Kyoto Protocol, Paris Climate Agreement, Fossil Fuel Reserves, World Energy Needs, and The Need for Renewable Energy

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2020
https://myelms.umd.edu/courses/1291919

Topics for today:

- **Kyoto Protocol**
- **Paris Climate Agreement**
- **Fossil Fuel Reserves**
- **World Energy Needs**
- **Need for Renewable Energy, Sooner Rather Than Later !**

Lay the ground work for rest of the semester

Lecture 18

19 November 2020

Announcements: Class

- Problem Set #3:

  https://www2.atmos.umd.edu/~rjs/class/fall2020/problem_sets/ACC_2020_problem_set_03.pdf

  and had been due on Thursday, 12 November.

- A few people requested and received extensions

- Final deadline is Mon, 23 Nov, at 6 pm

- Please email both me and Laura McBride <mcbridel@terpmail.umd.edu> with any questions

Monday, 23 November, 6 pm:

Review of Problem Set 3

&

Review of Second Exam

will be held on the normal

class Zoom channel.

Will do our best to record for anyone who can not attend.

Announcements: Outside of Class

1) Today, 5 Nov: AOSC Weekly Seminar (3:30 pm)

Dr. Craig Long, NOAA

Monitoring the stratosphere: events and interactions with the troposphere

The NOAA Climate Prediction Center (CPC) monitors the stratosphere for both short term events and for long term trends. This presentation will provide an overview of what CPC monitors in the stratosphere and why. Short term events include Sudden Stratospheric Warmings and alternatively Vortex Intensification. Both events are not only unique to the stratosphere, but also can impact the tropospheric circulation for multiple weeks. Another short term event is the Antarctic Ozone Hole and, the quite rare, Arctic Ozone Hole. These “manmade” phenomena have only been in existence since the 1980’s. However, they too have impacts upon the tropospheric circulation. CPC utilizes NCEP models to forecast the development of these events and then monitors them as they develop, peak, and decline. CPC then relates these events with past events to determine relationships with precursors. Lastly, CPC then historically relates these events to determine patterns or trends. As time allows, additional topics that will be presented are Stratospheric Intrusions and the UV Index forecasts.

https://aosc.umd.edu/seminars/department-seminar

Email Joseph Knisely at jknisely@umd.edu for Zoom connection info

AT 18

Q1. According to Chemistry in Context, what was the goal of the Kyoto Protocol?

- Binding emission reduction targets for six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6), relative to 1990 emission levels, among 38 developed nations.

  Good job!

- Binding emission reduction of CO_2, the most important anthropogenic GHG, relative to 1990 emission levels, among 38 developed nations.

  The Kyoto Protocol considers CH_4, N_2O, HFCs, PFCs, and SF_6, in addition to CO_2.

- Binding emission reduction targets for six greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6), relative to 1990 emission levels, among nearly all of the nations of the world.

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AT 18

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Correct Answer

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Kyoto Protocol

- Negotiated in Kyoto, Japan in November 1997
  - Annex I countries: Developed countries (Table 10.1 of Houghton) with varying emission targets, 2008-2012 relative to 1990, ranging from +10% (Iceland) to –8% (EU-15)

Table 10.1 *Emissions targets (1990*–2008/2012) for greenhouse gases under the Kyoto Protocol*

Country	Target (%)
EU-15**, Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Romania, Slovakia, Slovenia, Switzerland	−8
USA***	−7
Canada, Hungary, Japan, Poland	−6
Croatia	−5
New Zealand, Russian Federation, Ukraine	0
Norway	+1
Australia	+8
Iceland	+10

* Some economies in transition (EIT) countries have a baseline other than 1990.
** The fifteen countries of the European Union have agreed an average reduction; changes for individual countries vary from −28% for Luxembourg, −21% for Denmark and Germany to +25% for Greece and +27% for Portugal.
*** The USA has stated that it will not ratify the Protocol.

Houghton, *Global Warming: The Complete Briefing*, 3d Edition, 2004

Kyoto Gases

GHG	GWP, 100-yr	Industrial Use	Lifetime
CO_2	1	Fossil fuel combustion; Land use changes	Multiple
CH_4	28	Fossil fuel combustion; Rice paddies; Animal waste; Sewage treatment and landfills; Biomass burning	12.4 yrs
N_2O	265	Agriculture & river chemistry associated with pollution Biomass burning & fossil fuel combustion	121 yrs
HFCs	116 to 12,400	Refrigerant (HFC–143a: $C_2H_3F_3$), foam blowing agent, and by product of HCFC manufacture	Range from 1.3 to 242 yrs
PFCs	6290 to 11,100	Aluminum smelting (CF_4) Semiconductor manufacturing (CF_4)	2000 to 50,000 yrs
SF_6	23,500	Insulator in high voltage electrical equipment Magnesium casting Shoes and tennis balls (minor source)	3200 yrs

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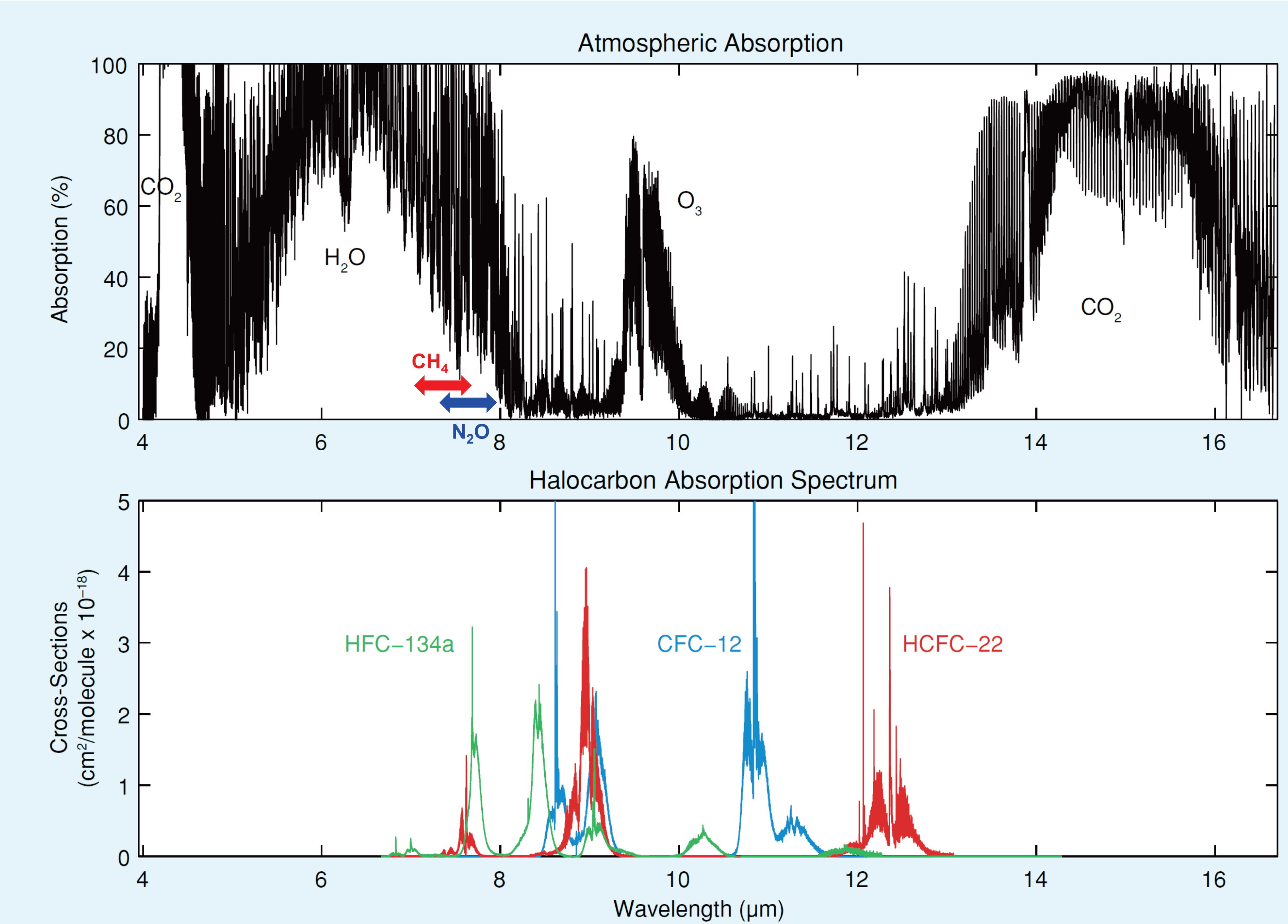
Absorption vs. Wavelength



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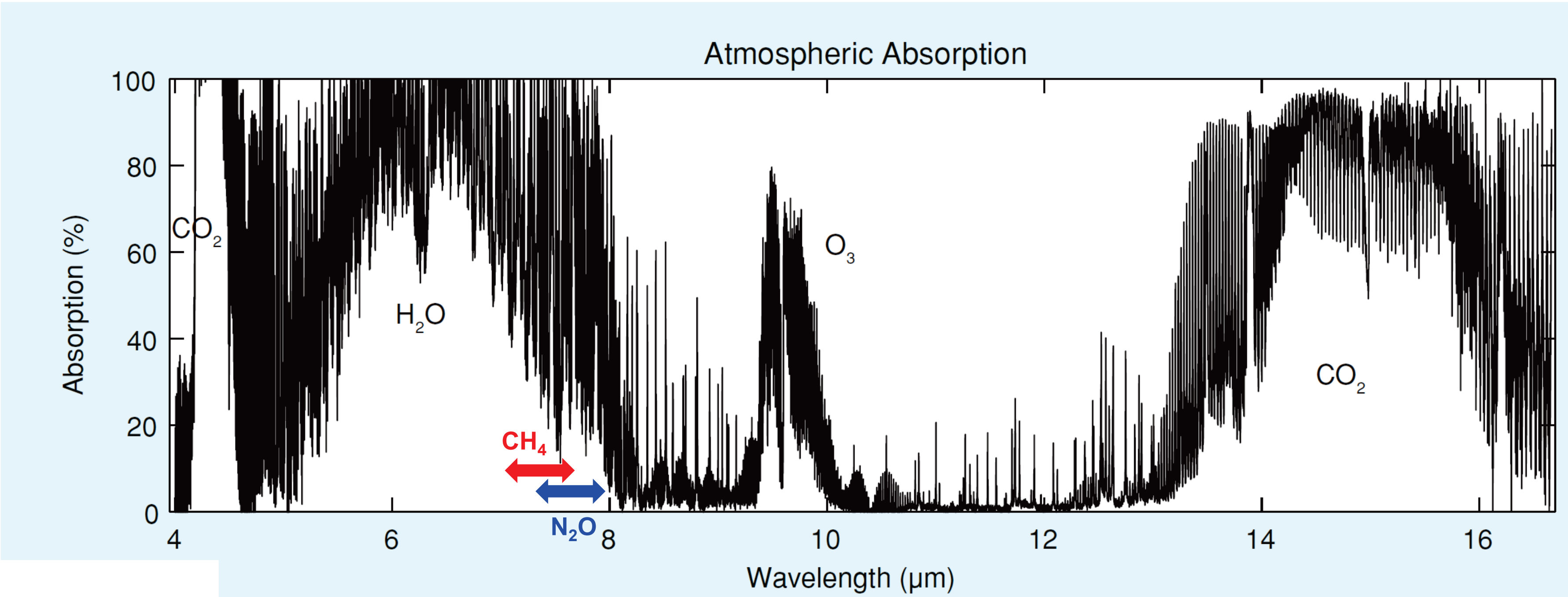

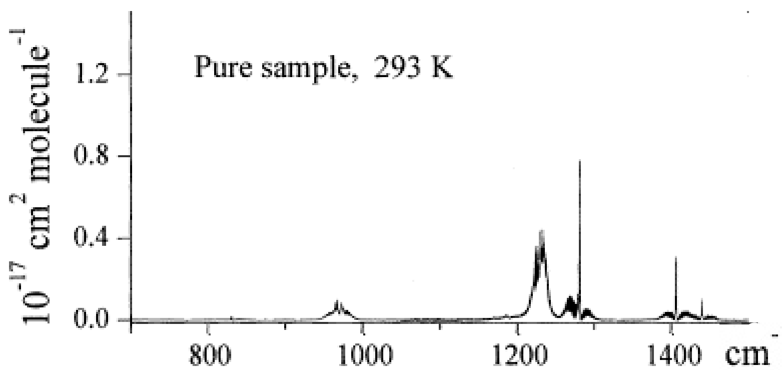

Absorption cross section of HFC-143a
DiLonardo and Masciarelli, 2000
https://www.sciencedirect.com/science/article/pii/S0022407399002125

Wavenumber = 1 / Wavelength

1 / 1220 cm^{-1} = 8.2×10^{-4} cm = 8.2×10^{-6} m = 8.2 μm

GWP – Global Warming Potential

$$\text{GWP (HFC}-143\text{a)} = \frac{\int_{\text{time initial}}^{\text{time final}} a_{\text{HFC}-143\text{a}} \times [\text{HFC}-143\text{a(t)}]\ \text{dt}}{\int_{\text{time initial}}^{\text{time final}} a_{\text{CO2}} \times [\text{CO}_2\text{(t) dt}]}$$

where:

$a_{HFC-143a}$ = Radiative Efficiency (W m^{-2} ppb^{-1}) due to HFC-143a

a_{CO2} = Radiative Efficiency (W m^{-2} ppb^{-1}) due to CO_2

HFC-143a (t) = time-dependent response to an instantaneous release of a pulse of HFC-143a

CO_2 (t) = time-dependent response to an instantaneous release of a pulse of CO_2

Note: HFC-143a is $C_2H_3F_3$
HCFC-22 is CH_3CClF_2

		GWP Time Horizon		ODP
	τ (yr)	20-yr	100-yr	n.a.
HFC-143a	51	7050	5080	0
HCFC-22	12	5310	1780	0.034
CFC-11	52	7090	5160	1.0

Table 8.A.1, IPCC (2013)

