Million barrels daily
OIL consumption increasing
Asian growth
100
90
80
70
60
50
40
30
20
10
0
93
98
03
08
13
18

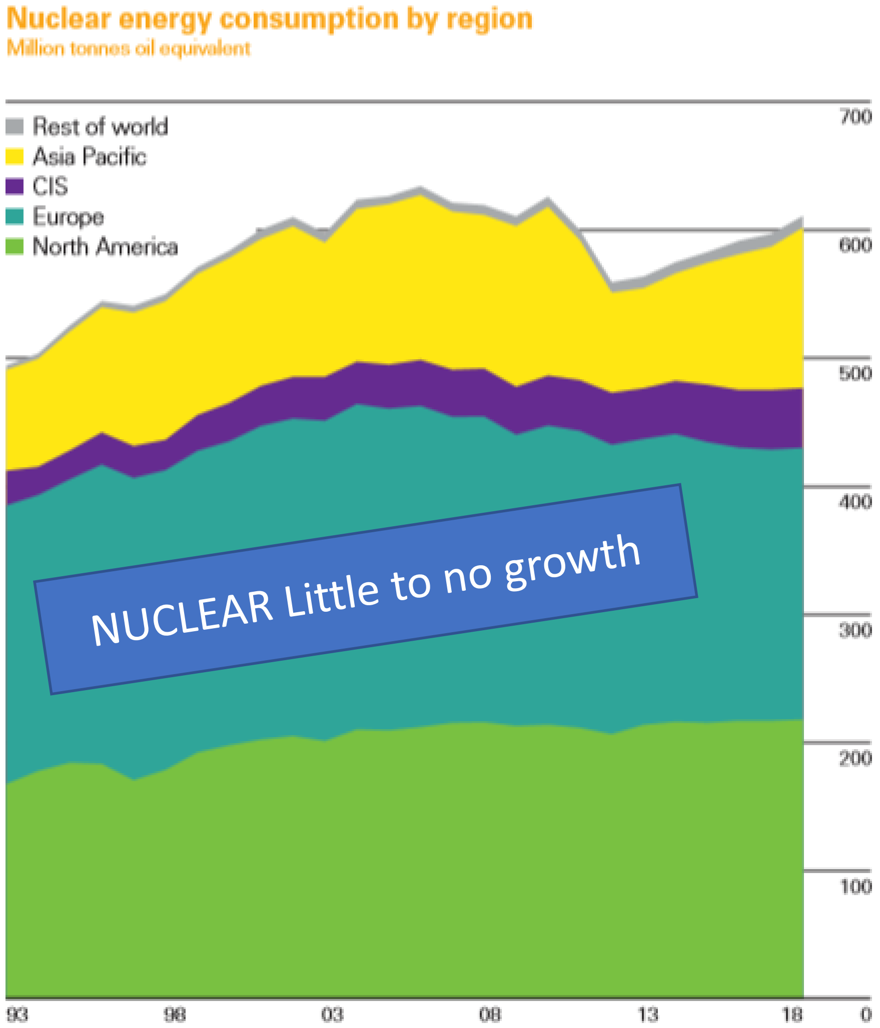


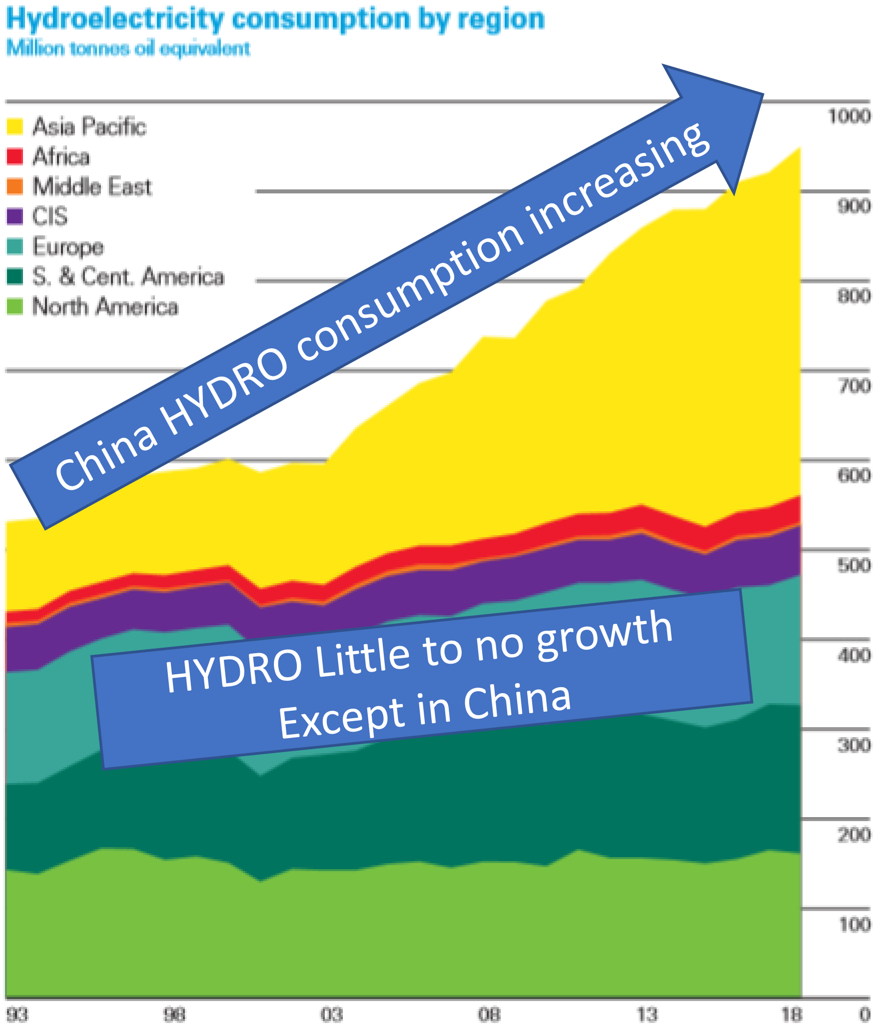
Gas production and consumption registered record-high volumetric increases in 2018. Production increased by 5.2%, the highest rate since 2010 and more than double the 10-year average growth rate of 2.3%. US (86 bcm) and Russia (34 bcm) accounted for almost two thirds of global growth. Similarly, gas consumption increased by 5.3%, with the US (78 bcm) registering the strongest growth on record. China also saw above-average growth of 17.7% (43 bcm).





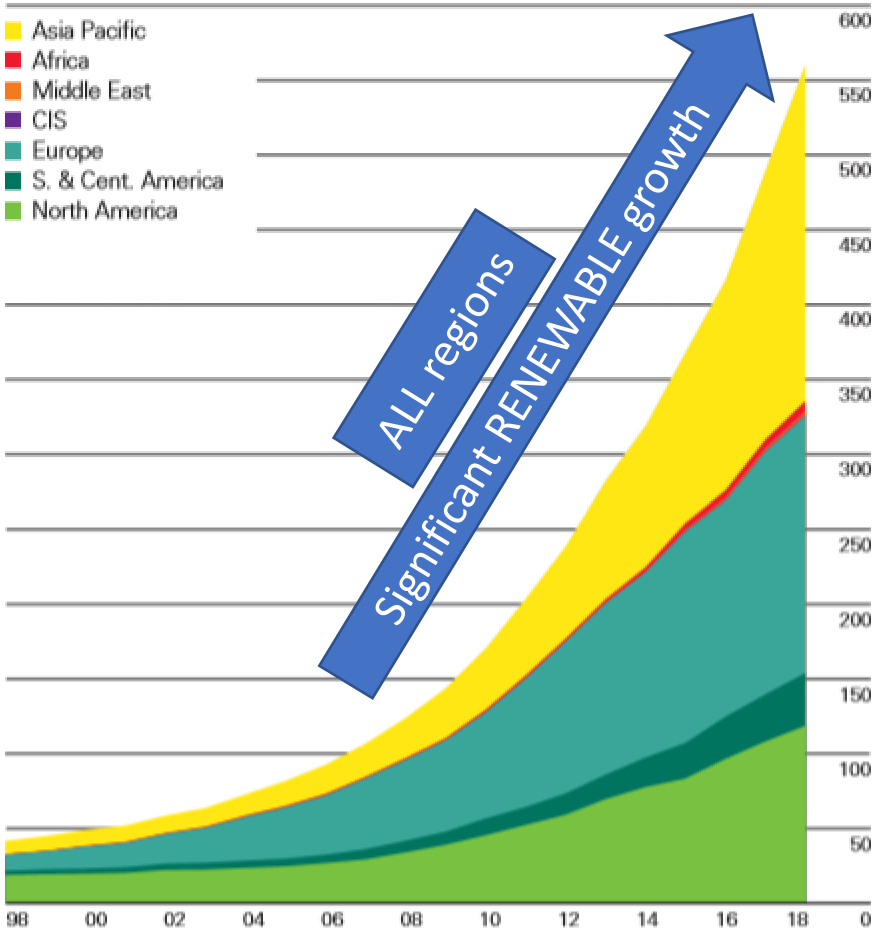
Global coal production increased by 4.3% in 2018, significantly above the 10-year average of 1.3%. Production growth was concentrated in Asia Pacific (163 mtoe) with China accounting for half of global growth and Indonesian production up by 51 mtoe. Coal consumption increased by 1.4% in 2018, the fastest growth since 2013. Growth was again driven by Asia Pacific (71 Mtoe), and particularly by India (36 Mtoe). This region now accounts for over three quarters of global consumption, while 10 years ago it represented two thirds.



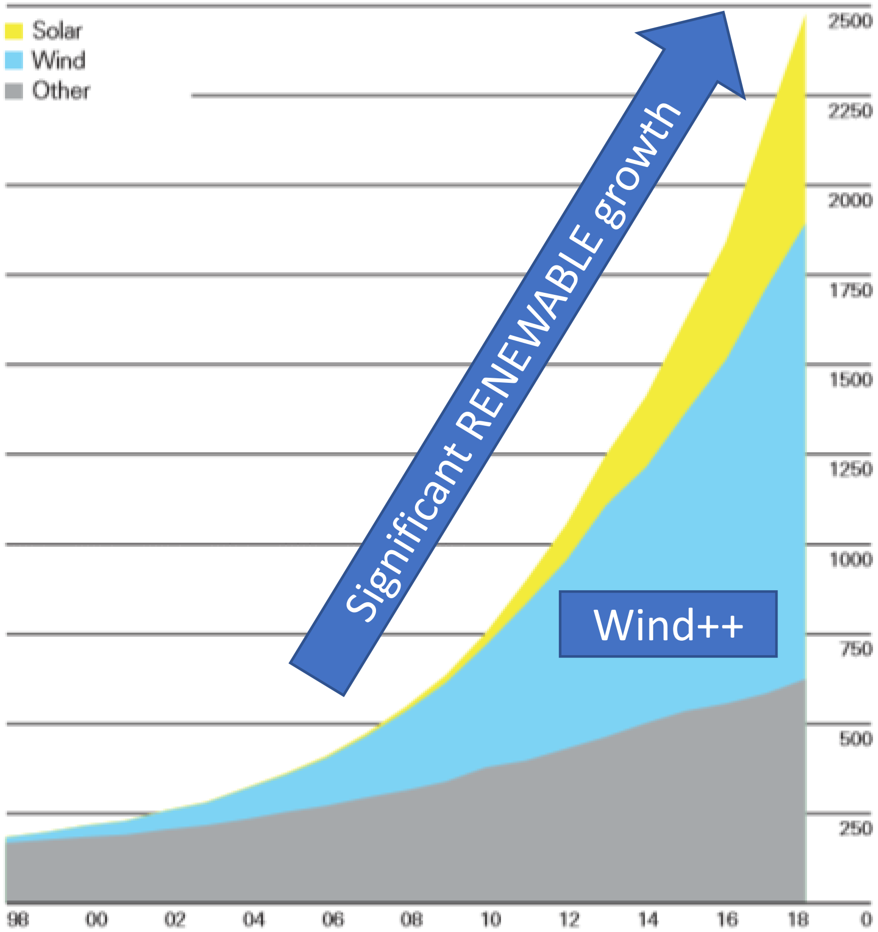


Nuclear consumption increased by 2.4% in 2018. China (10 mtoe) accounted for almost three quarters of global growth. In fact, nuclear consumption in China has more than quadrupled in the last 10 years. The largest declines were recorded in South Korea (-3 mtoe) and Belgium (-3 mtoe).
World hydroelectric consumption rose by 3.1%, slightly above the 10-year average (2.8%). China (8 mtoe) and Brazil (4 mtoe) posted the largest contributions. Asia Pacific's global share has increased significantly in recent years: in 2018 Asia Pacific accounted for 41% of global consumption, 20 years ago it accounted for only 20%.