Not all HFCs are equal wrt Global Warming

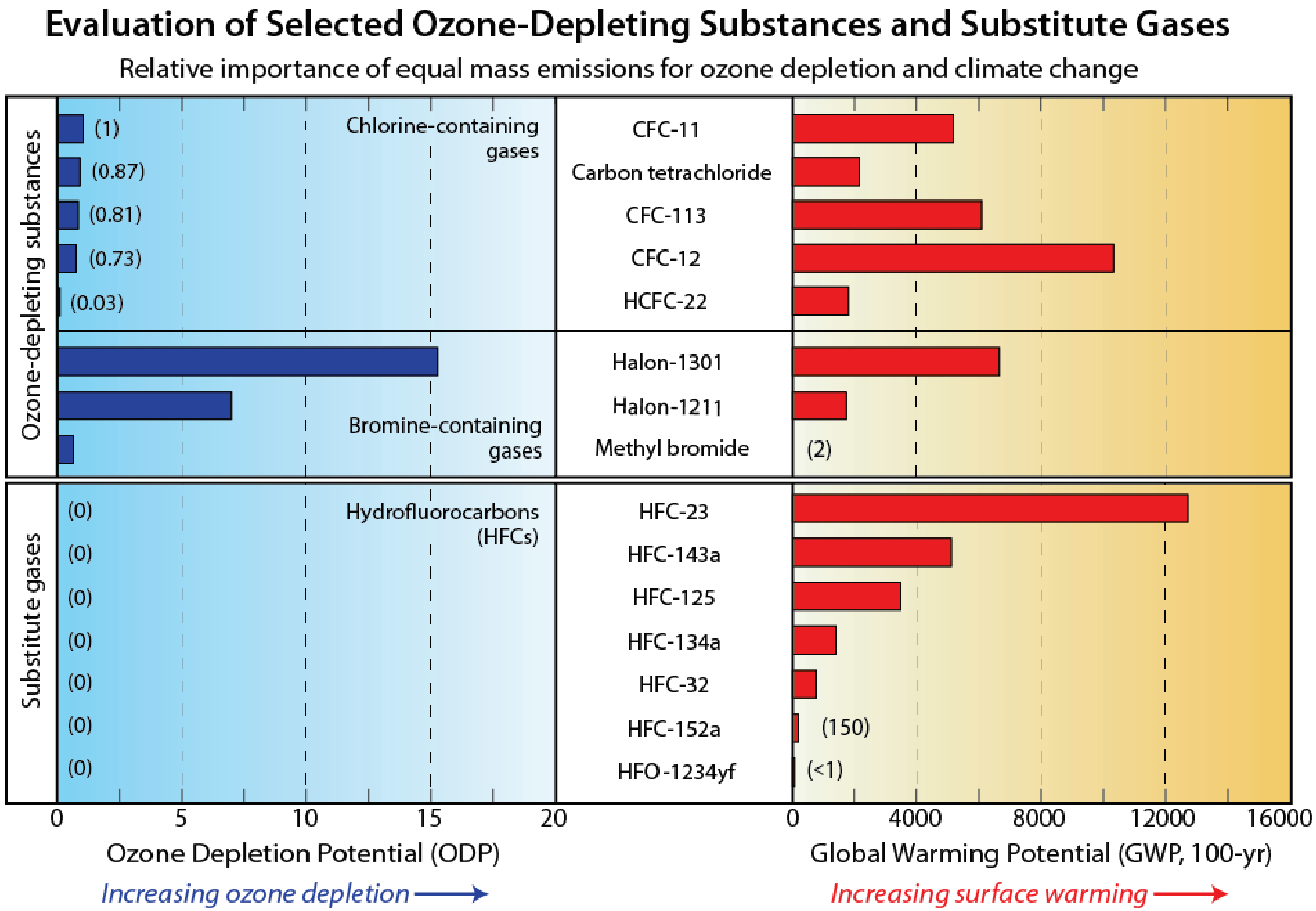

Fig Q17-3, *WMO/UNEP Twenty QAs Ozone*

Kigali Amendment to the Montreal Protocol

Kigali, Rwanda, October 2016
Placed HFCs, which have an ODP of 0.0, under the Montreal Protocol

https://www.unenvironment.org/news-and-stories/news/kigali-amendment-montreal-protocol-another-global-commitment-stop-climate

Konstantina Birbili
Executive Secretary of the U.N. Vienna Convention for the Protection of the Ozone Layer
PhD in Environmental Management and Economics from Imperial College of Science, Technology and Medicine, London
https://en.wikipedia.org/wiki/Tina_Birbili

Vincent Biruta
Minister of the Environment, Rwanda
Physician; Masters in Planning and Management from University of Brussels, Belgium
https://en.wikipedia.org/wiki/Vincent_Biruta

Effect of the Kigali Amendment to the Montreal Protocol

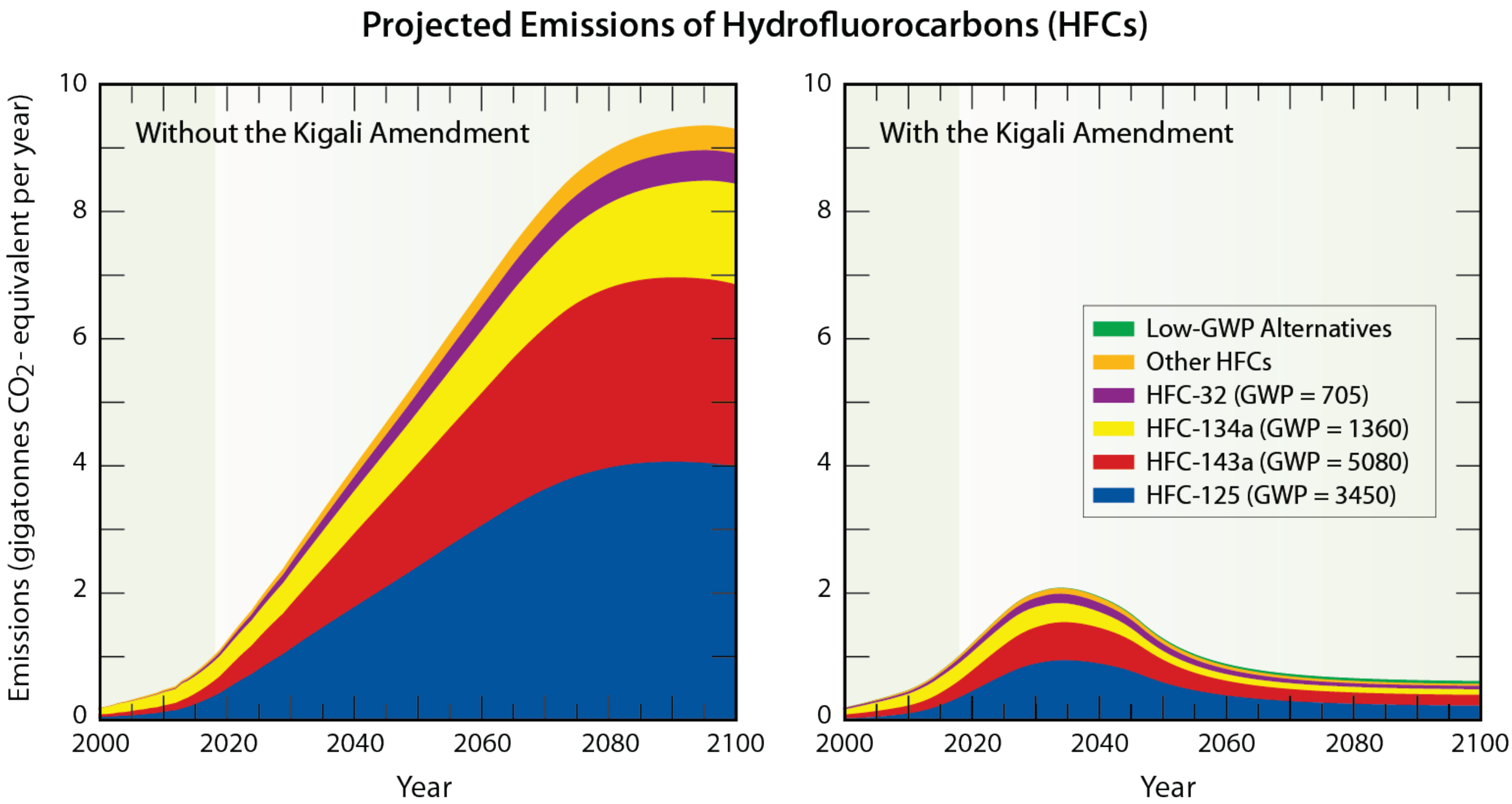

Fig Q19-1, *WMO/UNEP Twenty QAs Ozone*

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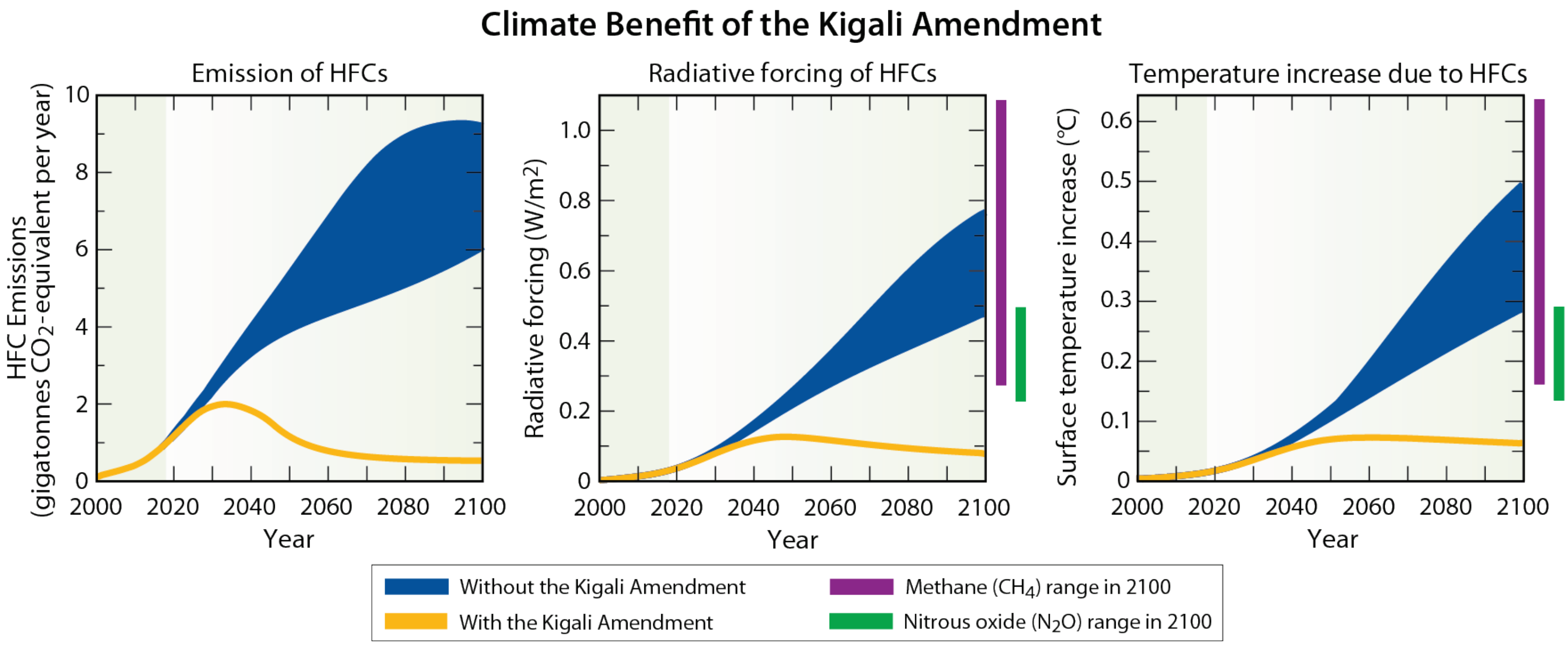


Fig Q19-2, *WMO/UNEP Twenty QAs Ozone*

Radiative Forcing due to PFCs

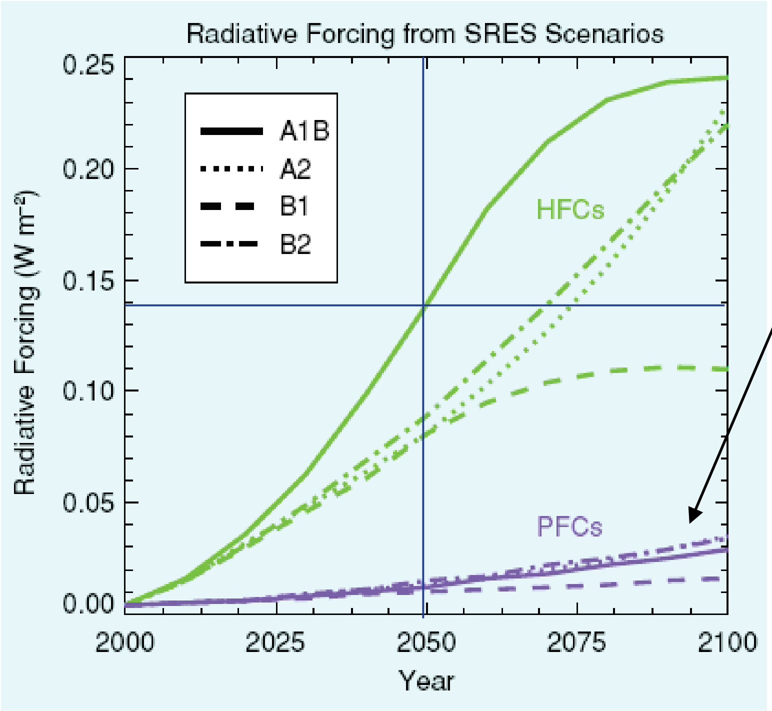


Fig 2.9

IPCC "SROC": Special Report on Safeguarding the Ozone Layer & Global Climate System, 2005