Renewables consumption by region
Million tonnes oil equivalent



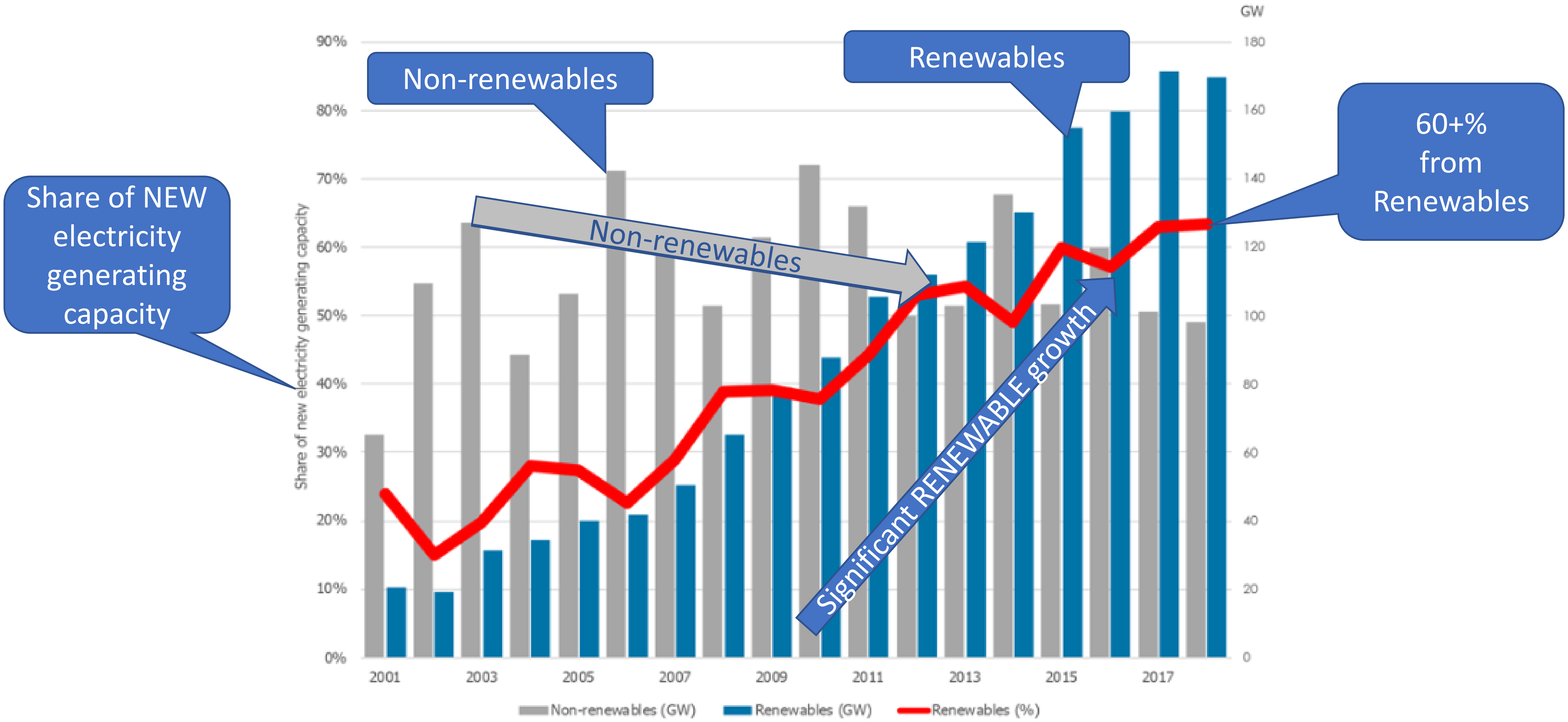
Renewables generation by source
Terawatt-hours



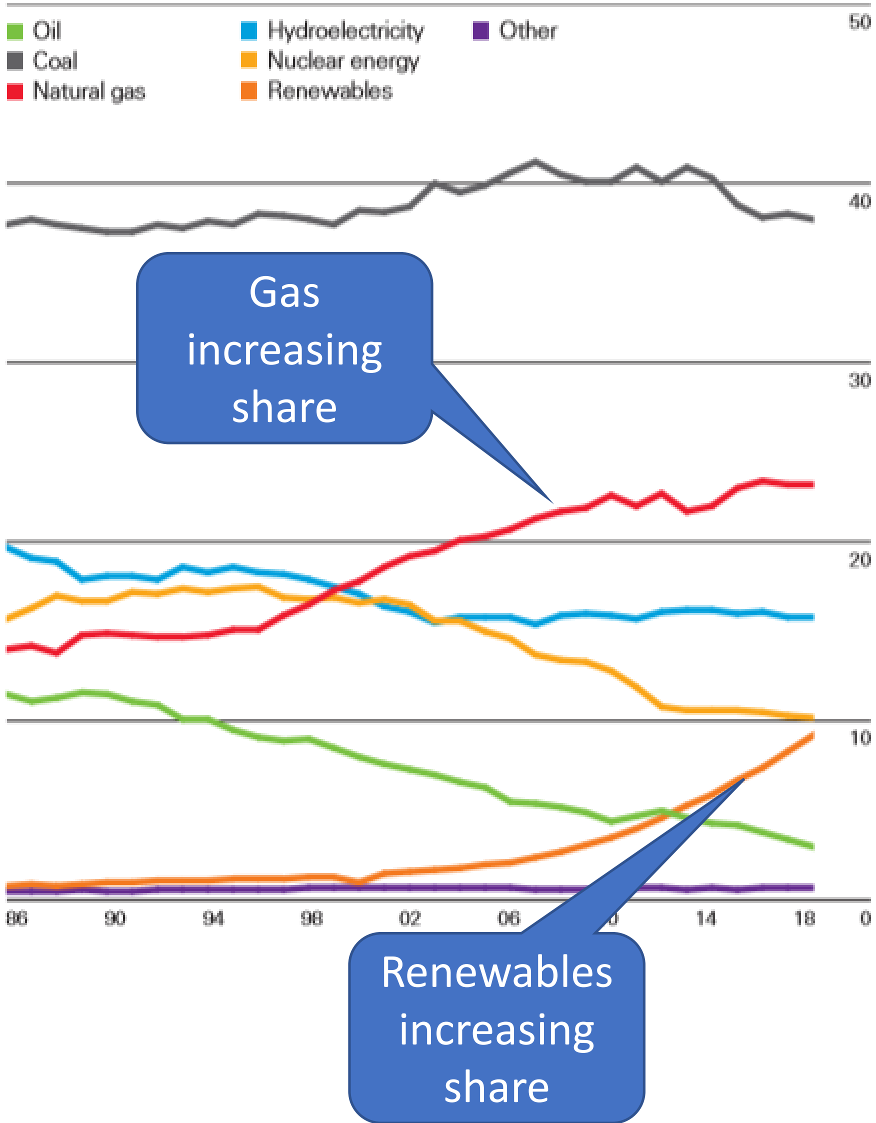
Renewable energy in power generation (excluding hydro) increased by 14% in 2018, slightly below 10-year average growth (16%). However, its increase in energy terms (71 mtoe) was slightly below the record-breaking increase of 2017. China accounted for 45% of global growth and its consumption has increased 20-fold in the last 10 years.

Wind (142 TWh) contributed more to renewable generation growth than solar (131 TWh). Wind has accounted for around 50% of renewables generation in the last few years. Solar has constantly increased its share and now represents 24%, 13 percentage points higher than in 2013.

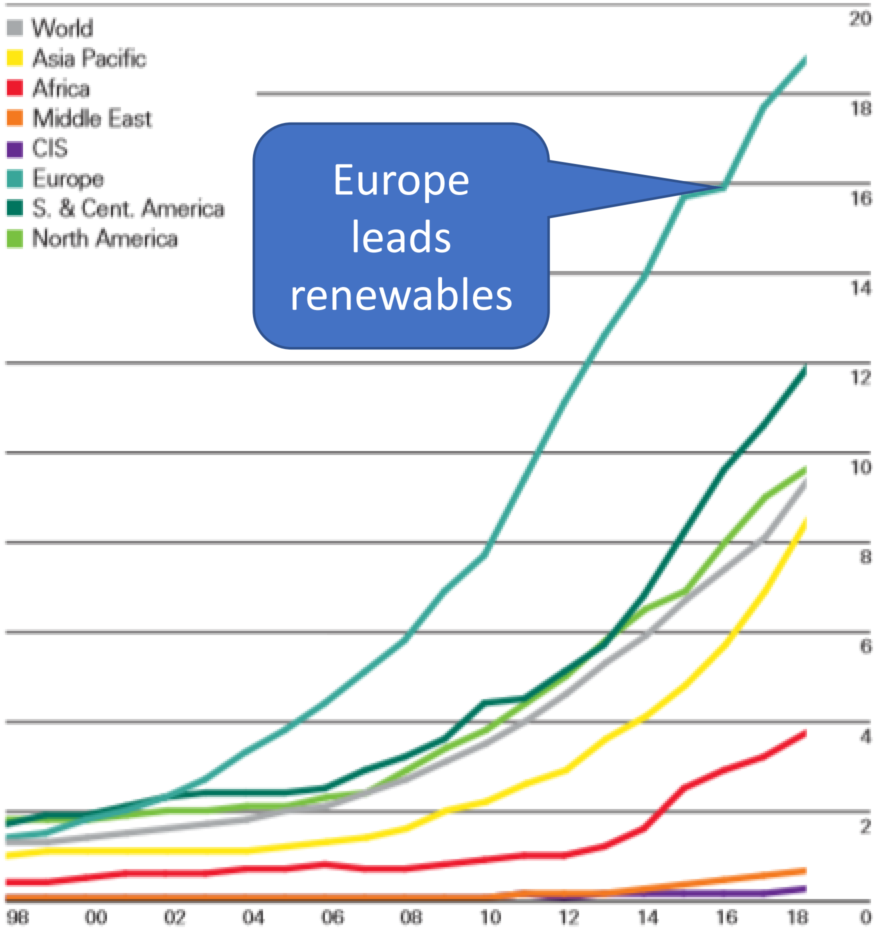
Annual additions to Electricity Generating Capacity

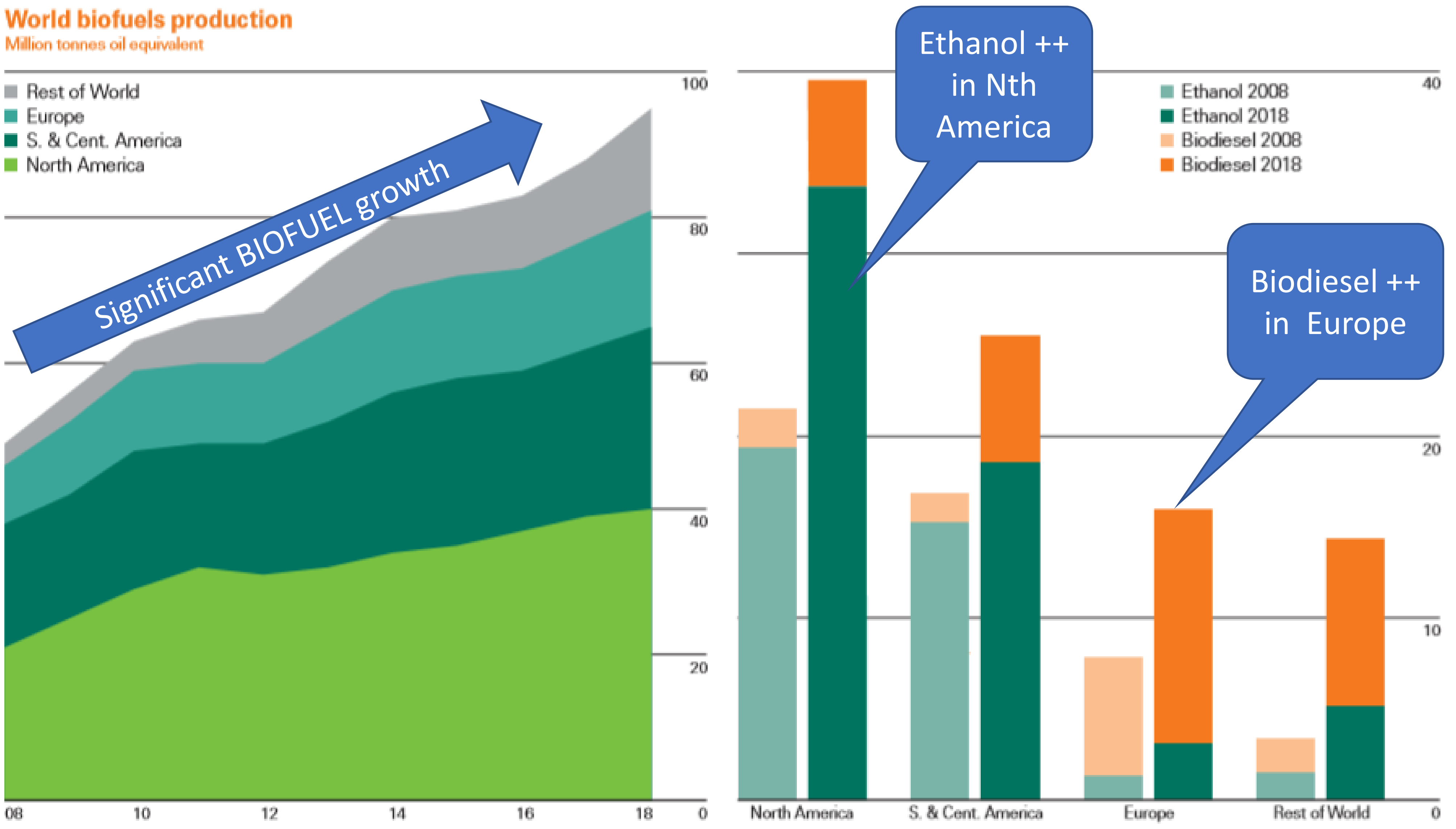


Share of global electricity generation by fuel
Percentage



Renewables share of power generation by region
Percentage




World biofuels production
Million tonnes oil equivalent
Rest of World
Europe
S. & Cent. America
North America
Significant BIOFUEL growth
100
80
60
40
20
0
08
10
12
14
16
18
Ethanol ++ in Nth America
Ethanol 2008
Ethanol 2018
Biodiesel 2008
Biodiesel 2018
Biodiesel ++ in Europe
40
20
10
0
North America
S. & Cent. America
Europe
Rest of World

BP Data shows

Last 20 years Growth in the production and consumption of energy

Can we expect to slow or stop this growth?

Can we change how we produce energy?

Can we offset the products of combustion by sequestering C?

SKY…Shell's proposal ….a pathway for the rest of the century

THE CONCLUSION

Delivering Sky will be challenging. Achieving long-term public goals requires long-term public policy to initiate and guide developments that the private sector will need to deliver and the public will need to choose or accept.

www.shell.com/skyscenario.

SKY recognizes that a simple extension of current efforts is insufficient.

Sky presents a possible pathway to achieving a balance between anthropogenic emissions by sources and removals by sinks of GHGs.

The target is
net zero emissions by 2070

Shell Renewables

- 1 of 5 core divisions ($100 million/yr budget)
- Established 1997
- Renewables will supply 50% by 2050
- Proponent of decarbonization direct path to renewables supported by gas in medium term: 2 businesses……
- Shell Solar
  - 2 plants Camarillo (Cal), Gelsenkirchen (Germany)
  - Total PV cell annual output 75 mW
- Shell WindEnergy
  - Current capacity 240 mW worldwide
  - Targets 2000 mW by end 2005

CHALLENGES AHEAD FOR **SKY**

Because we need energy for just about everything we make and do, achieving Sky essentially involves **re-wiring the whole global economy** to reach net-zero emissions in just 50 years. We face some major challenges.

- Population growth, development, new energy services, and the extended use of existing services will all contribute to **energy demand growth**. Demand growth can potentially be slowed through rapid efficiency gains, but efficiency tends to lower the cost of energy services, leading to increasing consumption by consumers - a double-edged sword.
- A stark reality of the early 21st century is the lack of a clear development pathway for an emerging **economy that doesn't include coal.** Coal is a relatively easy resource to make use of and offers a great deal, including electricity, heating, chemicals, and, very importantly, smelting to make iron. It remains an important energy resource.
- Some progressive regions may need to consider net-zero emissions as an objective for the 2050s, in part to balance countries that arrive at this point much later in the century. But net-zero emissions in almost any industrial economy is a tough ask due to the current **lack of low-carbon substitutes** for, e.g. aviation, shipping, road freight, cement manufacture, some chemicals processes, smelting and glass manufacture. **Energy-dense portable fuels will be a continuing need**.
- Wind and solar power can grow rapidly, but produce electricity which makes up less than 20% of final energy consumption today. Major contributions to decarbonisation and increased efficiency require deep electrification of the economy, but **electrification** has been slow and its market share is currently growing at only 2%-points per decade, which **needs to triple.**
- Some promising low-carbon technologies are currently stalled, with **hydrogen,** perhaps, being the most notable example. Progress in biofuels technology and **Carbon Capture and Storage** (CCS) have also been **slower** than originally anticipated.

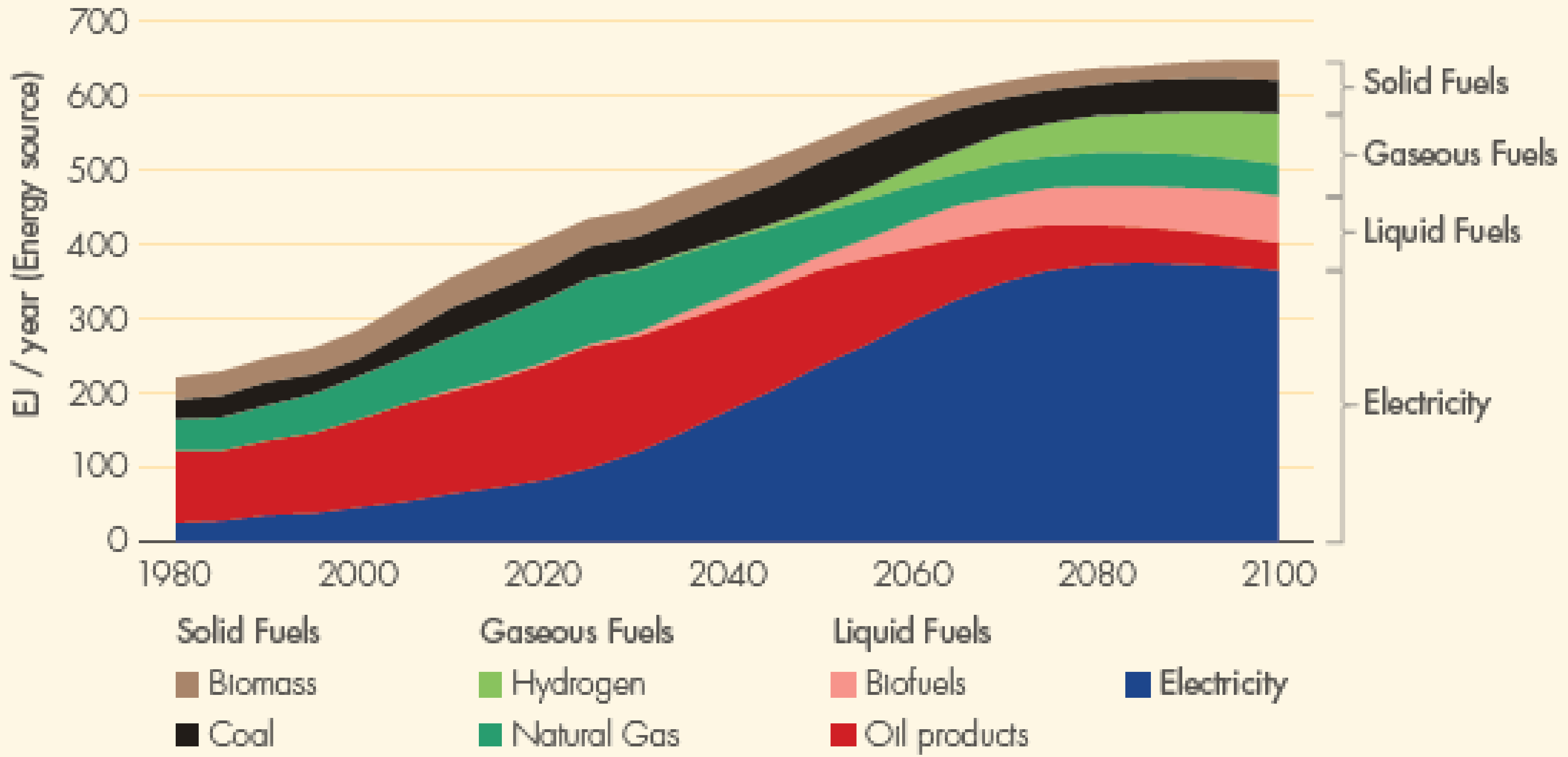
Achieving net-zero emissions in just 50 years leaves no margin for interruption, stalled technologies, delayed deployment, policy indecision, or national back-tracking. Rather, **it requires a broad process that is embraced by societies and led by public policy.**

A SCENARIO FOR SUCCESS

THE VISION: The route to net-zero emissions by 2070 is increased electrification –

- the increasing replacement of direct fossil fuel use (such as gasoline for mobility) by electricity and perhaps by **hydrogen (air travel).**
- **Electricity** exceeds 50% of end-use energy consumption, **five times the size of that seen in 2017**.
- **Fossil fuels** are effectively **absent from power generation** with **solar starting to dominate**.
- Electrification begins most clearly in the transport system through intergovernmental initiatives and pledges by countries and cities to **phase out internal combustion engine passenger cars**.
  - As early as 2030, more than **half of global car sales** are electric,
  - Extending to **all cars** by 2050
  - **Electrifying rail corridors in Nth America. China, Europe and Japan are far ahead.**
- **Biomass generation has emerged**, linked with CCS to offer an important carbon sink. **CCS is a huge challenge!**
- Government-led **carbon pricing** emerges in Sky as a suite of **taxes, levies, and market mechanisms**. By 2030, a common understanding is reached between governments as to the appropriate level of the cost of emissions.