http://www.ipcc.ch/pdf/special-reports/sroc/sroc_full.pdf

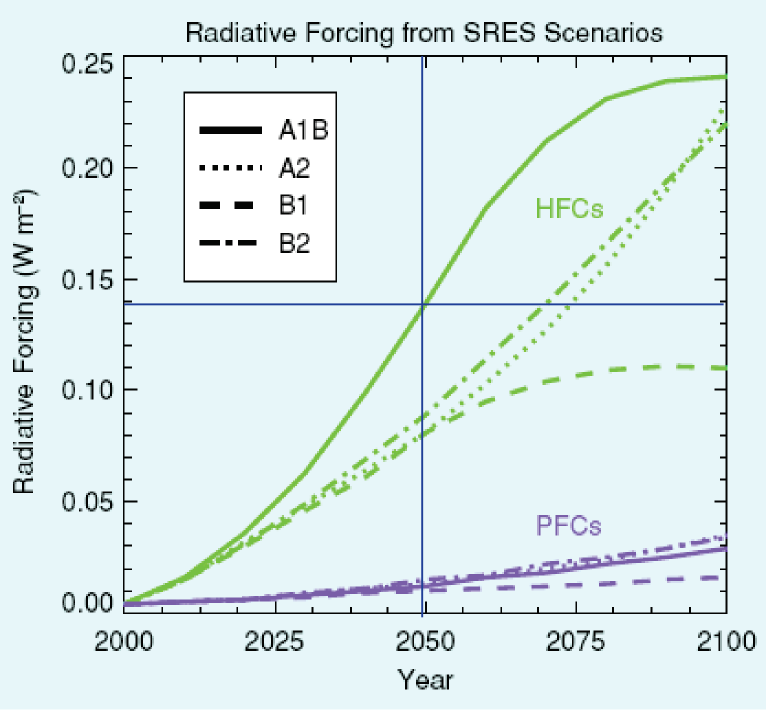
PFC: Perfluorocarbons

- Contain only C & F
- Strong bonds: chemically stable

  τ_{CF4} = 50,000 yr !
- Applications: medical, electrical, cosmetics

https://www.sciencedirect.com/science/article/pii/S0950423001000675

Radiative Forcing due to PFCs



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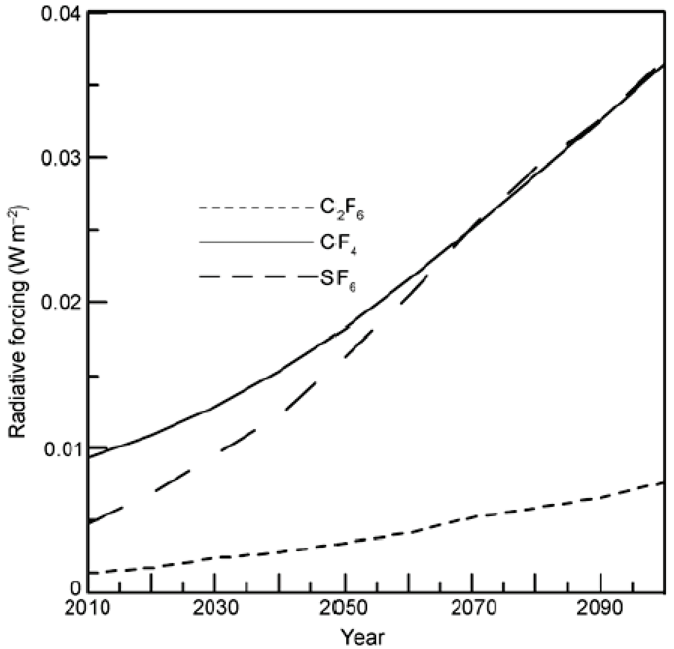
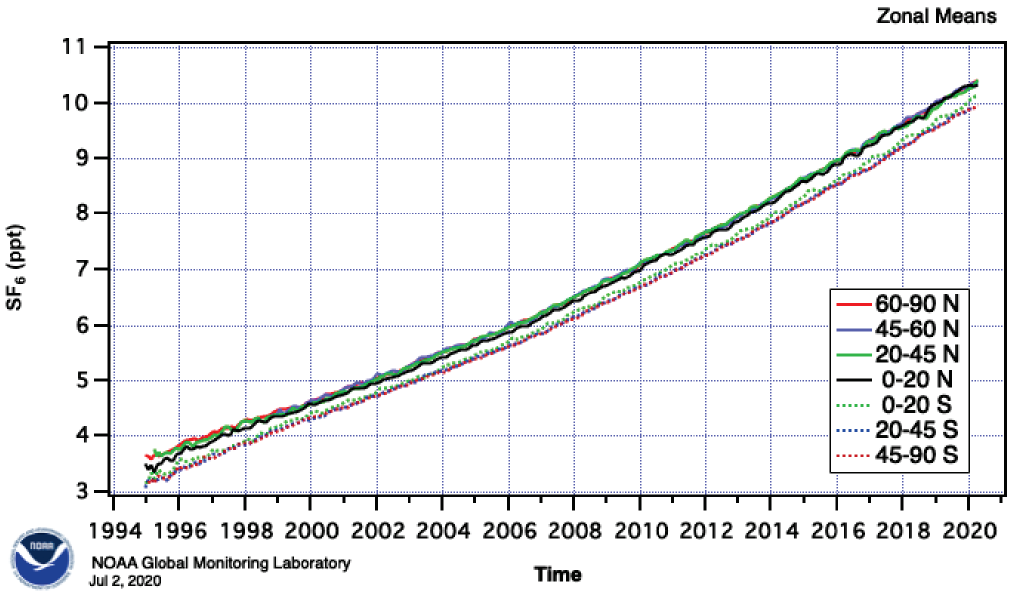


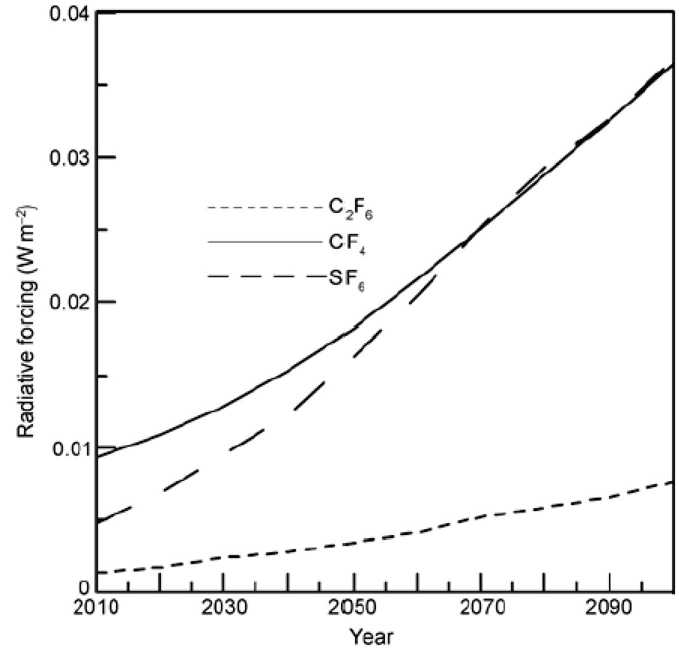
Figure 4 Radiative forcing of C_2F_6, CF_4, and SF_6 from 2010 to 2100.

Zhang et al., Sci China Earth Sci, 2011

Radiative Forcing due to SF_6



https://www.esrl.noaa.gov/gmd/webdata/hats/combined/hats_sf6_zones.png



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SF_6: Sulfur hexafluoride

- τ_{SF6} = 3,200 yr
- Applications: gaseous dielectric in electrical transformers; insulator for windows; retina surgery
- Also had been used in sneakers but Nike has phased out this use:

https://www.bloomberg.com/news/articles/2006-09-24/nike-goes-for-the-green

UNFCCC Basket of Gases

GHG	GWP, 100-yr	Industrial Use	Lifetime
CO_2	1	Fossil fuel combustion; Land use changes	Multiple
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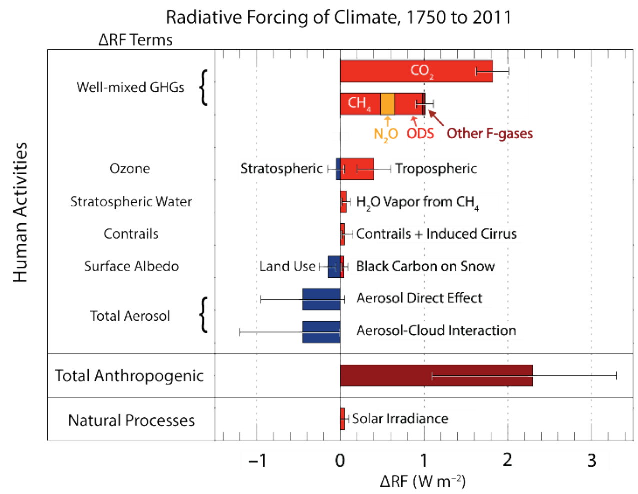

Why doesn't tropospheric ozone appear?

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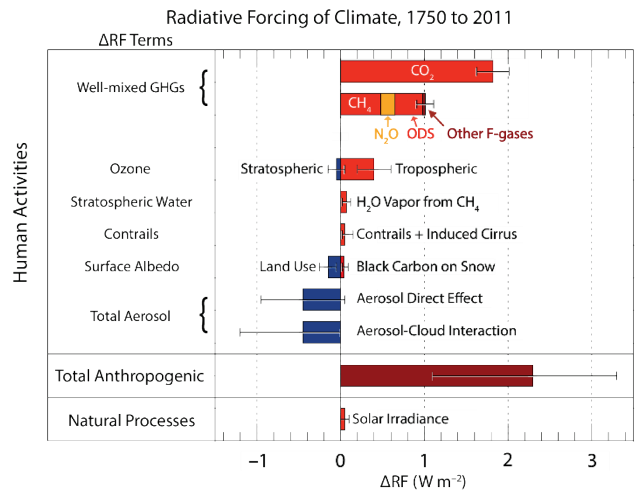

Why doesn't tropospheric ozone appear?

Why not CFCs and HCFCs ?

AT 18

Q2. According to Chemistry in Context:
- a) when did the Kyoto Protocol go into effect?
- b) what country's ratification triggered the Kyoto Protocol going into effect?
- c) what country had never opted to participate, and why did this county opt to not participate?

a) 2005

b) The Russian Federation

c) The United States, due to the fear of serious harm to the U.S. economy

Excellent

---

a) 1997

b) The United States

c) China, due to the fear of serious harm to the Chinese economy

Please review material on page 145 of *Chemistry in Context.*

---

a) 2005

b) China

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Kyoto Protocol

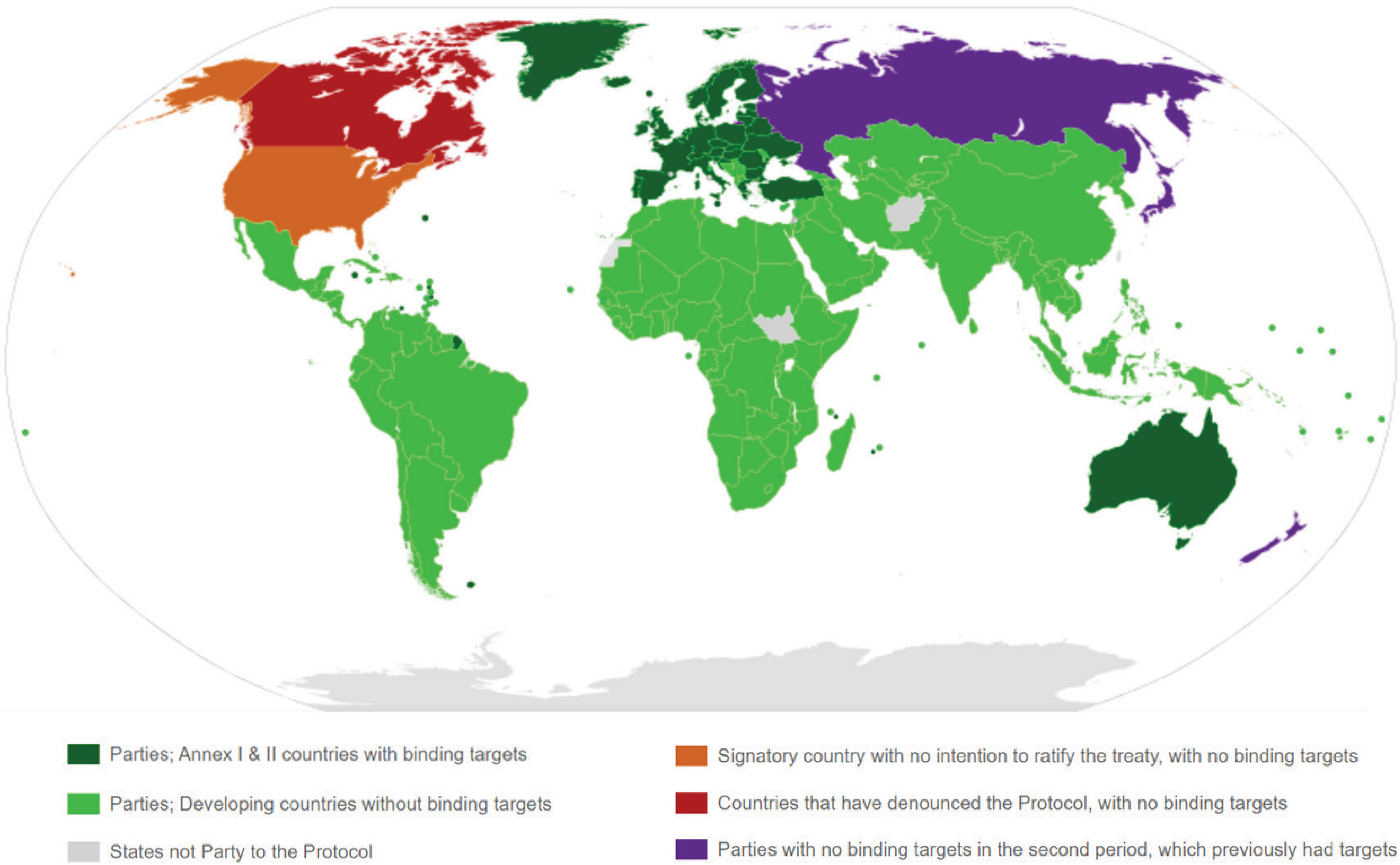
- Negotiated in Kyoto, Japan in November 1997
  - Annex I countries: Developed countries (Table 3.1 of *Paris: Beacon of Hope*) with varying emission targets, 2008-2012 relative to 1990, ranging from +10% (Iceland) to –8% (EU-15)
  - Annex II countries: sub-group of Annex I countries that agree to pay cost of technology for emission reductions in developing countries
    - Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States of America
  - Developing countries: all countries besides those in Table 3.1 of *Paris: Beacon of Hope*
  - Went into effect in 16 February 2005 after signed by __Russia___
- Annex I countries:
  - agree to reduce GHG emissions to target tied to 1990 emissions. If they cannot do so, they must buy emission credits or invest in conservation
- Developing countries:
  - no restrictions on GHG emissions
  - encouraged to use new technology, funded by Annex II countries, to reduce emissions
  - can not sell emission credits

Kyoto Protocol

Table 3.1 Annex I nations of the Kyoto Protocol

Australia	Greece	Norway
Austria	Hungary	Poland
Belarus	Iceland	Portugal
Belgium	Ireland	Romania
Bulgaria	Italy	Russia
Canada	Japan	Slovakia
Croatia	Latvia	Slovenia
Cyprus	Liechtenstein	Spain
Czech Republic	Lithuania	Sweden
Denmark	Luxembourg	Switzerland
Estonia	Malta	Turkey
Finland	Monaco	Ukraine
France	Netherlands	United Kingdom
Germany	New Zealand	United States

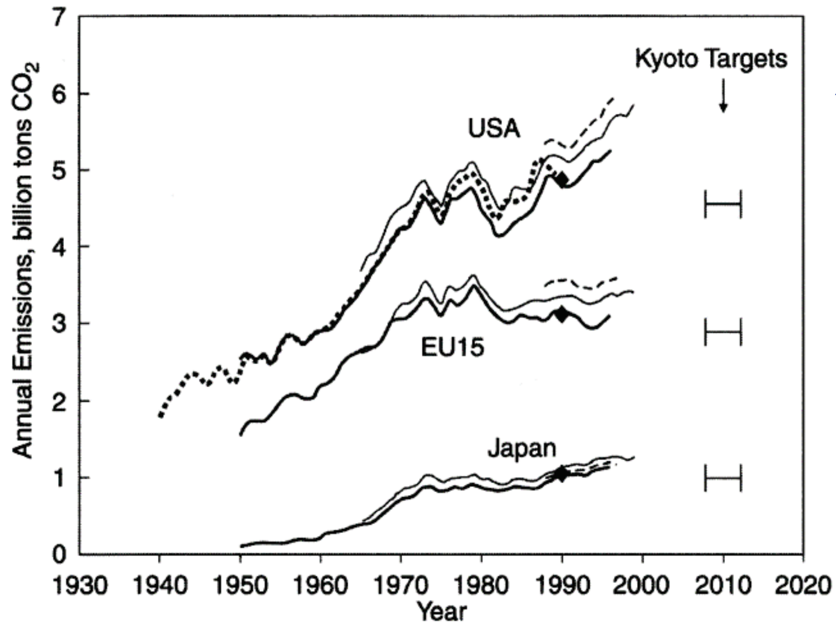
Kyoto Protocol



https://www.climate-change-guide.com/kyoto-protocol.html

Kyoto Protocol Targets

CO_2 emissions



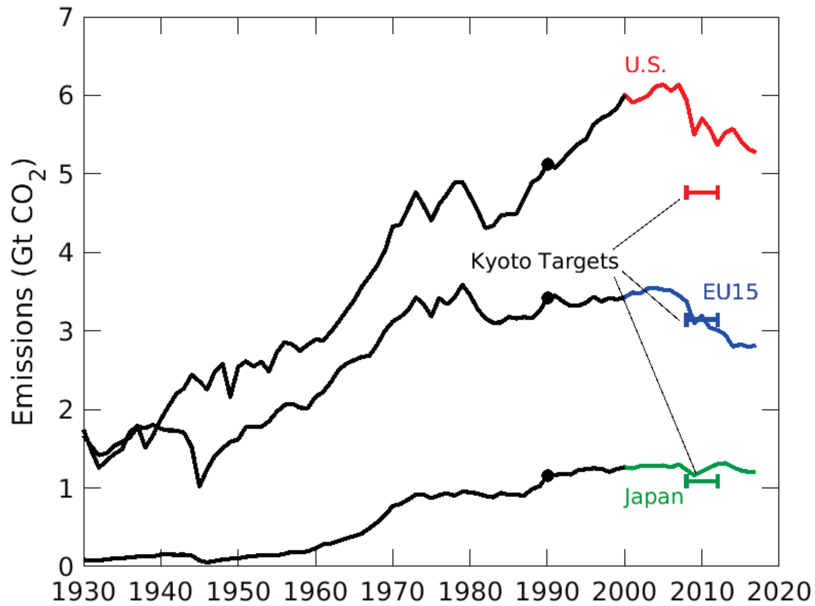
Does not include:
- **LULUCF (land use, land-use change and forestry)**
- **GHGs other than CO_2**

Kyoto target (2008 to 2012) for emissions of CO_2, relative to **1990 emissions**
selected locations

Australia	108%
EU15	92%
Iceland	110%
Japan	94%
New Zealand	100%
Norway	101%
Russia	100%
US	93%

The Collapse of the Kyoto Protocol and the Struggle to Slow Global Warming
David G. Victor, Princeton University Press, 2001.

Kyoto Protocol Targets



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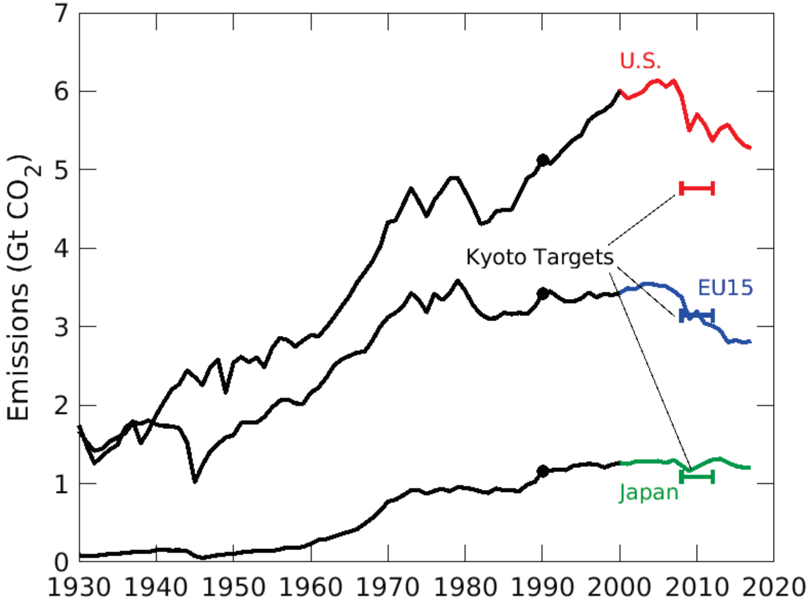

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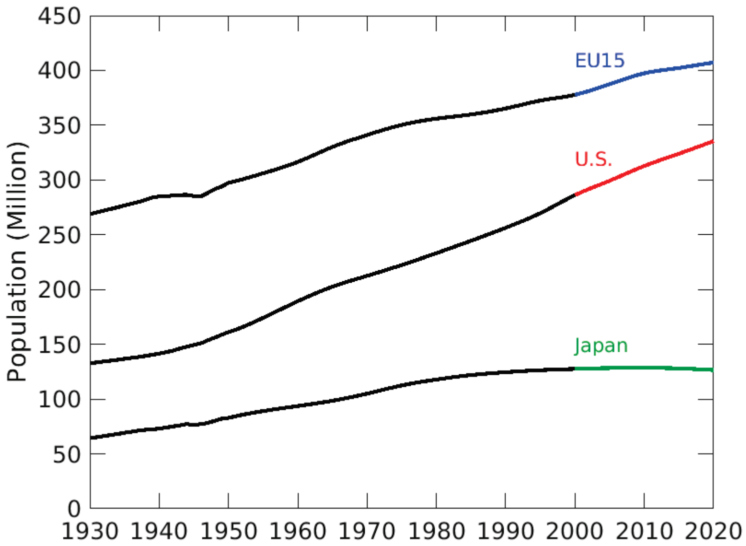

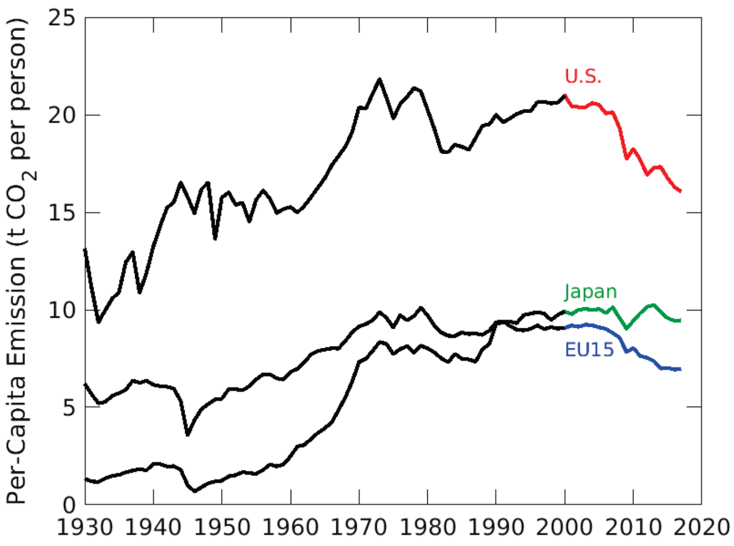

AT 18

Q3: According to *Chemistry in Context*, based on the values of energy difference for combustion of one gram of natural gas and combustion of one gram of coal (assumed for sake of argument to be pure carbon) how much more efficient is the generation of electricity by the combustion of natural gas (CH_4) compared to generation of electricity by the combustion of coal? You may assume the heat released by the two combustion processes can be converted into electricity at the same efficiency.

Correct Answer

○ Since 50.1 kJ/g / 32.8 kJ g = 1.5, about 50% more electricity can be produced via the combustion of natural gas than can be produced by the combustion of coal.

> Indeed; will delve into more nuance of this relation during class.

○ Since 50.1 kJ/g / 14.2 kJ g = 3.5, about 3 times more electricity can be produced via the combustion of natural gas than can be produced by the combustion of coal.

> The value of 14.2 kJ / g is for oxidation of glucose, rather than combustion of coal.

○ Since 32.8 kJ/g / 14.2 kJ g = 2.3, about twice as much electricity can be produced via the combustion of natural gas than can be produced by the combustion of coal.

> The value of 14.2 kJ / g is for oxidation of glucose, rather than combustion of coal.

○ Since 44.4 kJ/g / 28.9 kJ /g = 1.5, about 50% more electricity can be produced via the combustion of natural gas than can be produced bu the combustion of coal.

> The 50% part is correct.
>
> However, 44.4 kJ/g is for octane (here, should use 50.1 kJ/g for natural gas) and the 28.9 kJ/g is for ethanol (here, should use 32.8 kJ/g for coal).

AT 18

Q3: According to *Chemistry in Context*, based on the values of energy difference for combustion of one gram of natural gas and combustion of one gram of coal (assumed for sake of argument to be pure carbon) how much more efficient is the generation of electricity by the combustion of natural gas (CH_4) compared to generation of electricity by the combustion of coal? You may assume the heat released by the two combustion processes can be converted into electricity at the same efficiency.

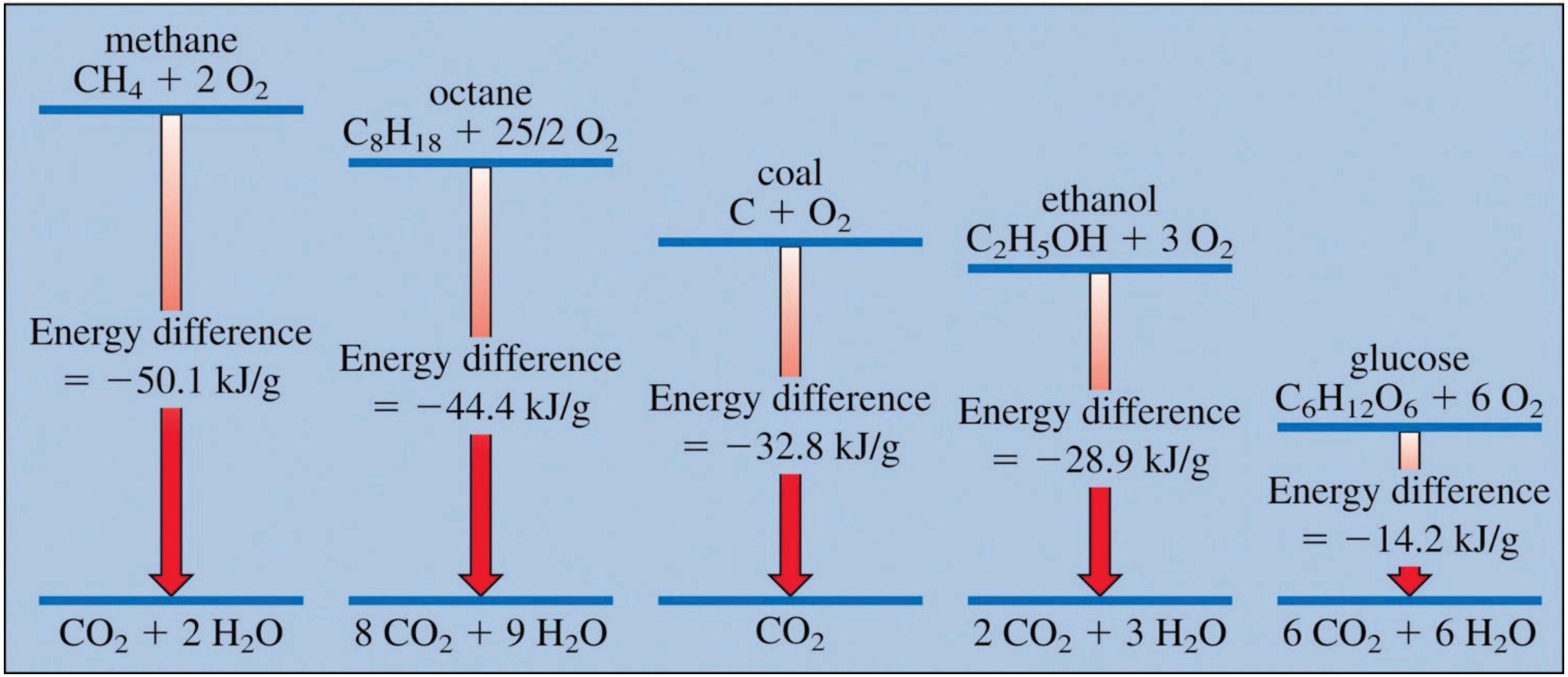

Fig 4.16. Energy differences (in kJ/g) for the combustion of methane (CH_4), n-octane (C_8H_{18}), coal (assumed to be pure carbon), ethanol (C_2H_5OH), and wood (assumed to be glucose).

AT 18

Combustion of 1 gram of CH_4 results of 50.1 kJ of energy
Combustion of 1 gram of C results in 32.8 kJ of energy

Therefore, we might conclude natural gas is 50.1 / 32. 8 = 1.53 times more efficient, which I would write as 53% (i.e., about 50%) more efficient.

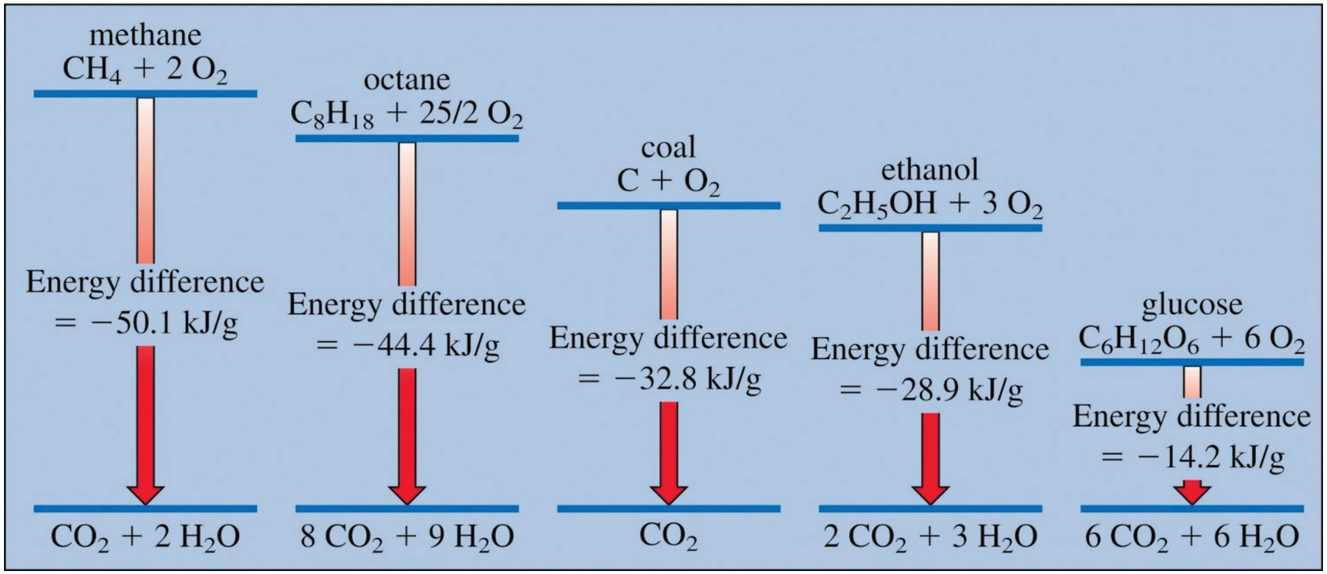

Fig 4.26. Energy differences (in kJ/g) for the combustion of methane (CH_4), n-octane (C_8H_{18}), coal (assumed to be pure carbon), ethanol (C_2H_5OH), and wood (assumed to be glucose).

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Combustion of 1 gram of C results in 32.8 kJ of energy

Therefore, we might conclude natural gas is 50.1 / 32. 8 = 1.53 times more efficient, which I would write as 53% (i.e., about 50%) more efficient.