GLOBAL END ENERGY-USE CONSUMPTION



Note: In Sky, deep electrification occurs across the energy system, but molecules remain an important energy carrier.

Source: Shell analysis, Sky Scenario.

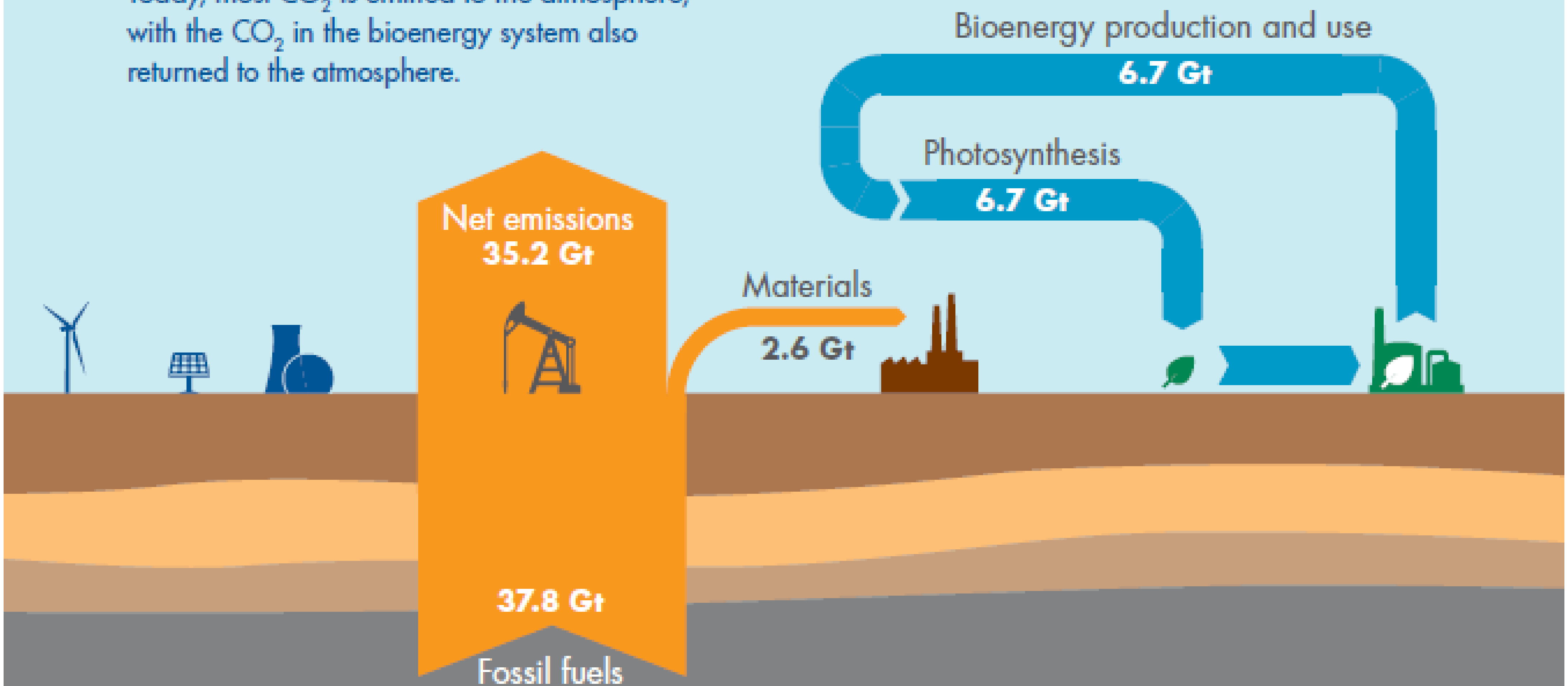
By the middle of the century the energy mix is starting to look very different, with **solar the dominant primary energy supply source by around 2055**. Energy system **CO_2 emissions peak in the mid-2020s at around 35 Gt, and fall sharply thereafter.**

- **Efficiency** improves continuously.
- **biofuels** play a critical role in Sky (Biofuels increasingly supplement the fossil liquid fuelmix: This needs discussion.)
- **Coal** declines rapidly with the peak already behind us but coal remains important in various processes with CCS applied to manage CO_2 emissions
- 10,000 **CCS** plants are built compared with fewer than 50 today
- **Hydrogen** also emerges as an important fuel in the 2030s, although not until after 2050 for heavy industry.
- For **fossil fuels** in Sky, the first clear signs of the transition emerge in the 2020s;
- **Oil** demand peaks at 83 million barrels per day and begins to decline by the 2030s.
- By 2070, however, oil production remains at **50 million barrels per day**, albeit declining, due to the broad swathe of services that it still supplies.
- **Net zero deforestation** requires Re foresting an area size of Brazil
- **Natural gas** plays an important early role in supplanting coal in power generation and backing up renewable energy intermittency. Demand then falls after 2040.
- Sky does not contemplate significant growth in **nuclear** energy (5% to 11%) Why is that?