However, combustion of 1 gram of C results in 44/12 = 3.667 gram of CO_2
whereas combustion of 1 gram of CH_4 results in 44/16 = 2.75 gram of CO_2

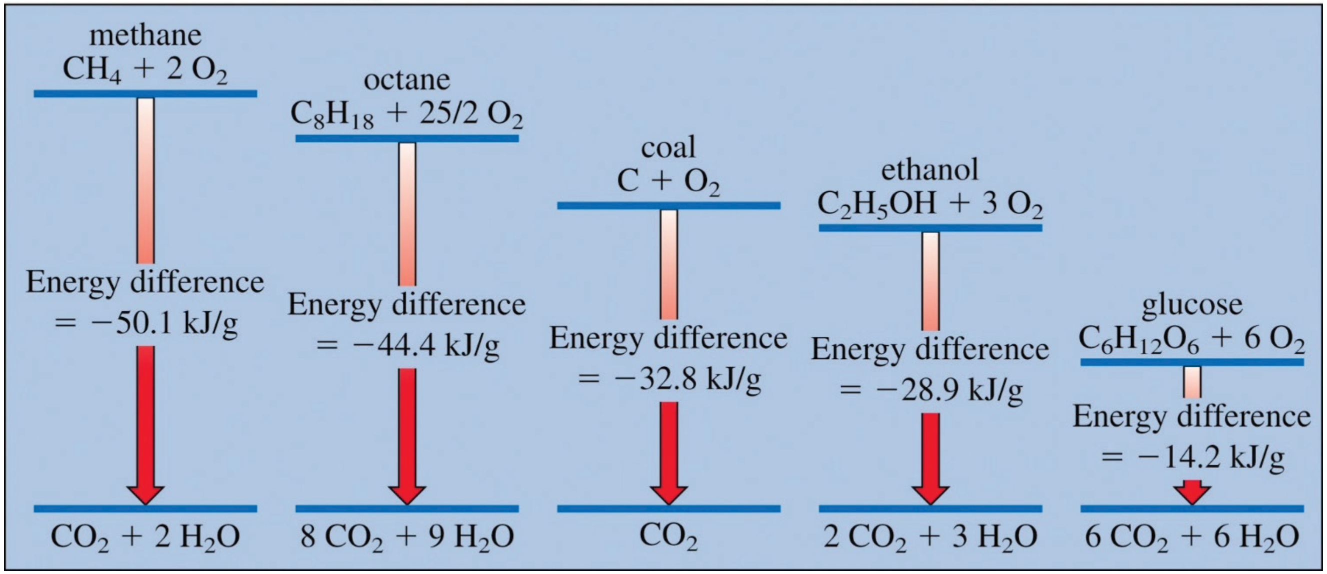

Fig 4.26. Energy differences (in kJ/g) for the combustion of methane (CH_4), n-octane (C_8H_{18}), coal (assumed to be pure carbon), ethanol (C_2H_5OH), and wood (assumed to be glucose).

AT 18

Combustion of 1 gram of CH_4 results of 50.1 kJ of energy
Combustion of 1 gram of C results in 32.8 kJ of energy

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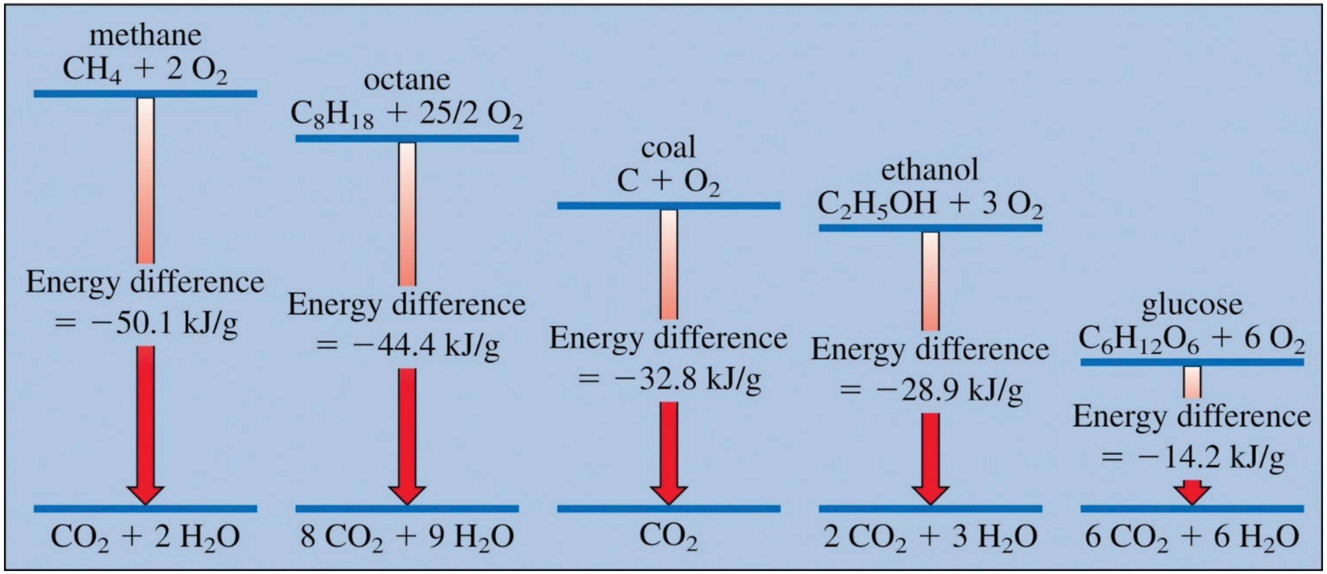

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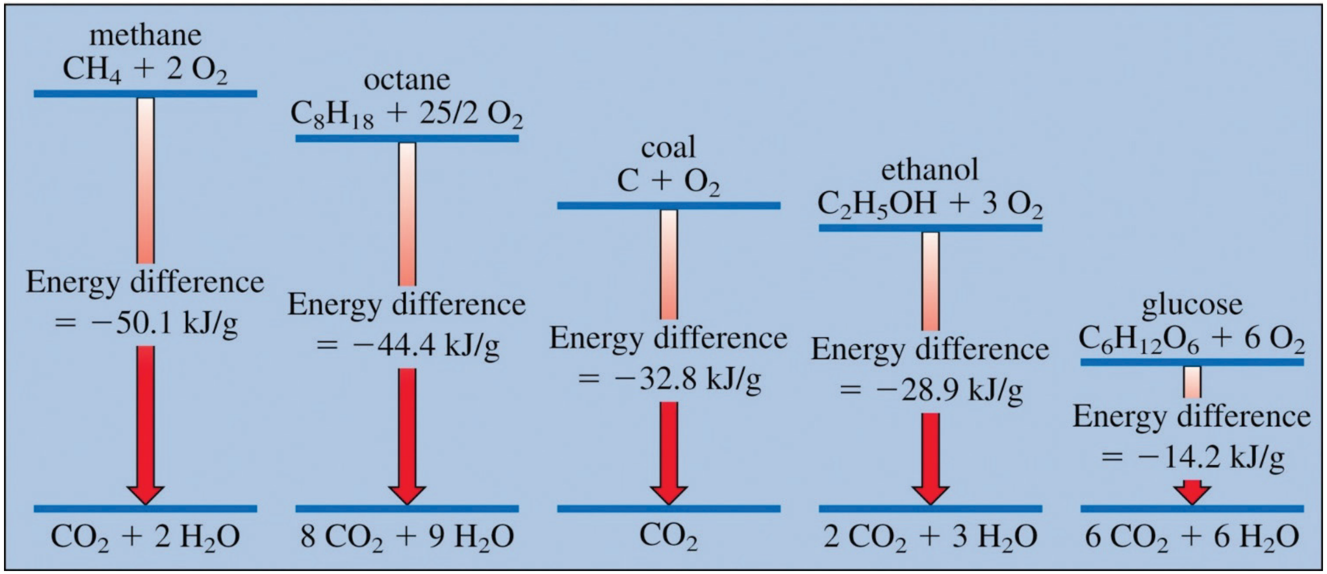
We find natural gas is 1.33 × 1.53 = 2.0; i.e., natural gas is about 100% more efficient than coal.



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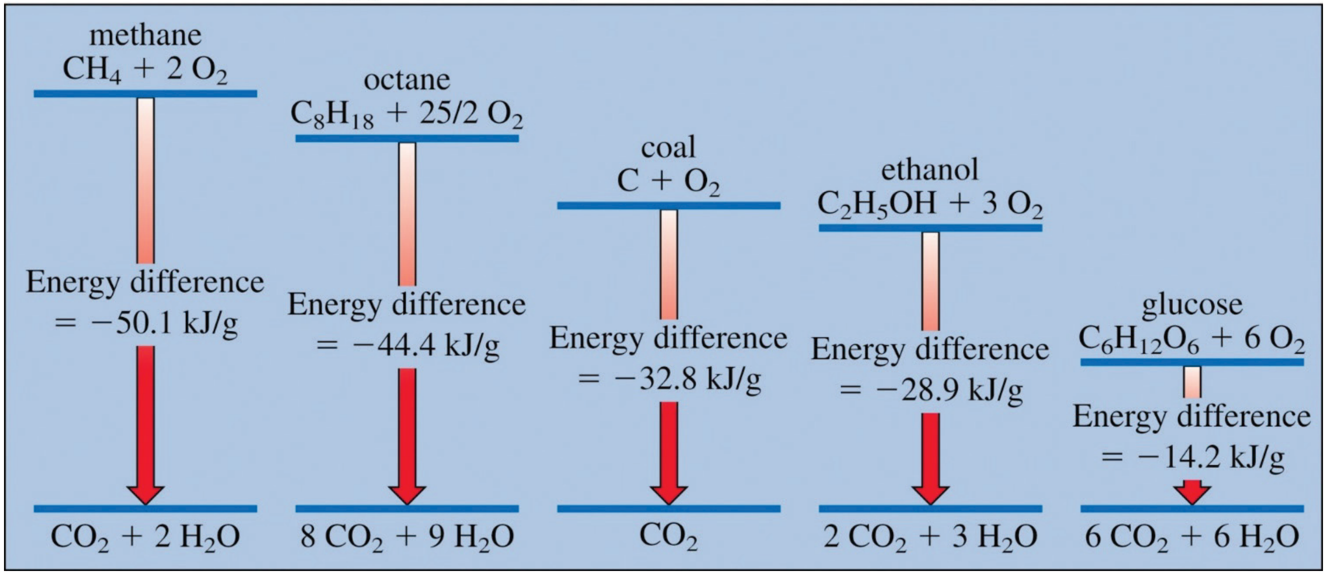
Combustion of 1 gram of C results in 32.8 kJ of energy

Alas, coal is not pure carbon in the real world. Rather, notational formula for coal is $C_{135}H_{96}O_9NS$ (page 162 of *Chemistry in Context*): i.e., coal has a carbon content of 85% by mass.

Therefore, an even better estimate where the ratio of C to H in coal and natural gas is treated in the same manner, we would write:

Natural gas is $(1.33 \times 1.53) / 0.85 = 1.73$; i.e., natural gas is about 70% more efficient than coal, in terms of energy yield per mole of CO_2.



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Future Use of Fossil Fuels

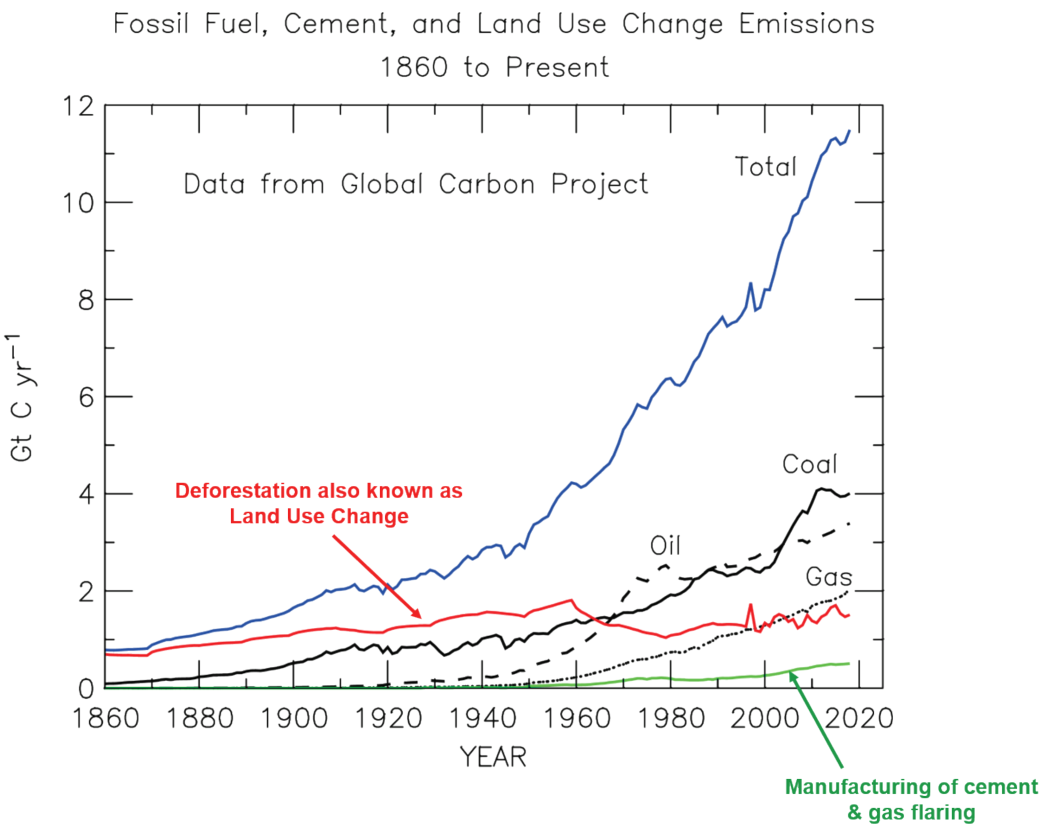
Table that is commonly used:

Fossil Fuel	GHG Output (pounds CO_2 per kWh)
Oil Sands	5.6
Coal	2.1
Oil	1.9
Gas	1.3

Natural gas produces (1/1.3) / (1/2.1) = 1.6; i.e., 61% more energy than coal, per CO_2 released
Natural gas produces (1/1.3) / (1/5.6) = 4.3; i.e., more than 4× more energy than oil sands, per CO_2 released

http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html
https://iopscience.iop.org/article/10.1088/1748-9326/4/1/014005/meta

Fossil Fuel Emissions and Reserves



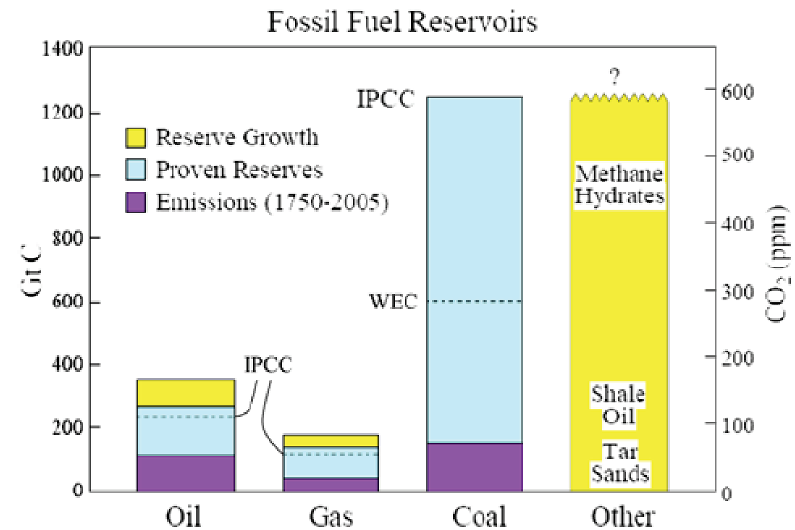
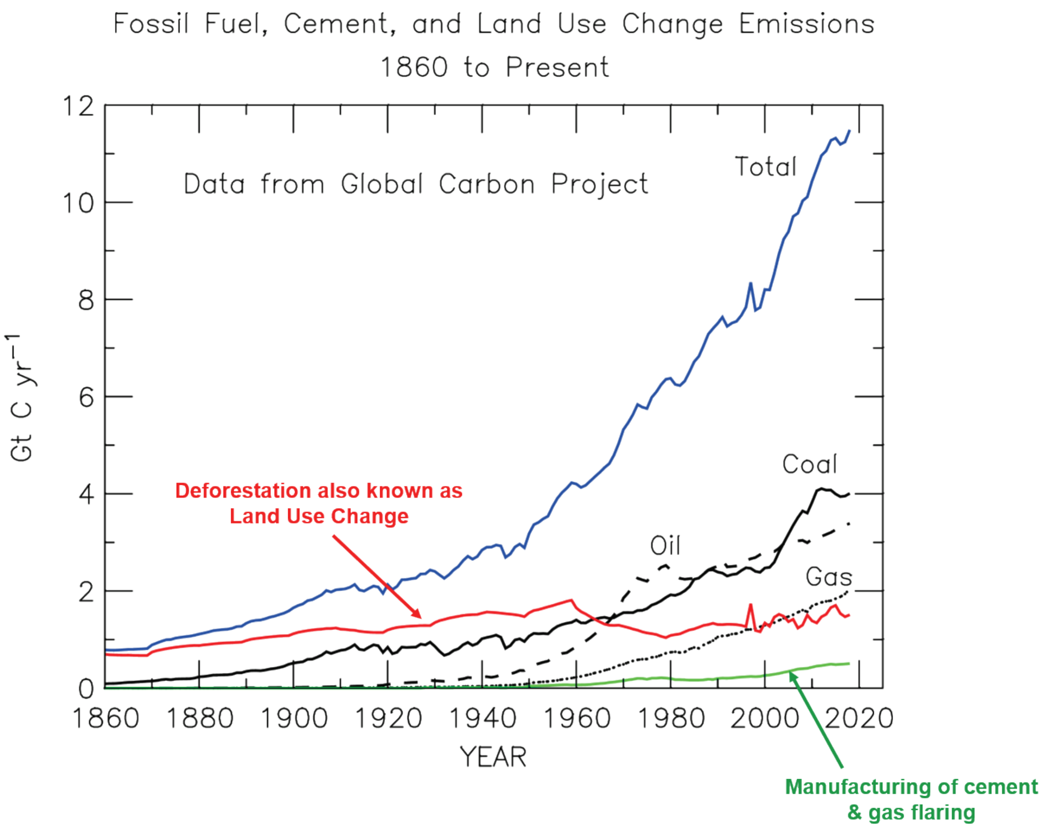