THE EVOLVING ENERGY SYSTEM CO_2 BALANCE IN SKY

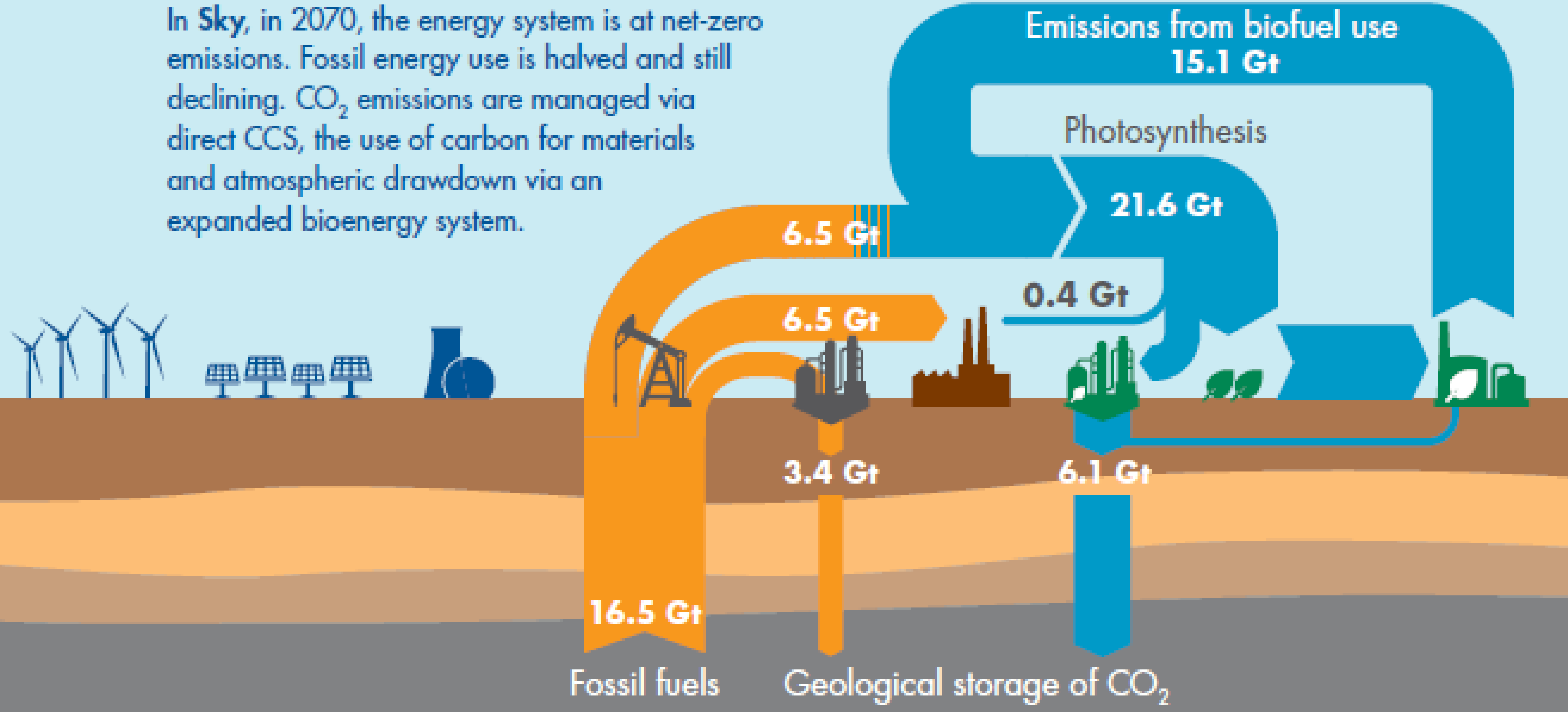
2020

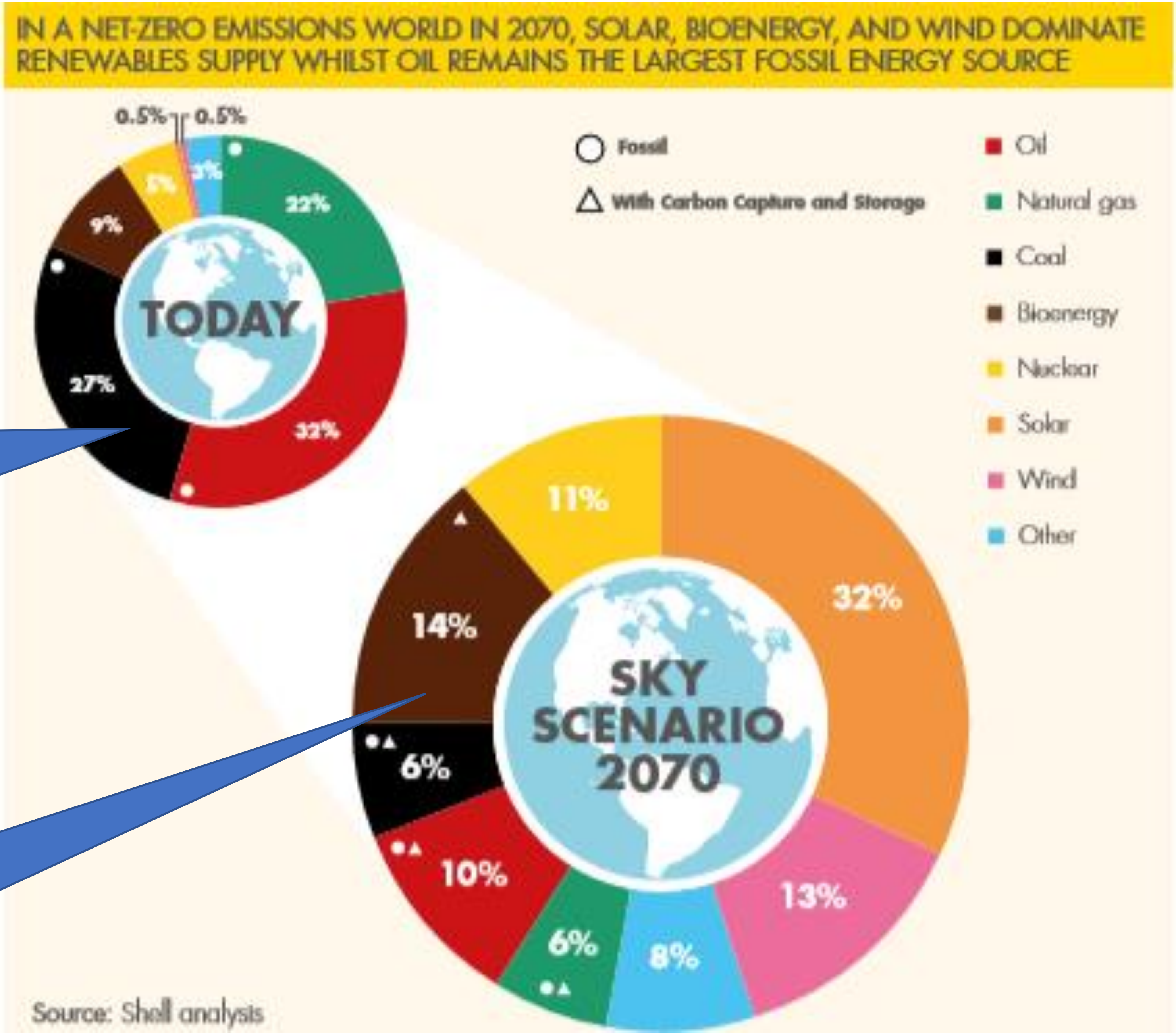
Today, most CO_2 is emitted to the atmosphere, with the CO_2 in the bioenergy system also returned to the atmosphere.



2070

In **Sky**, in 2070, the energy system is at net-zero emissions. Fossil energy use is halved and still declining. CO_2 emissions are managed via direct CCS, the use of carbon for materials and atmospheric drawdown via an expanded bioenergy system.

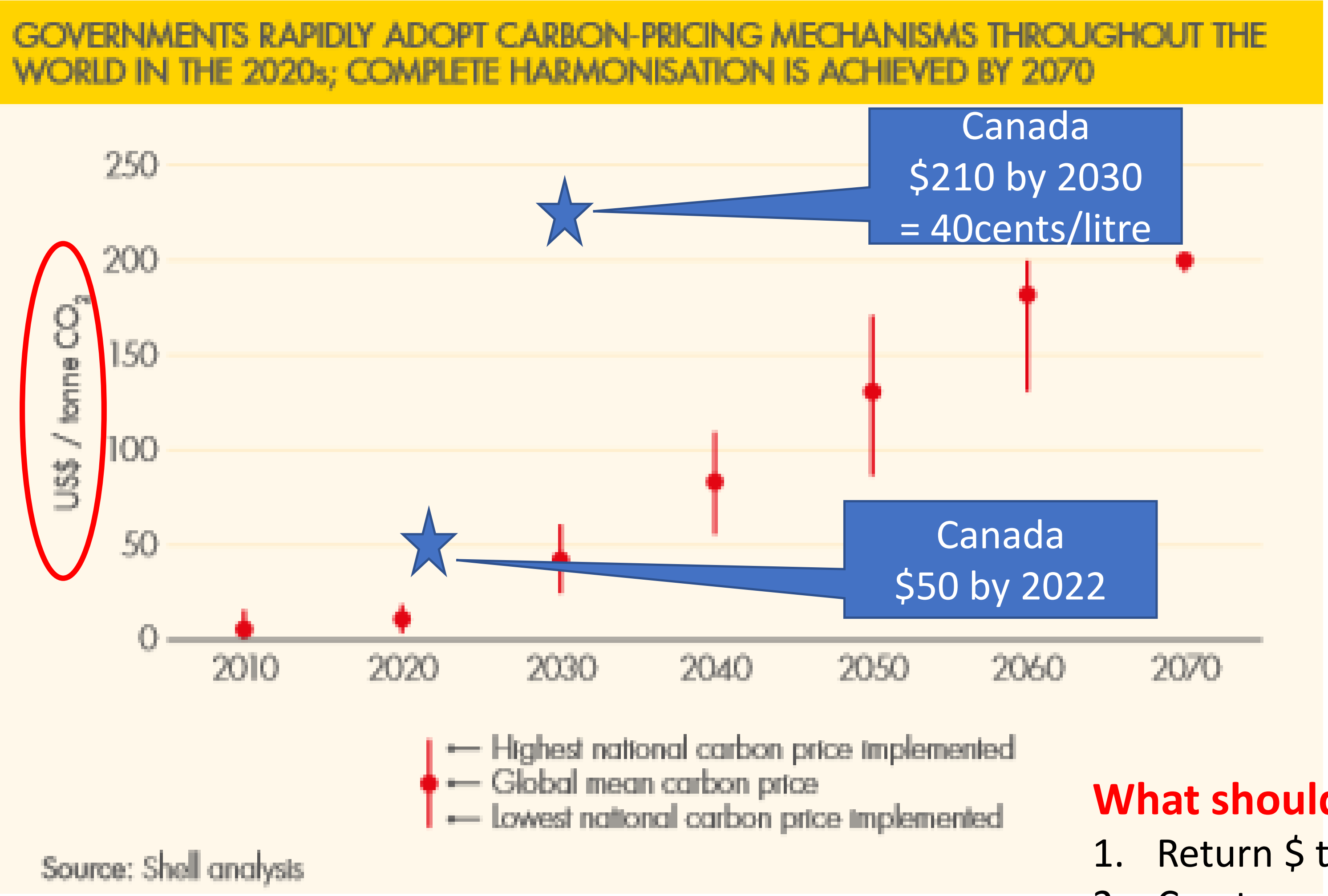




92% combustible fuels

36% combustible fuels

In **Sky**, government-led carbon pricing emerges as a suite of **taxes, levies, and market mechanisms**.



In **Sky**, Global implementation of carbon **pricing** by governments is **complete by the late 2030s**, with all systems then achieving a credible limit to deter emissions.

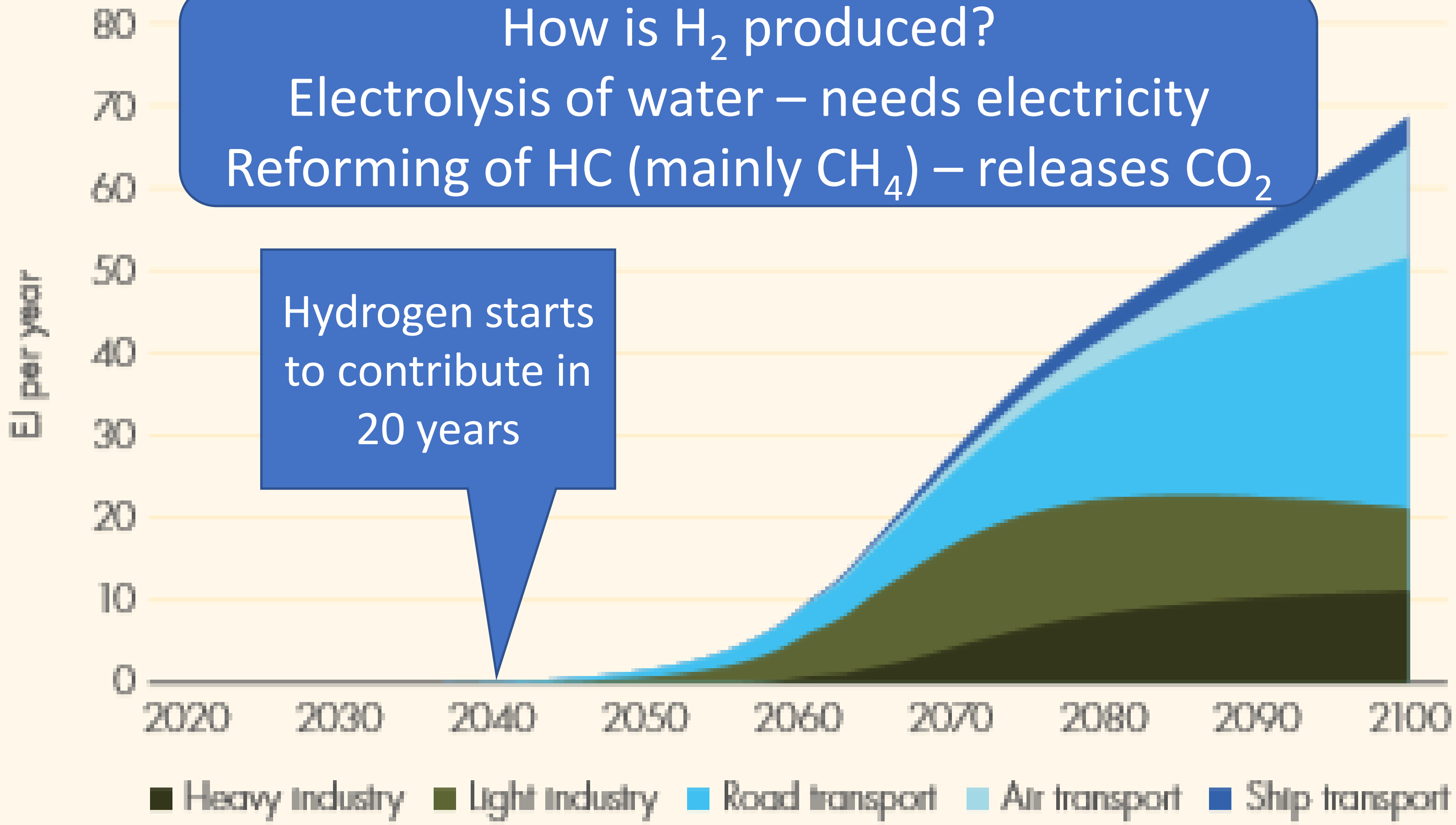
In **Sky**, carbon pricing.

1. speeds up the adoption of CCS for large emitters: **Construction of central CCS plants** eg. Petrocemical complexes
2. Drives the deployment of net-negative technologies like bioenergy with CCS. **?? What does this mean??**
3. Carbon pricing encourages emissions reduction across the whole economy, especially through improving energy efficiency, thus generating significant shifts in consumer and producer behaviour. **Proven to be the case in Sweden.**

What should governments do with increase revenues??