Figure 1. Fossil fuel-related estimates used in this study. Historical fossil fuel CO_2 emissions from the Carbon Dioxide Information Analysis Center [CDIAC; *Marland et al.*, 2006] and British Petroleum [*BP*, 2006]. Lower limits for current proven conventional reserve estimates for oil and gas from *IPCC* [2001a] (dashed lines), upper limits and reserve growth values from US Energy Information Administration [*EIA*, 2006]. Lower limit for conventional coal reserves from World Energy Council [*WEC*, 2007; dashed line], upper limit from *IPCC* [2001a]. Possible amounts of unconventional fossil resources from *IPCC* [2001a].

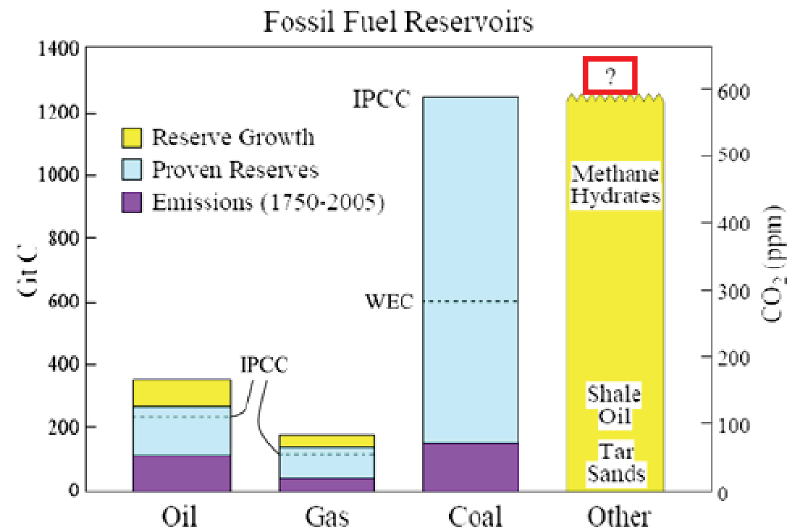
Lecture 5

Kharecha and Hansen, *GBC*, 2008.

Fossil Fuel Emissions and Reserves



Lecture 5



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Kharecha and Hansen, *GBC*, 2008.

Canadian oil sands (tar sands)

- May represent 2/3 of world's total petroleum resource
- Not considered in many estimates of fossil fuel reserves
- Because of oil sands production, **Canada is largest supplier of oil to US**
- About 10 to 20 years ago: “gold rush” like economic boom in Alberta, Canada
- **Fossil fuel extraction energy and water intensive: forests flattened & large waste water lakes created**

See http://en.wikipedia.org/wiki/Tar_sands for more info.

U.S. Petroleum

Earth the Sequel **by Fred Krupp & Miriam Horn states "U.S. vehicle fleet pumps 1.3 billion tons of CO_2 into the atmosphere every year, and $820 million in capital is exported *every day* for the oil needed to do so" in year 2008**

Today, does the U.S. export either a lot more, about the same, or a lot less for oil for our vehicle fleet?

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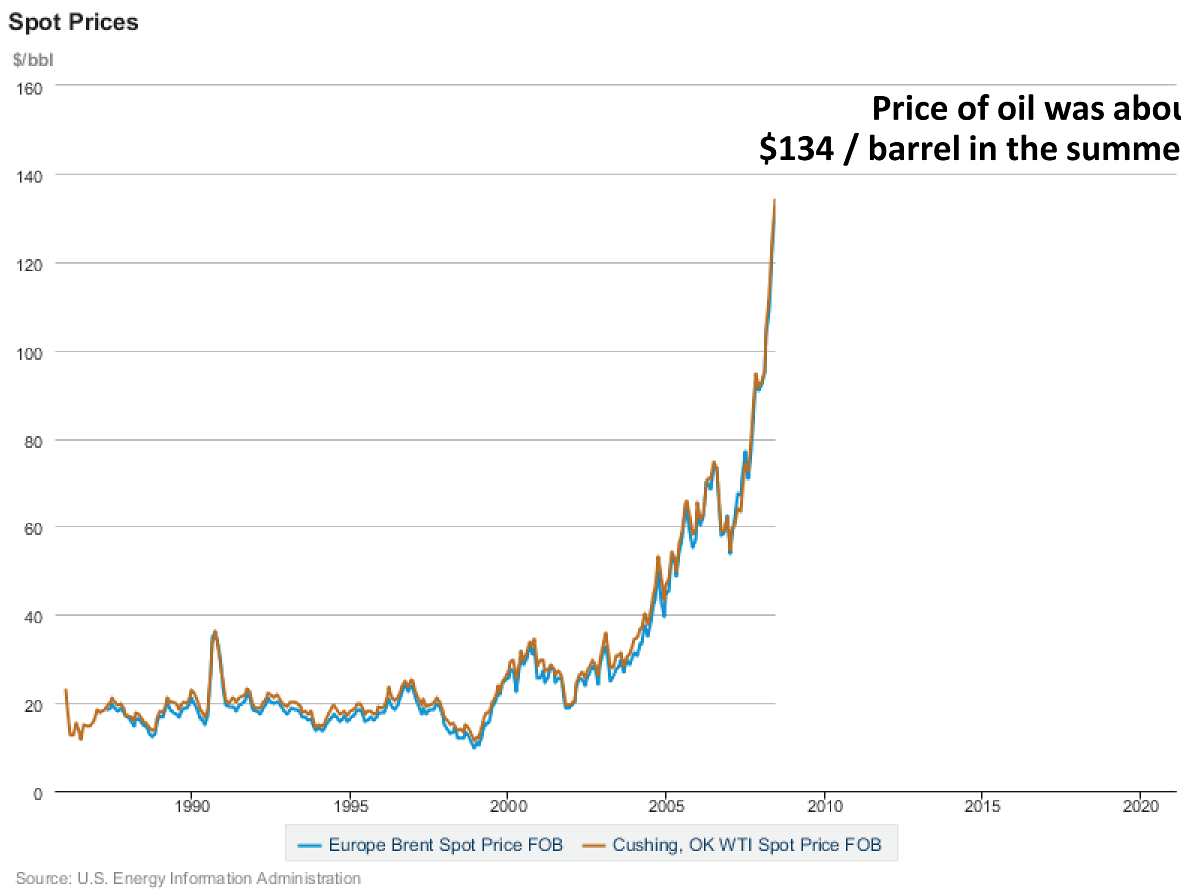

Price of oil was about $134 / barrel in the summer of 2008

https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

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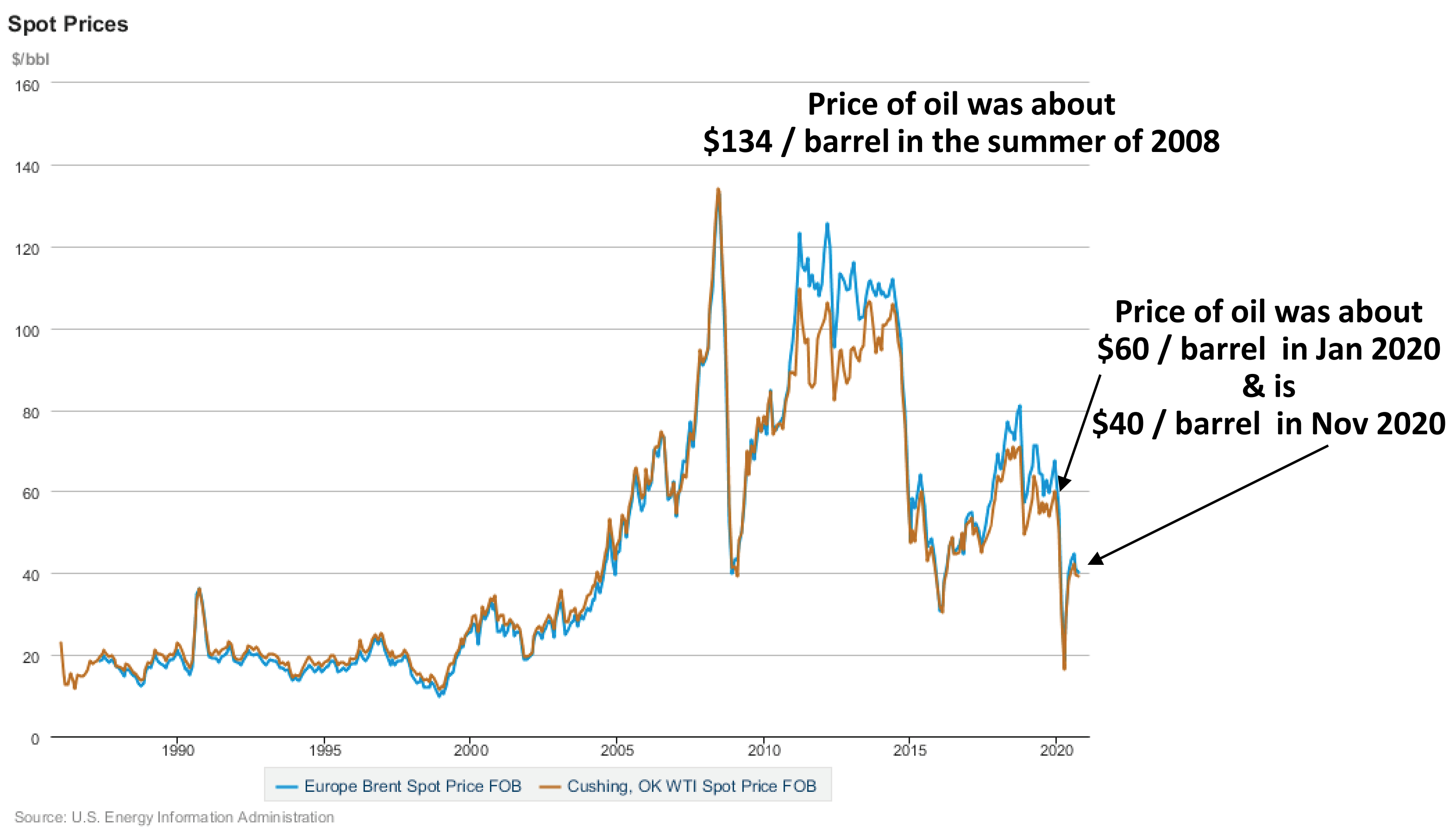
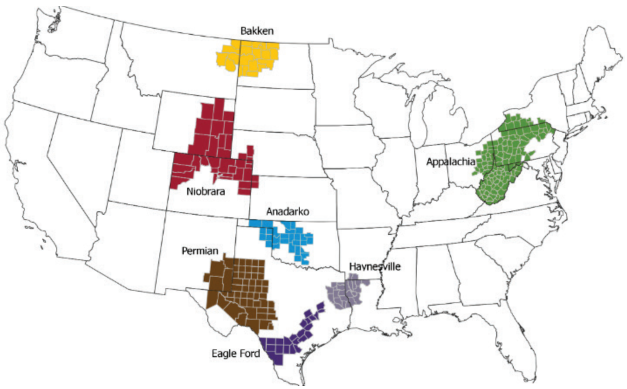


https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm

U.S. Petroleum

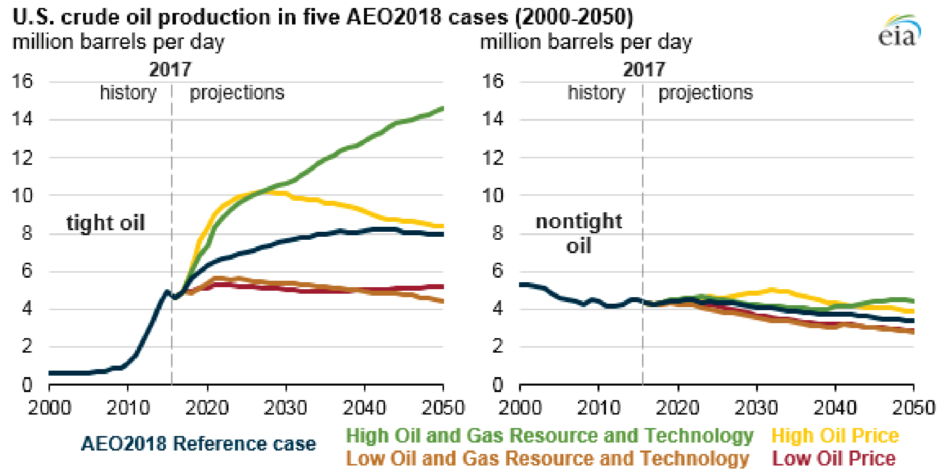
U.S. has greatly expanded production of so-called tight oil https://en.wikipedia.org/wiki/Tight_oil from the Permian, Bakken, and Eagle Ford deposits since 2008:



https://www.cnbc.com/2018/06/13/permian-will-soon-pump-enough-oil-to-be-opecs-2nd-biggest-producer.html