1. Return $ to consumers?
2. Create a pool of $ for technology development?
3. Other?

IN SKY, HYDROGEN EMERGES AS A MATERIAL ENERGY CARRIER AFTER 2040, PRIMARILY FOR INDUSTRY AND TRANSPORT



How is H_2 produced?
Electrolysis of water – needs electricity
Reforming of HC (mainly CH_4) – releases CO_2

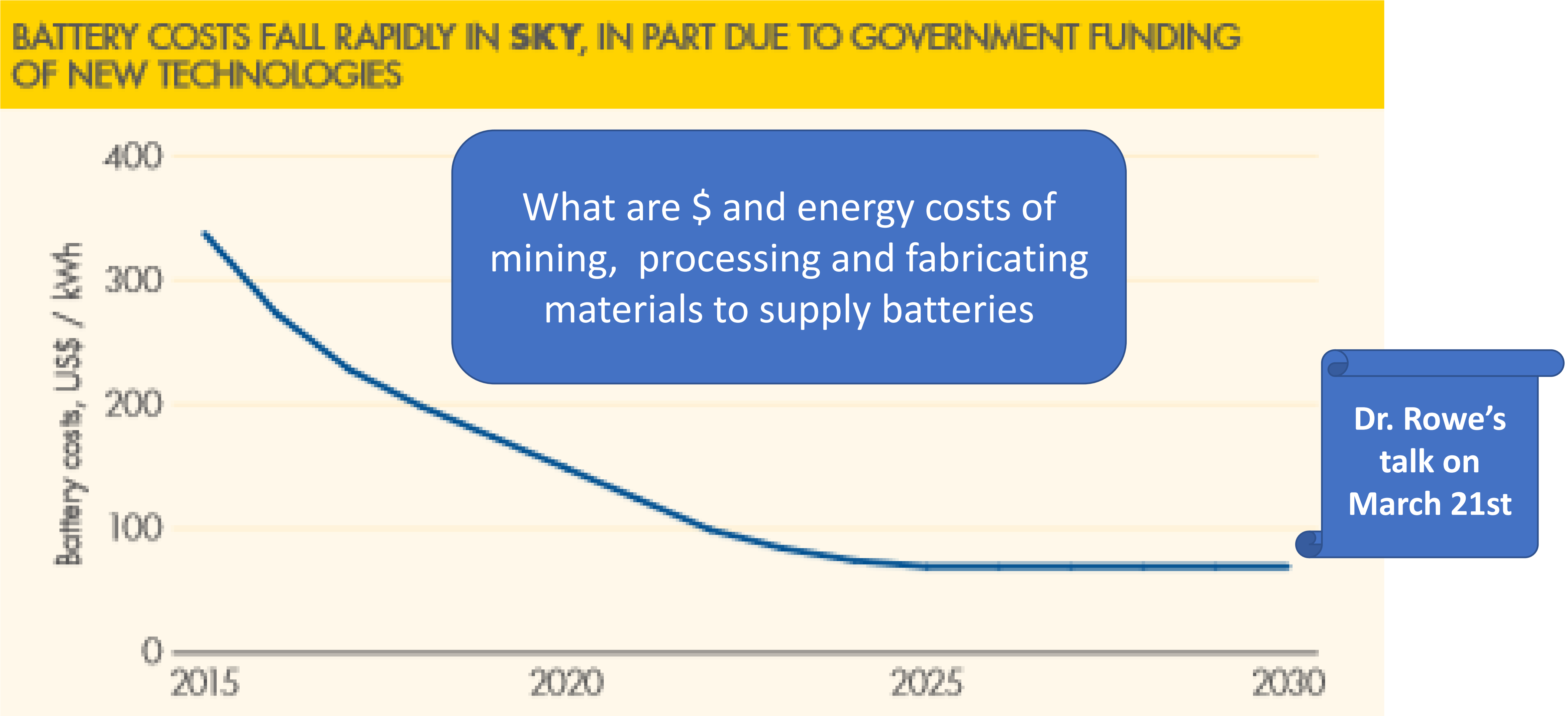
Hydrogen starts to contribute in 20 years

This is a huge bet! To supply 25% of transportation needs by 2100

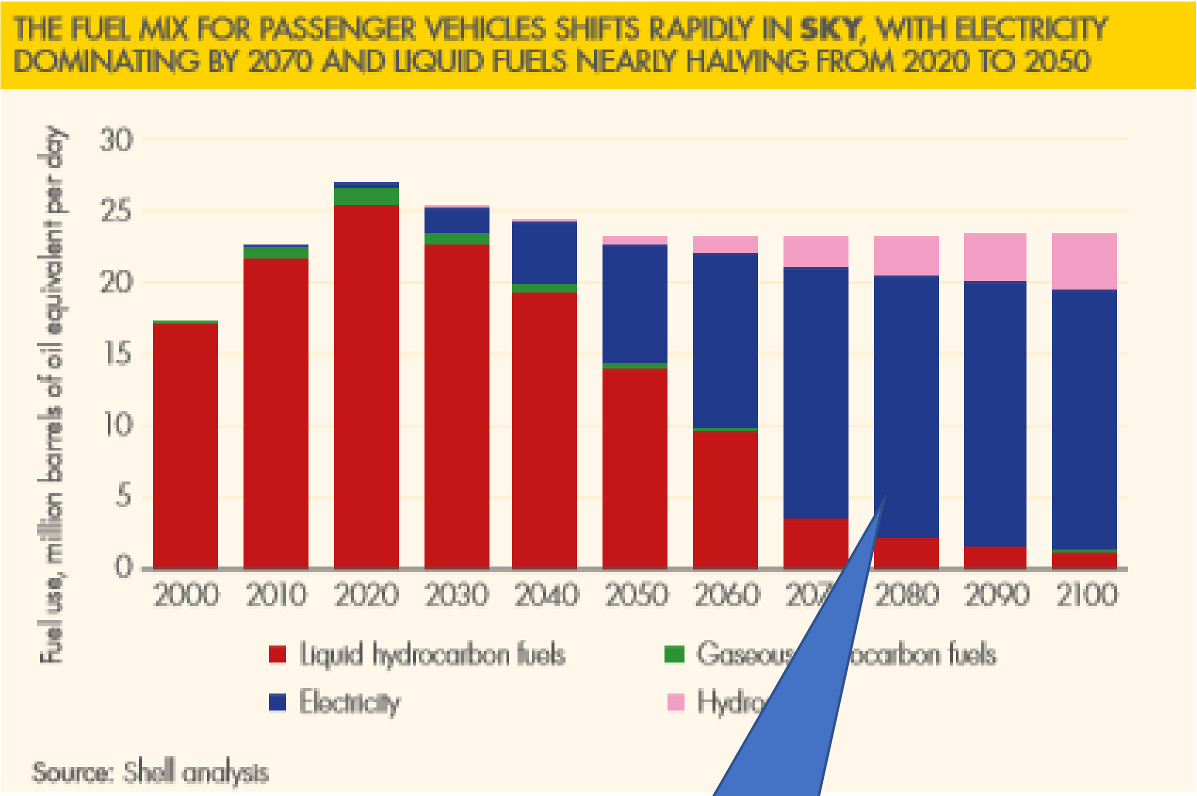
Nicolas Pocard's talk on February 8th

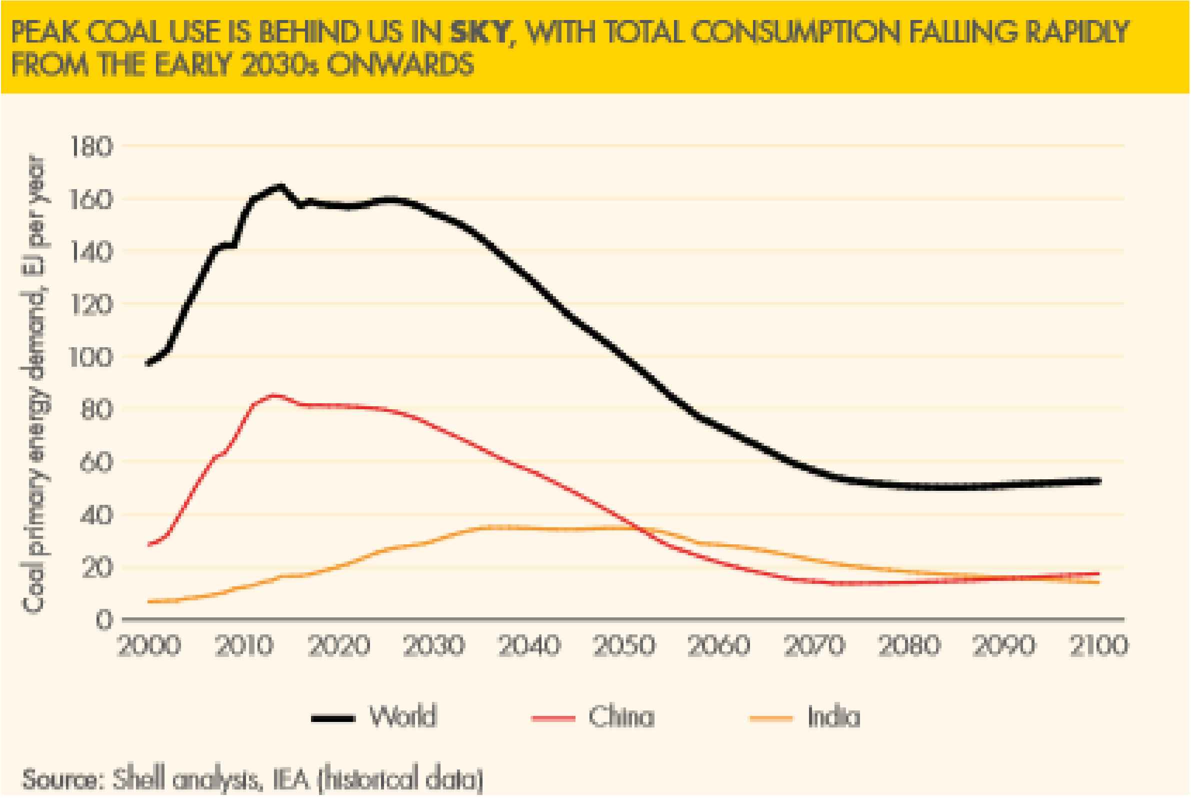
Note: By 2100, hydrogen supplies a quarter of all transport energy demand and over 10% of industrial energy

Source: Shell analysis

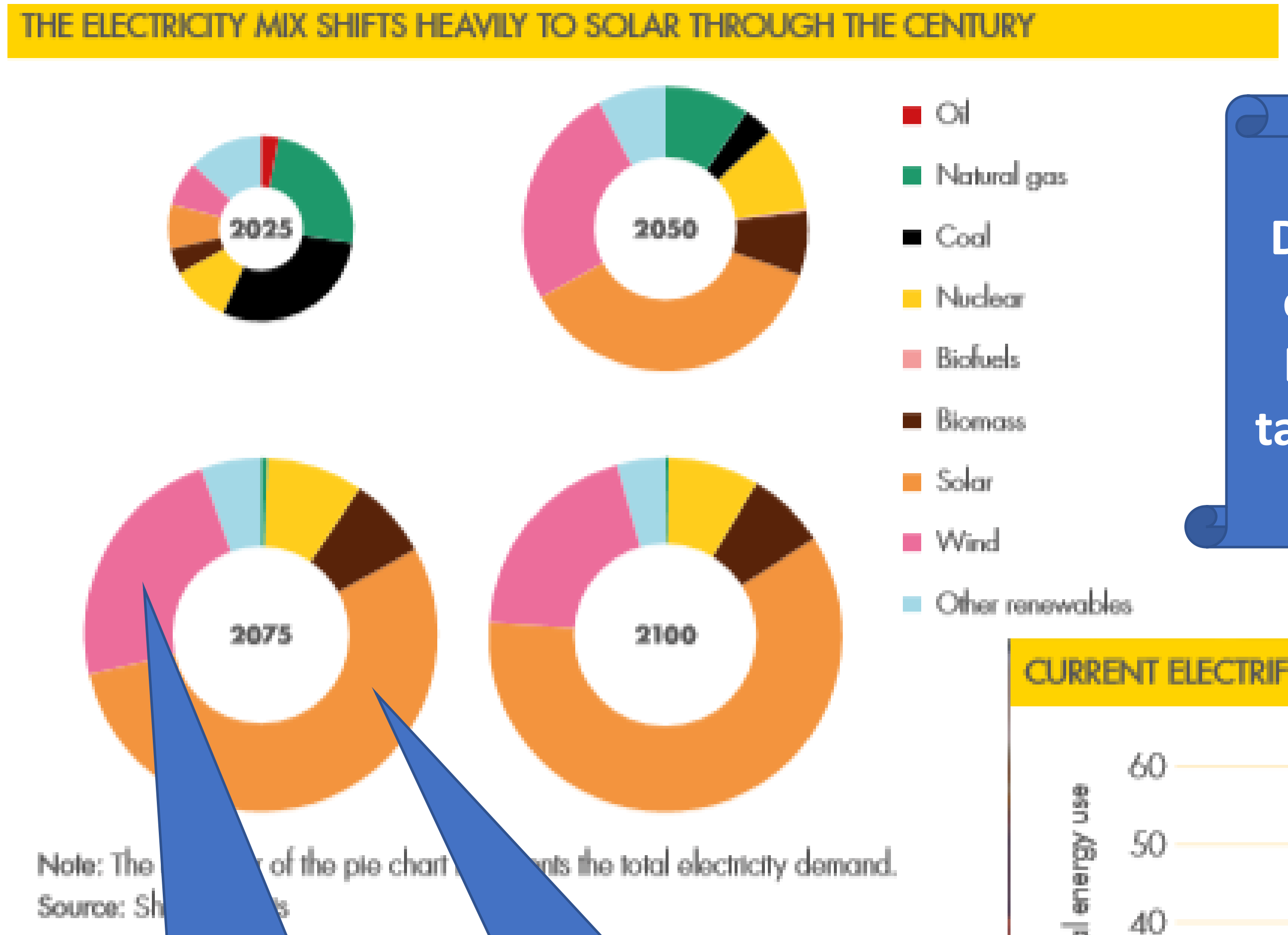


Source: Shell analysis, Bloomberg New Energy Finance (historical data)



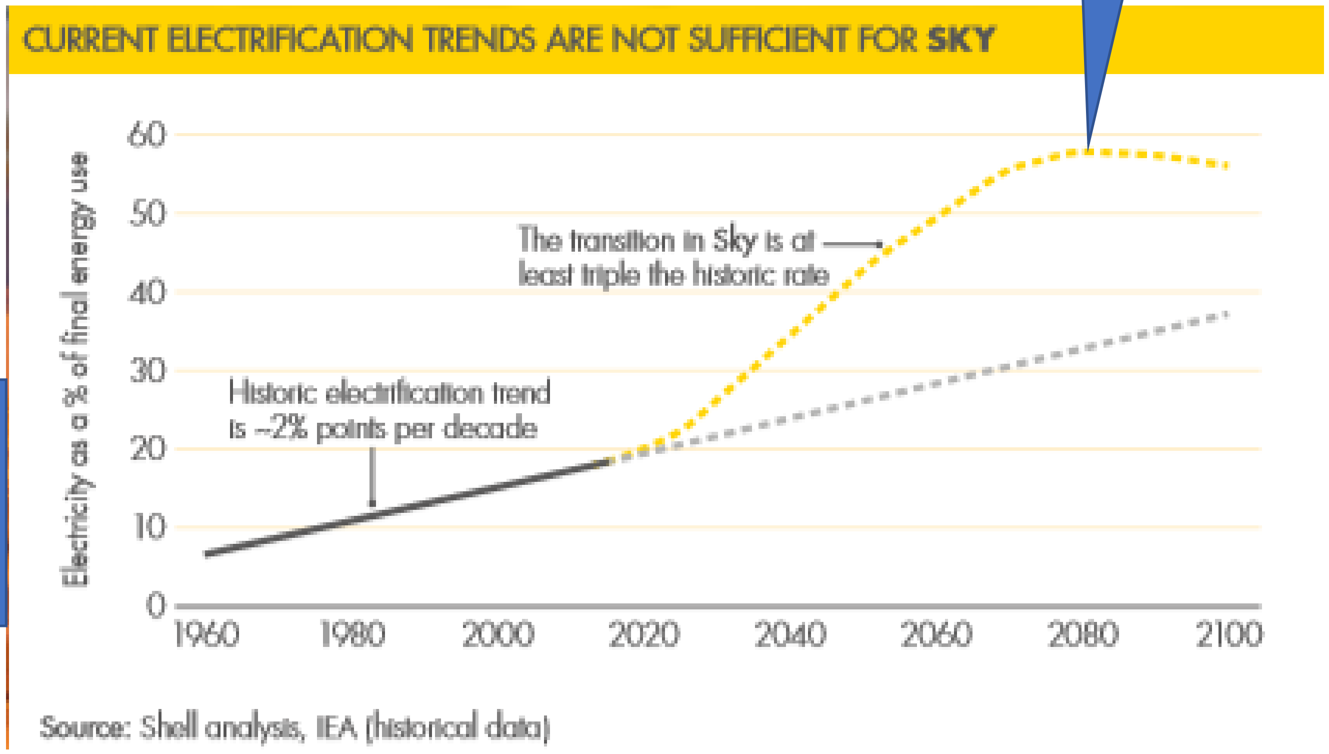


HUGE growth in Solar electricity by 2075



Dr. Tjiede's talk on Feb 15th & Dr. Crawford's talk on Feb 22nd

HUGE growth in electricity



HUGE growth in Wind electricity by 2075

HUGE growth in Solar electricity by 2075

ELECTRICITY IN THE 21st CENTURY

Today, global electricity demand stands at some **22,000** terrawatt hours (TWh) per year.

In **Sky** it rises to around **100,000** TWh per year during the second half of the century, or the **addition** of about **1,400** TWh of generation **per year** from now on.

As a reference, when complete, the 3.3 GW Hinkley Point nuclear power station being constructed in the UK will add about 29 TWh, so this pace of development is equivalent to some **50 giant power stations globally each year, or one additional such facility per week.**

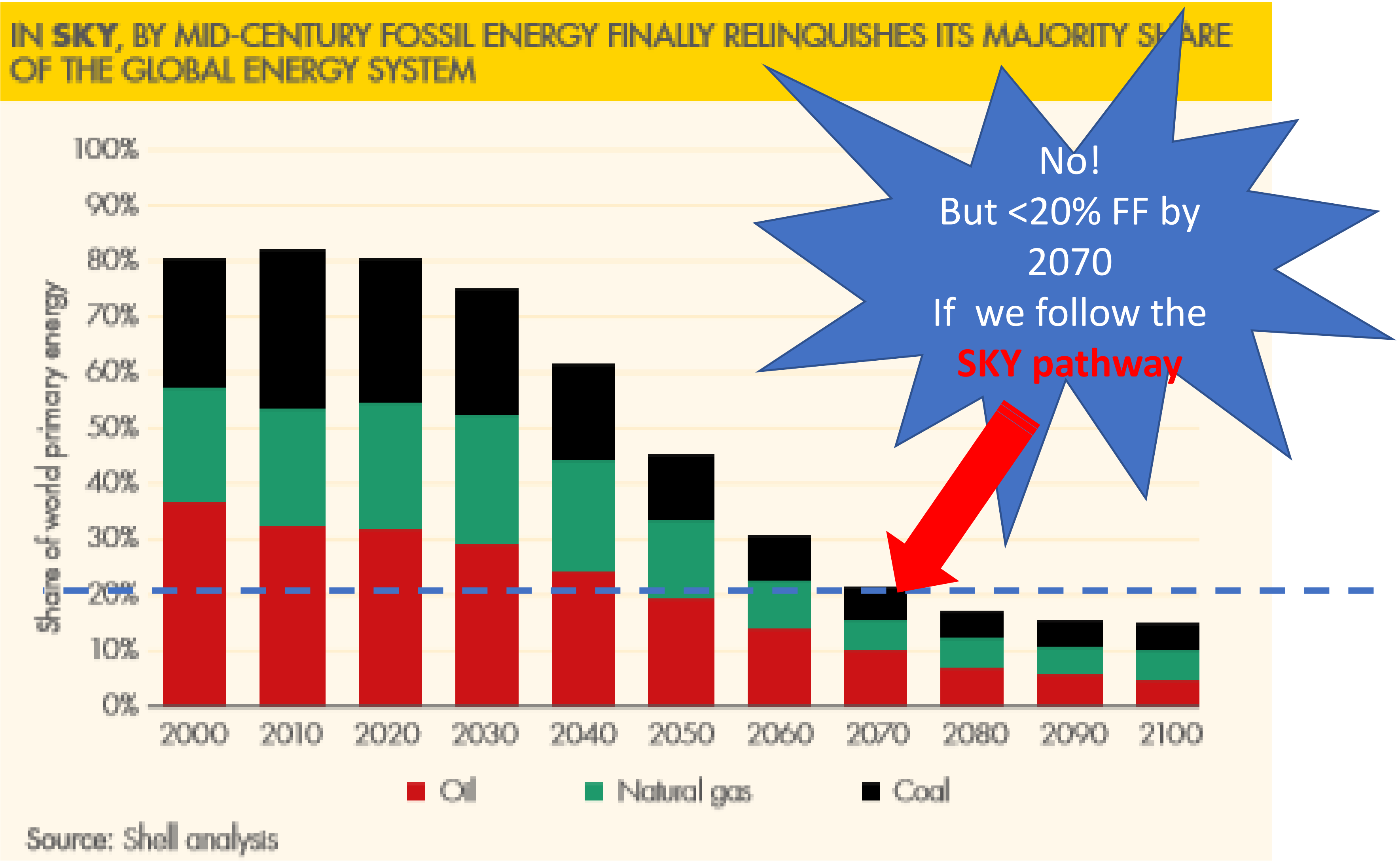
Global generation from wind and solar was around 1,200 TWh in 2016, with about 200 TWh added f… n of some 600 TWh.

What are $ and energy costs of mining, processing and fabricating materials to supply solar panels and wind turbines?

So, new solar and wind are not yet close to meeting additional generation demand. Although both are rising quickly, thermal power stations will continue to be needed to at least mid-century.

These thermal power stations should NOT be coal powered and in this transition period, we must look towards natural gas and nuclear

CAN WE
“LIVE WITHOUT OIL”?



Net zero emissions by 2070 and the Paris Ambition realized

Closing Statements
“LIVING WITHOUT OIL”?

Imperative 1
In my opinion we will never run out of hydrocarbons (oil, gas or coal). The commodities will become increasingly more costly to produce whether from fossil fuels or biofuels. Hydrocarbons from either source release GHGs upon combustion..

Combustion of hydrocarbons is essential to human existence. There are no substitutes for petrochemical products or ways to produce fertilizer, steel & cement without hydrocarbons. We cannot construct roads and highways. There is no alternative way to power aircraft. We cannot live without oil.

Imperative 2
The Paris Ambition set by IPCC is to achieve “Net zero emissions of GHGs by 2070” but it doesn’t say how. Shell maps out a PATHWAY called SKY showing us how the Paris Ambition can be achieved. This will be by reducing consumption through increased use of renewables and sequestering emissions of hydrocarbons we do have to burn. It gives us some hope and optimism for the future.