FEBRUARY 22, 2018

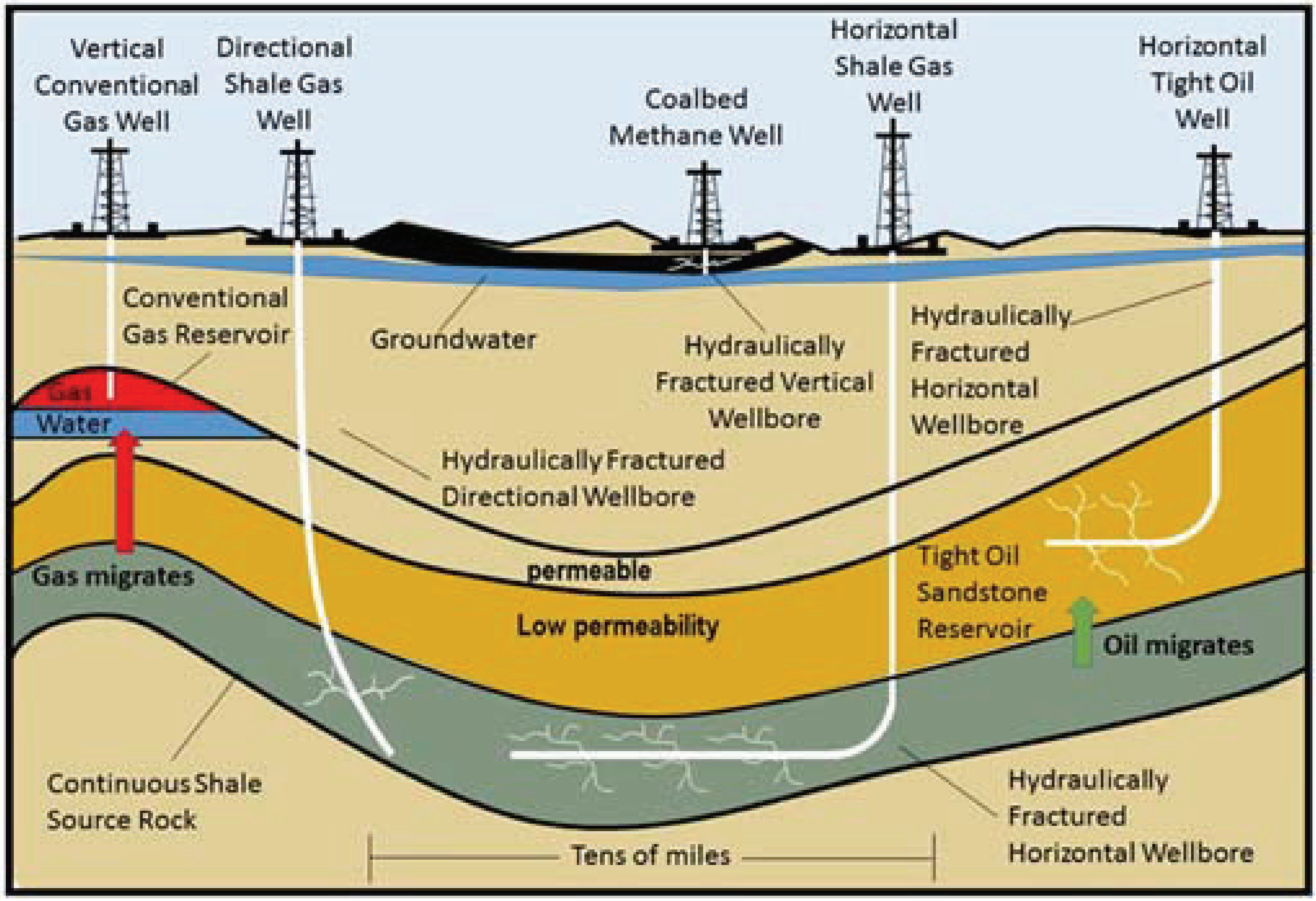
Tight oil remains the leading source of future U.S. crude oil production



https://www.eia.gov/todayinenergy/detail.php?id=35052

U.S. Petroleum

Tight oil is contained in petroleum-bearing formations of low permeability, such as shale or sandstone. Production requires hydraulic fracturing and often uses the same horizontal well technology used in the production of shale gas.

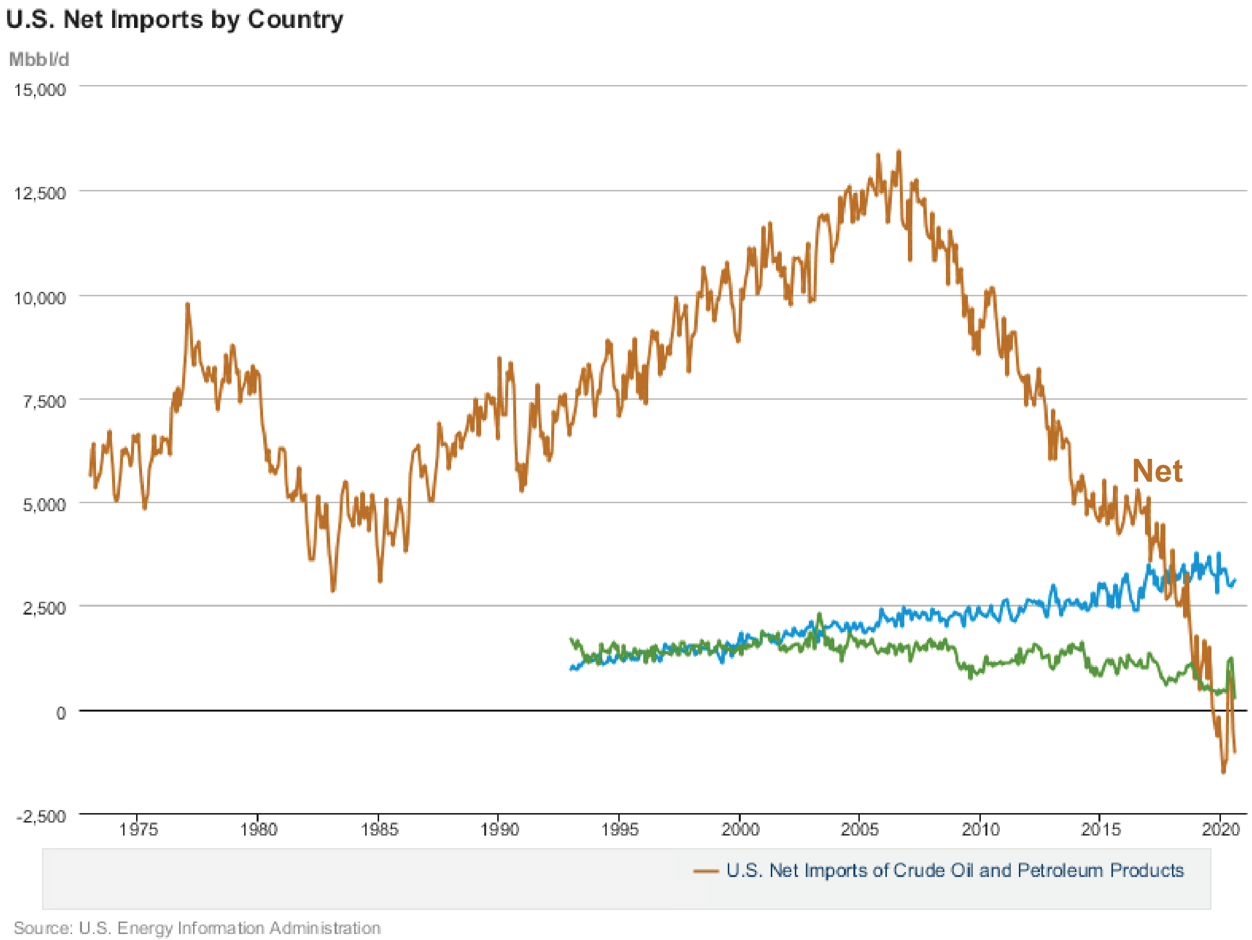


https://www.accessscience.com/content/hydraulic-fracturing-fracking/326700

https://en.wikipedia.org/wiki/Tight_oil

U.S. Petroleum

U.S. became a net exporter of crude oil in August 2019 and,
in January 2020 exported 605 thousand barrels per day in January 2020,
yielding about $38 million in capital per day



https://www.eia.gov/dnav/pet/pet_move_neti_a_EP00_IMN_mbblpd_m.htm

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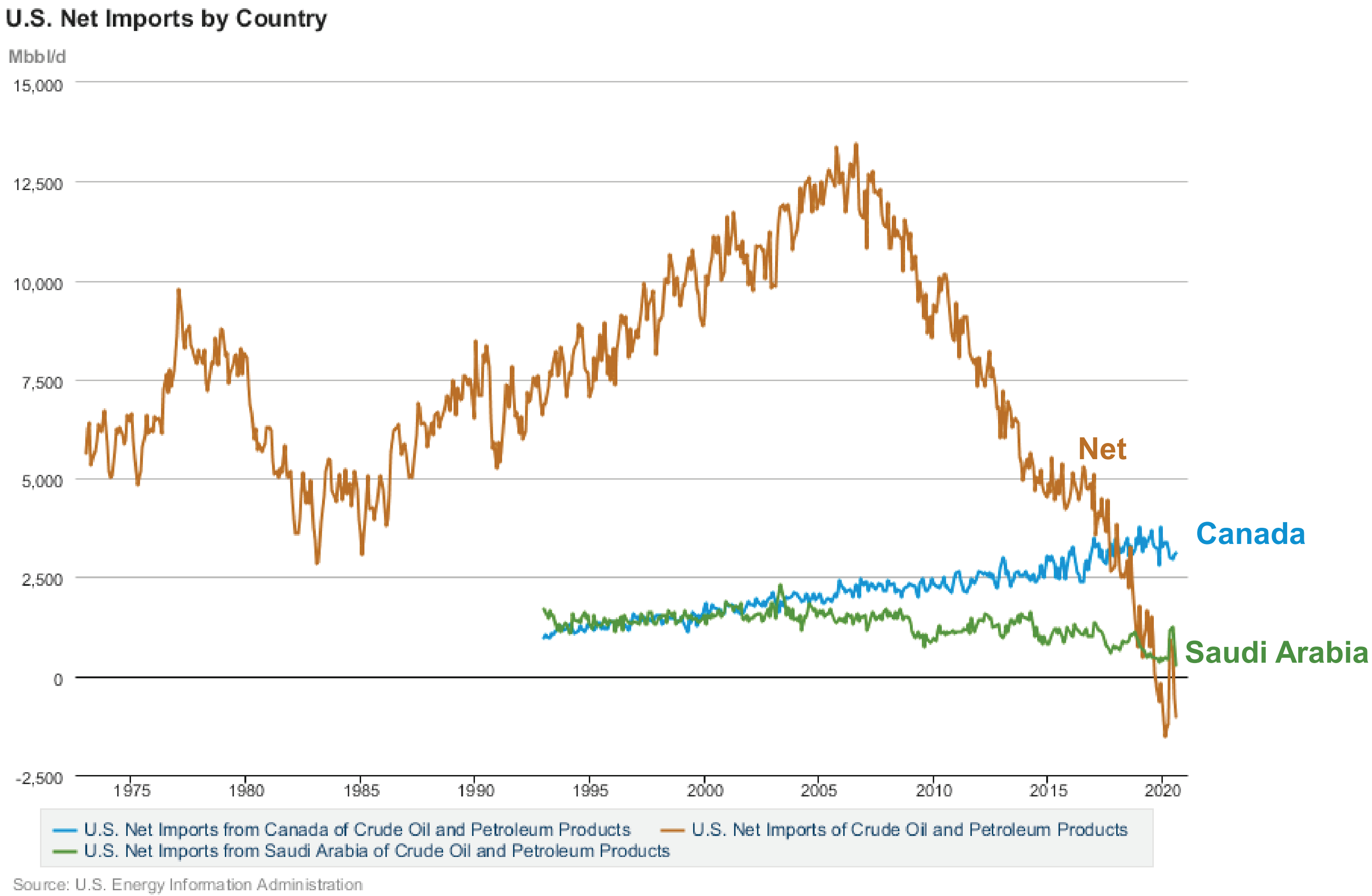

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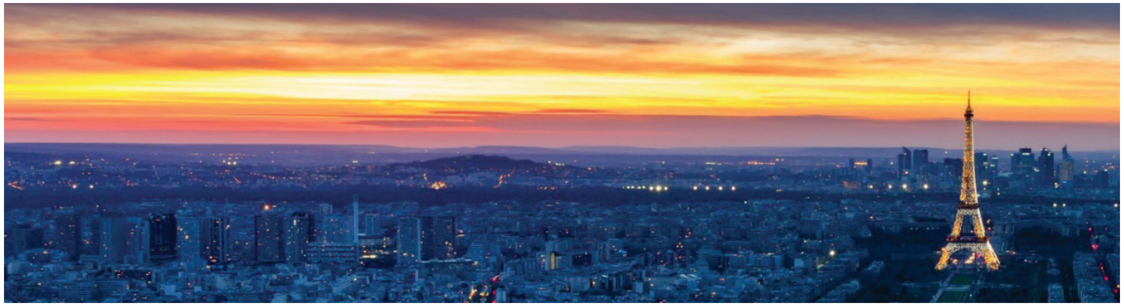
Two Super Heroes

US / China Announcement ⇒ Paris Climate Agreement

Nov 2014: Presidents Obama & Xi announced

U.S. would reduce GHG emissions to 27% below 2005 by 2025

China would peak GHG emissions by 2030 with best effort to peak early



Paris Climate Agreement:

Article 2, Section 1, Part a):

Objective to hold "increase in GMST to well below **2°C** above pre-industrial levels and to pursue efforts to limit the temperature increase to **1.5°C** above pre-industrial levels"

INDC: Intended **N**ationally **D**etermined **C**ontributions to reduce GHG emissions

- Submitted prior to Dec 2015 meeting in Paris
- Consist of either **unconditional** (promise) or **conditional** (contingent) pledges
- Generally extend from present to year 2030

One Villain

One Villain

25 July 1997

Senate approved a resolution regarding the conditions for the US becoming a signatory to any international agreement on greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC) that declared the mandate must include new, specific scheduled commitments to limit or reduce GHG emissions for Developing Country Parties … by a vote of 95 to 0

Paris Climate Agreement, Dec 2015:

a) Negotiated as an "agreement" (unilateral pledges to reduce GHG emissions by by member nations) rather than a treaty to avoid the need for Senate approval

https://www.senate.gov/artandhistory/history/common/briefing/Treaties.htm

b) Based on language of ratification, U.S. committed to agreement until 4 November 2020

https://qz.com/996882/paris-climate-agreement-trumps-renegotiation-is-not-realistic-in-any-way

https://www.theatlantic.com/science/archive/2017/08/trump-and-the-paris-agreement-what-just-happened/536040

Summer 2017:

President Trump states US intends to withdraw from Paris Climate Agreement

- "withdrawal" symbolic in that US is committed to the agreement until 4 Nov 2020

August 2018:

- Obama's plan for achieving the U.S. NDC had relied on implementation of the Clean Power Plan by the EPA
- Main gist of Clean Power Plan was transitioning power plants from coal to either natural gas or renewables
- Combustion of natural gas produces about 70% more energy per CO_2 released to the atmosphere than coal
- Clean power plan being abandoned by the US EPA
  https://psmag.com/environment/the-epa-publishes-its-proposed-replacement-for-the-clean-power-plan
  but the main reason natural gas has replaced coal for US power generation is economic, rather than regulatory

What occurred on 3 Nov 2020 ?!?