There is much wrong with SKY but it is worthy of discussion and debate.
If we accept the climate modelling as “settled science” and we believe in the premise that GHG emissions are causing global warming, can we look at past actions taken by mankind that have had an impact on the atmosphere and climate?

Nitrogen (Haber-Bosch) and Ozone Montreal Protocol. Both resulted in the award of Nobel Prizes.

What are the threats?

- CCS expectations are unrealistic
- Reliance on biofuels to replace fossil fuels: implausible & unnecessary
- Huge investment in electrification infrastructure
- Reliability of electrical supply (base load) given reliance on solar & wind
- Change in behavior unrealistic eg: stay at home tourism
- Hydrogen extremely challenging
- Nuclear underestimated as a potential transitional solution
- Is the science really settled?
- Are the models reliable: could they have under-estimated or over-estimated?
- Are countries prepared to meet their targets?

Nitrogen – fertilizer & explosives production

A message of successful geoengineering and the need for huge natural gas supplies to produce hydrogen

I want to encourage you to read Oliver Morton's book "The Planet Remade" (2016): specifically Chapter 7 simply titled "Nitrogen".

It describes the Haber- Bosch process of fixing nitrogen discovered by 2 German scientists in 1919.

High temp stream of N_2 and H_2 over a catalyst.

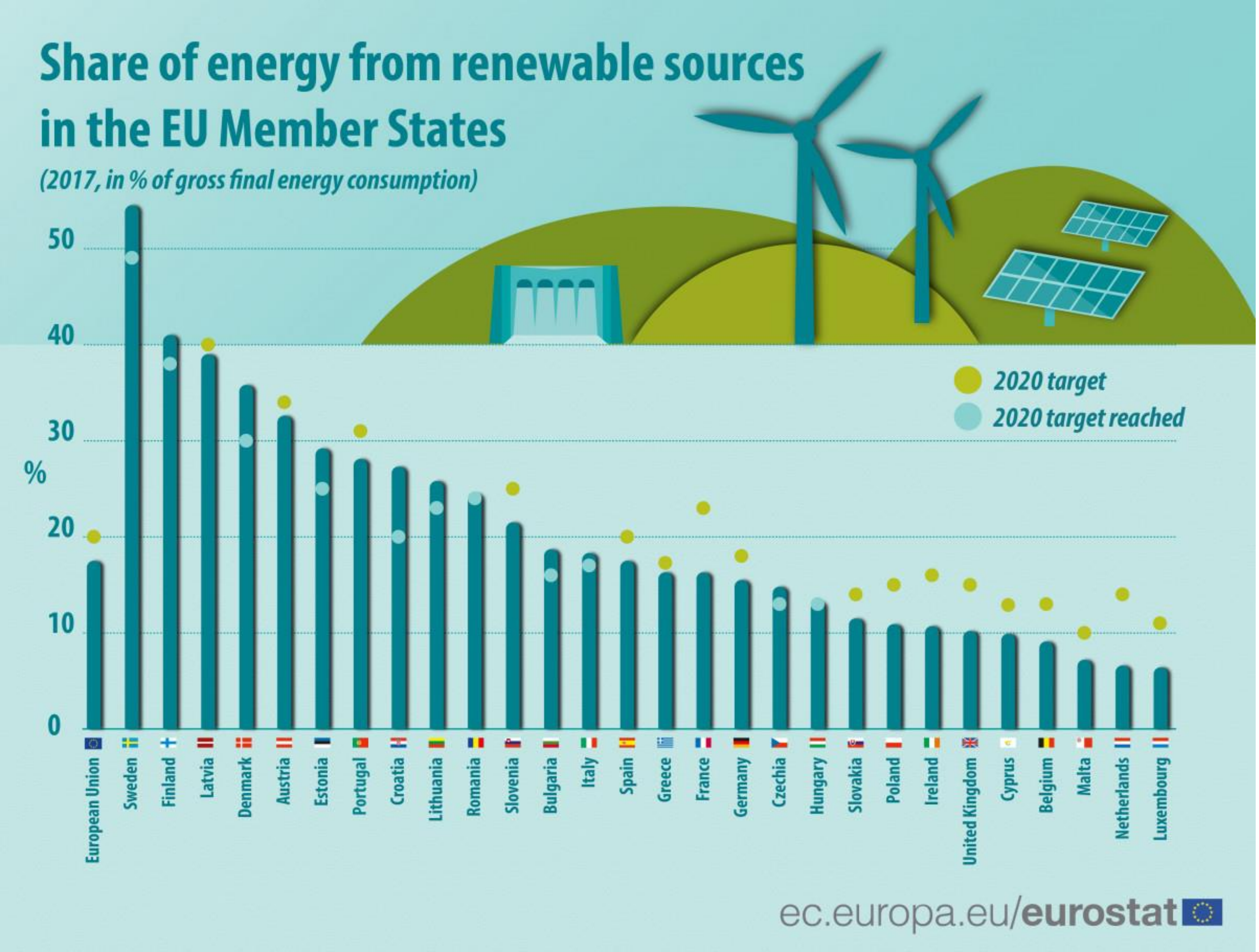
Hydrogen sourced from natural gas (3 to 5% of world NG supply: 1 to 2% of world energy supply)

The planet was running out of food. Natural sources of fixed nitrogen were being depleted (lake nitrates of Chile and guano deposits). Ammonia was in high demand making explosives.

The Haber-Bosch process is the best example of climate geoengineering taking a key constituent of the atmosphere (nitrogen), fixing it with hydrogen and saving the planet. Feeding the rapidly growing population. 3 Nobel prizes awarded. Can we and should we find a similar chemical process for fixing CO_2?

Demand grew from 500,000 tonnes in 1940s to 200+ million tonnes annually (10% used to produce biofuels) of ammonium nitrate /urea.

Not without problems: algae blooms, burning biofuels producing $NO_{X,}$ N_2O etc.



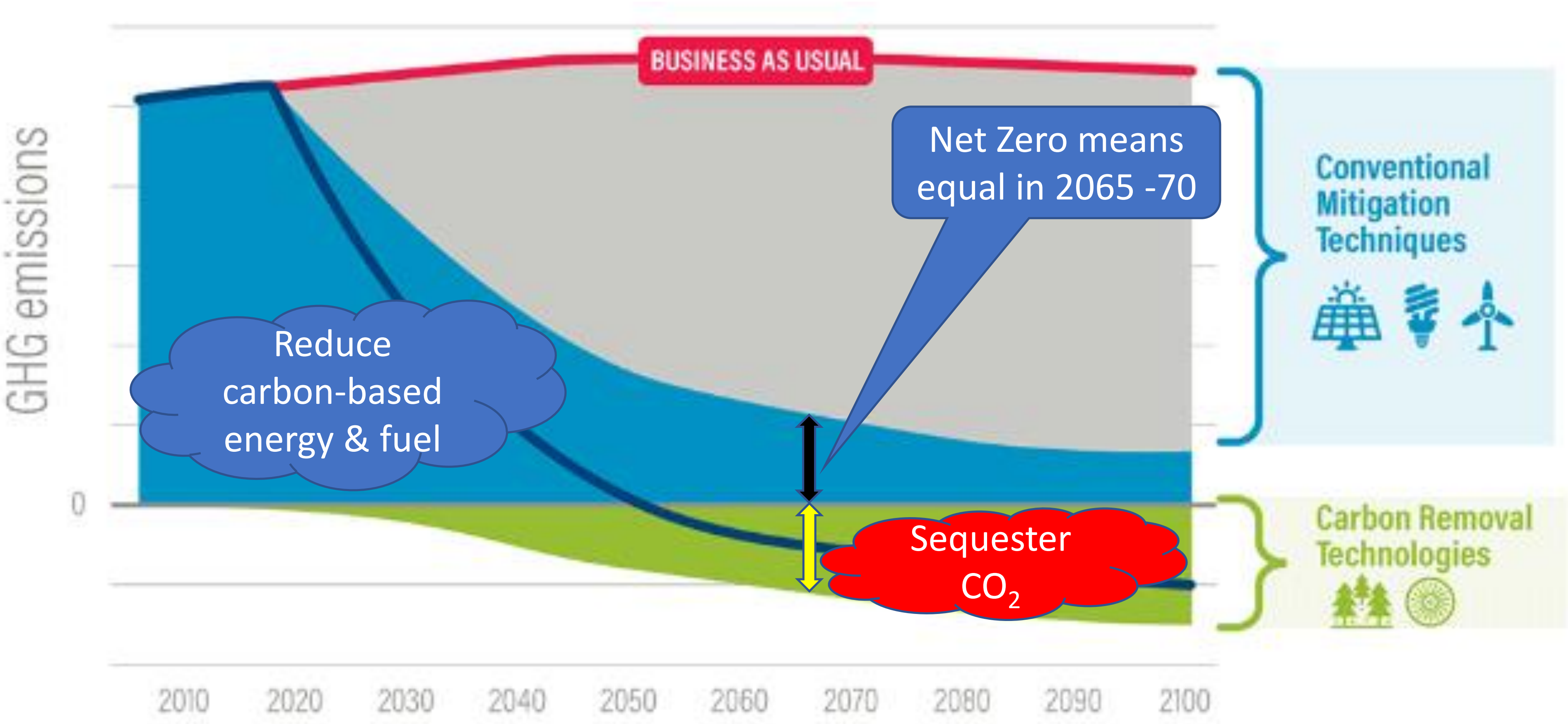
Share of energy from renewable sources in the EU Member States
(2017, in % of gross final energy consumption)
50
40
30
20
10
0
%
2020 target
2020 target reached
European Union
Sweden
Finland
Latvia
Denmark
Austria
Estonia
Portugal
Croatia
Lithuania
Romania
Slovenia
Bulgaria
Italy
Spain
Greece
France
Germany
Czechia
Hungary
Slovakia
Poland
Ireland
United Kingdom
Cyprus
Belgium
Malta
Netherlands
Luxembourg
ec.europa.eu/eurostat

What Can We Do?

Canada contributes 1.6% of CO_2 emissions and 0.5% world population. No significant change if we disappeared

- Eliminate destination tourism
- Prohibit all recreational travel not accessible by foot, bicycle, horse, canoe, sailboat or electric vehicle.
- If you care, stay at home!
- UN World Tourism estimates 5% of total emission come from far-away tourism (transportation accounts for 75%, accommodations 20%)
- Air travel (IATA, 2018)
  - 4.4 billion travelled by air on 38 million flights (2018)
  - 12% business, 88% tourism
  - Air travel doubled in 15 yrs due to cheap flights & rising income
  - 2.2 billion barrels of jet fuel requires 22 billion barrels oil (6% of world production)
  - 22 x Alberta's annual oil sands output
  - Commercial airliners emit 905 million tonnes CO_2 (2018)
  - 1 return trans Atlantic trip = CO_2 emitted by 80 Tanzanians in 1 year
  - 80% of world population never set foot on an airplane
- World's 314 Cruise ships burn 3 billion barrels oil annually moving 27 million people (2018)
- 47 new cruise ships ordered for delivery 2019 -27 (cruisecritic.com)

To Limit Warming to 1.5^{O}C: Can it be Done??



Paris Agreement, 2015
Report published Oct 2018
IPCC Special Report On Global Warming of 1.5^{O}C