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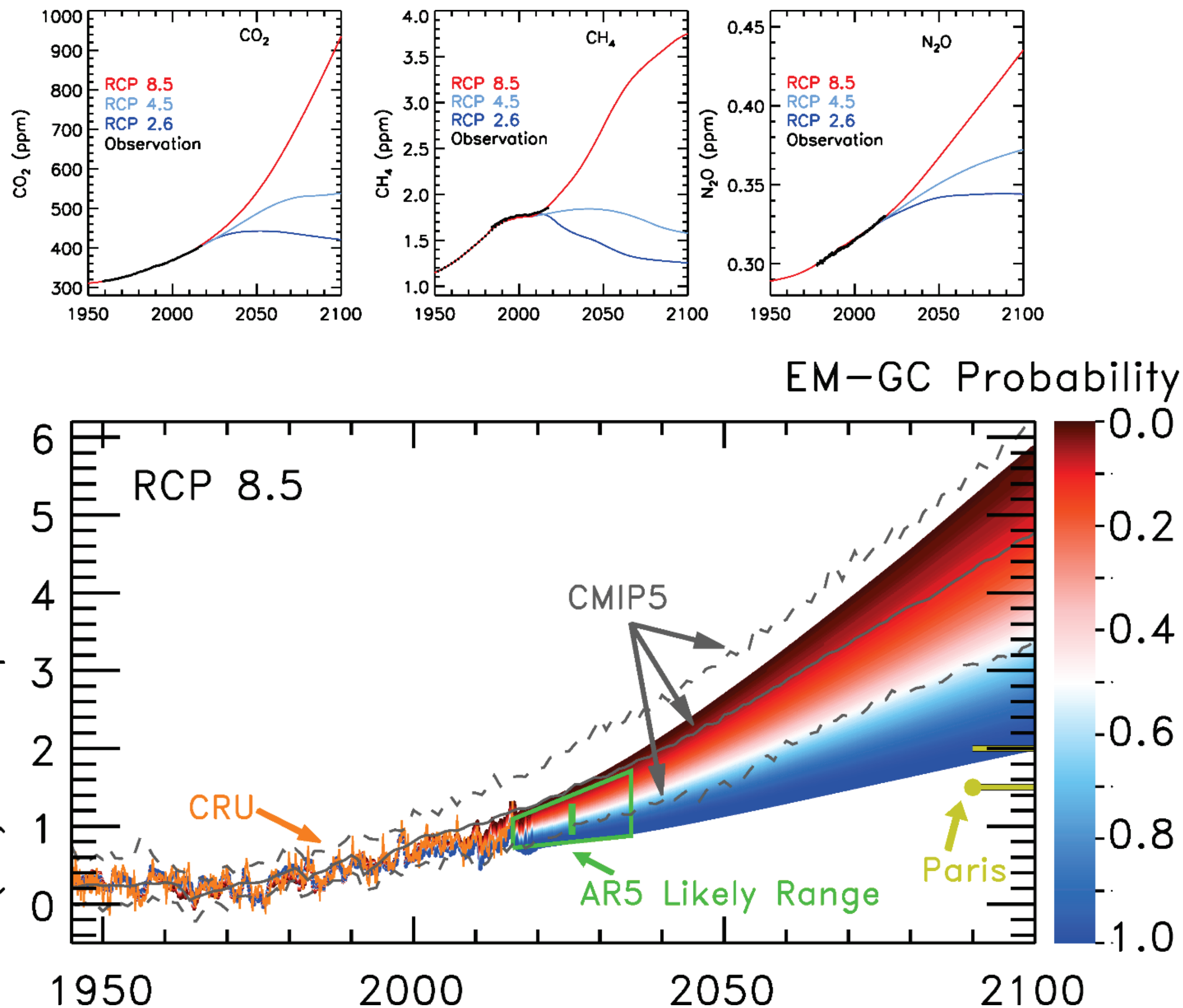
Presidential election occurred on 3 Nov 2020

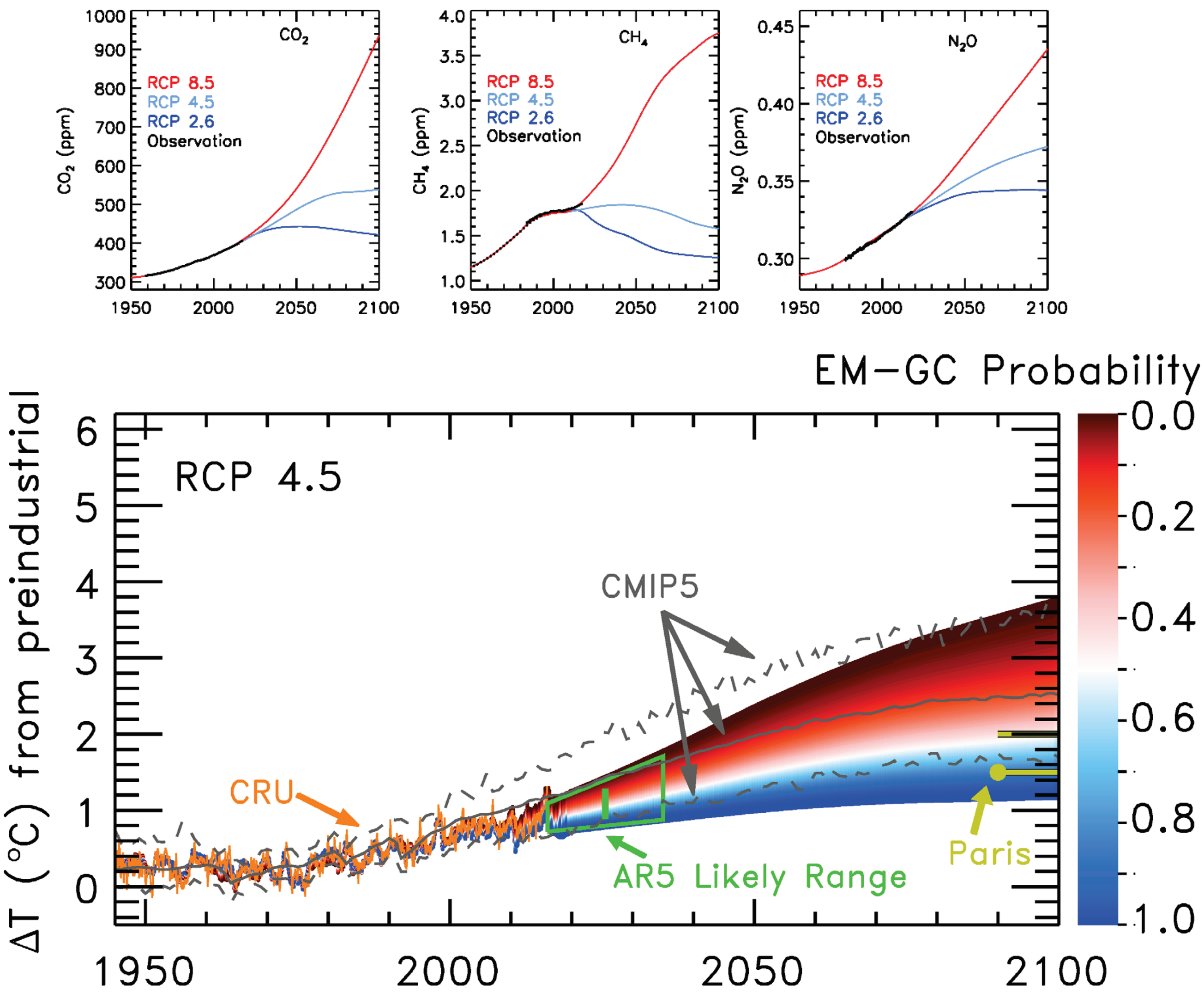
EM-GC Forecast vs CMIP5



If GHGs follow RCP 8.5, **0%** chance rise GMST stays below **1.5°C** and **0%** chance stays below **2.0°C**

Hope *et al.*, *JGR-Atmospheres*, submitted, 2020.

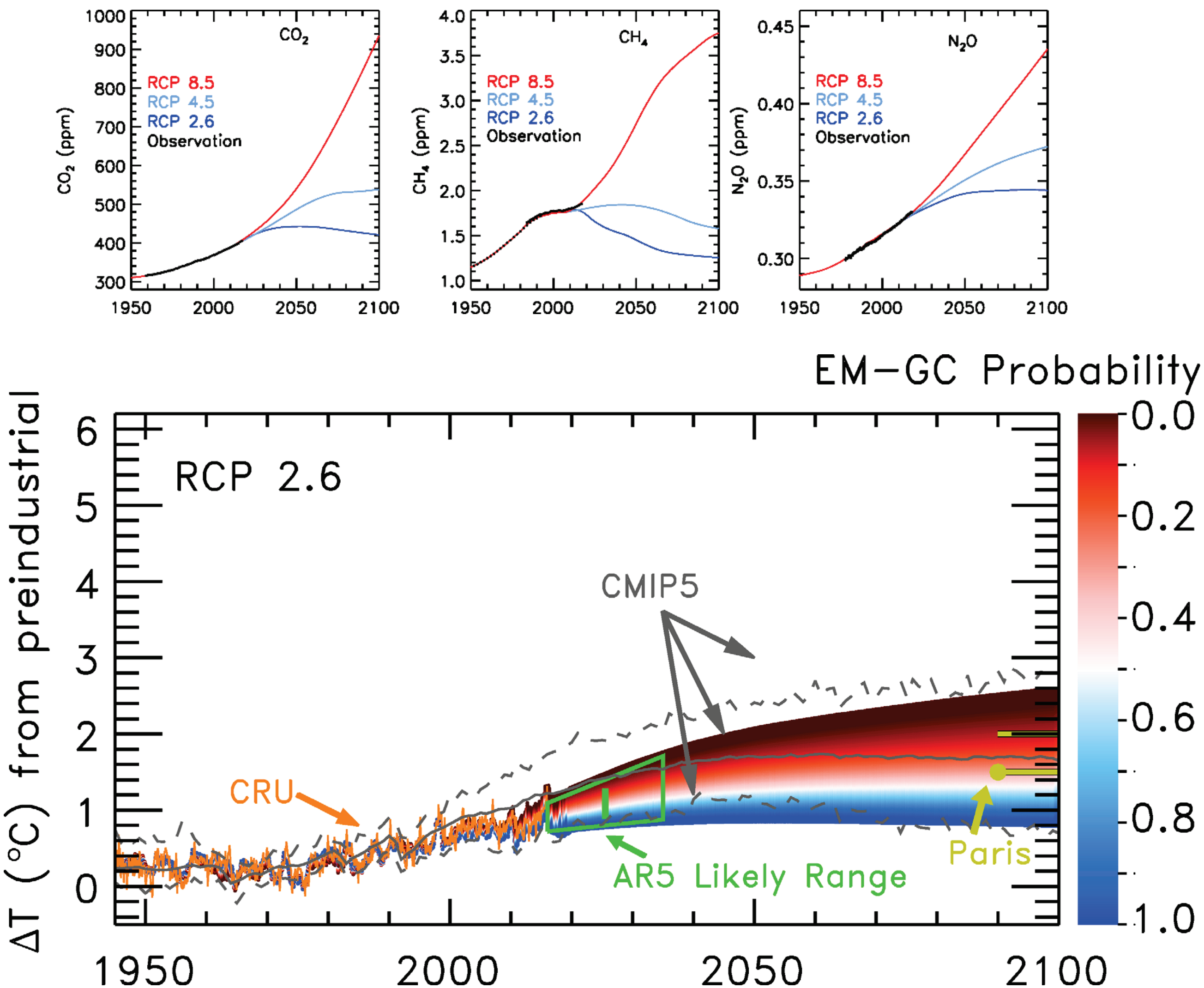
EM-GC Forecast vs CMIP5



If GHGs follow RCP 4.5, **10%** chance rise GMST stays below **1.5°C** and **50%** chance stays below **2.0°C**

Hope *et al.*, *JGR-Atmospheres*, submitted, 2020.

EM-GC Forecast vs CMIP5



If GHGs follow RCP 2.6, **67%** chance rise GMST stays below **1.5°C** and **92%** chance stays below **2.0°C**

Hope *et al.*, *JGR-Atmospheres*, submitted, 2020.

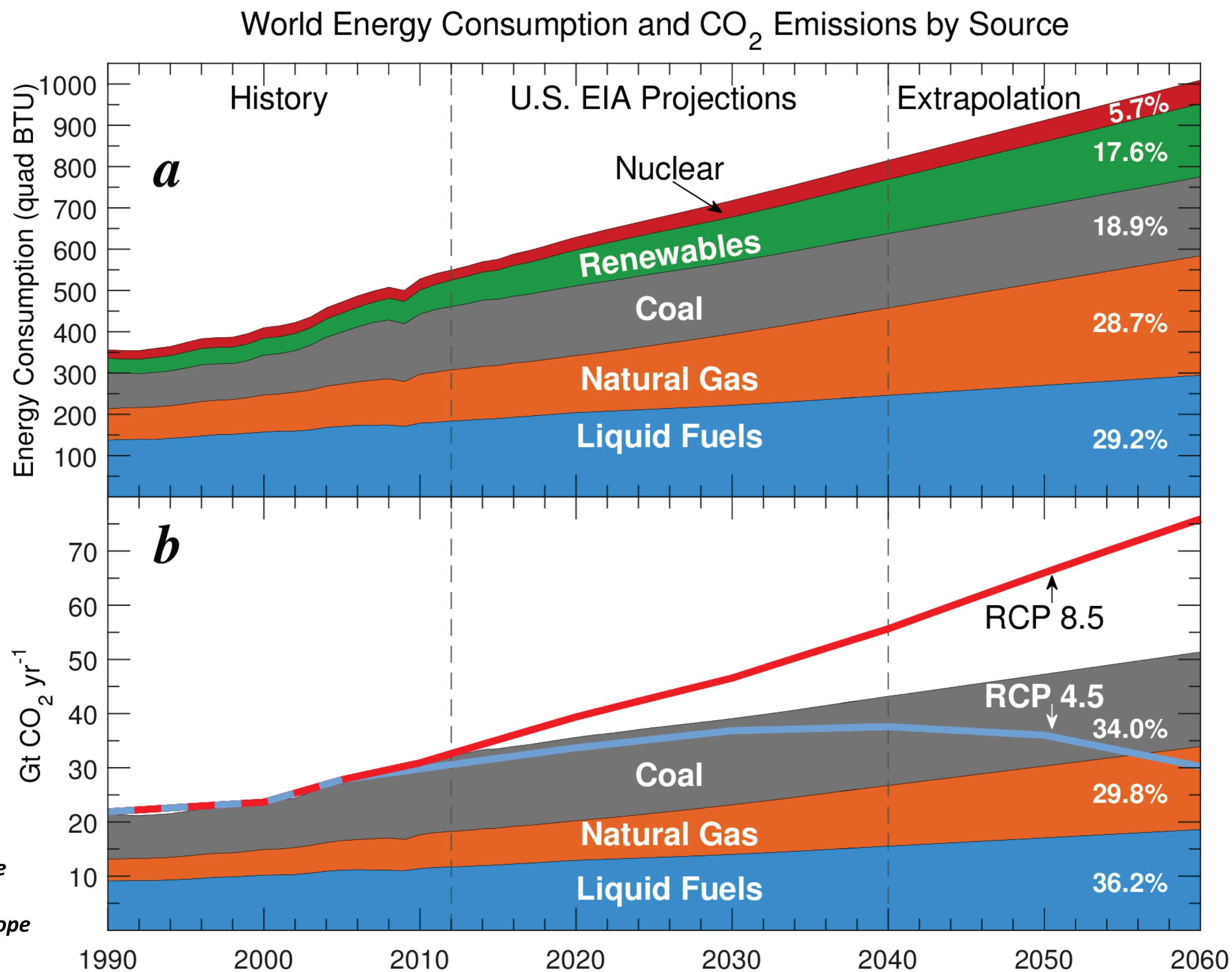


Fig 4.2
Paris Climate Agreement: Beacon of Hope

Business As Usual (i.e., projection of current trajectory) places the world in between RCP 4.5 and RCP 8.5 trajectories for global emission of CO_2

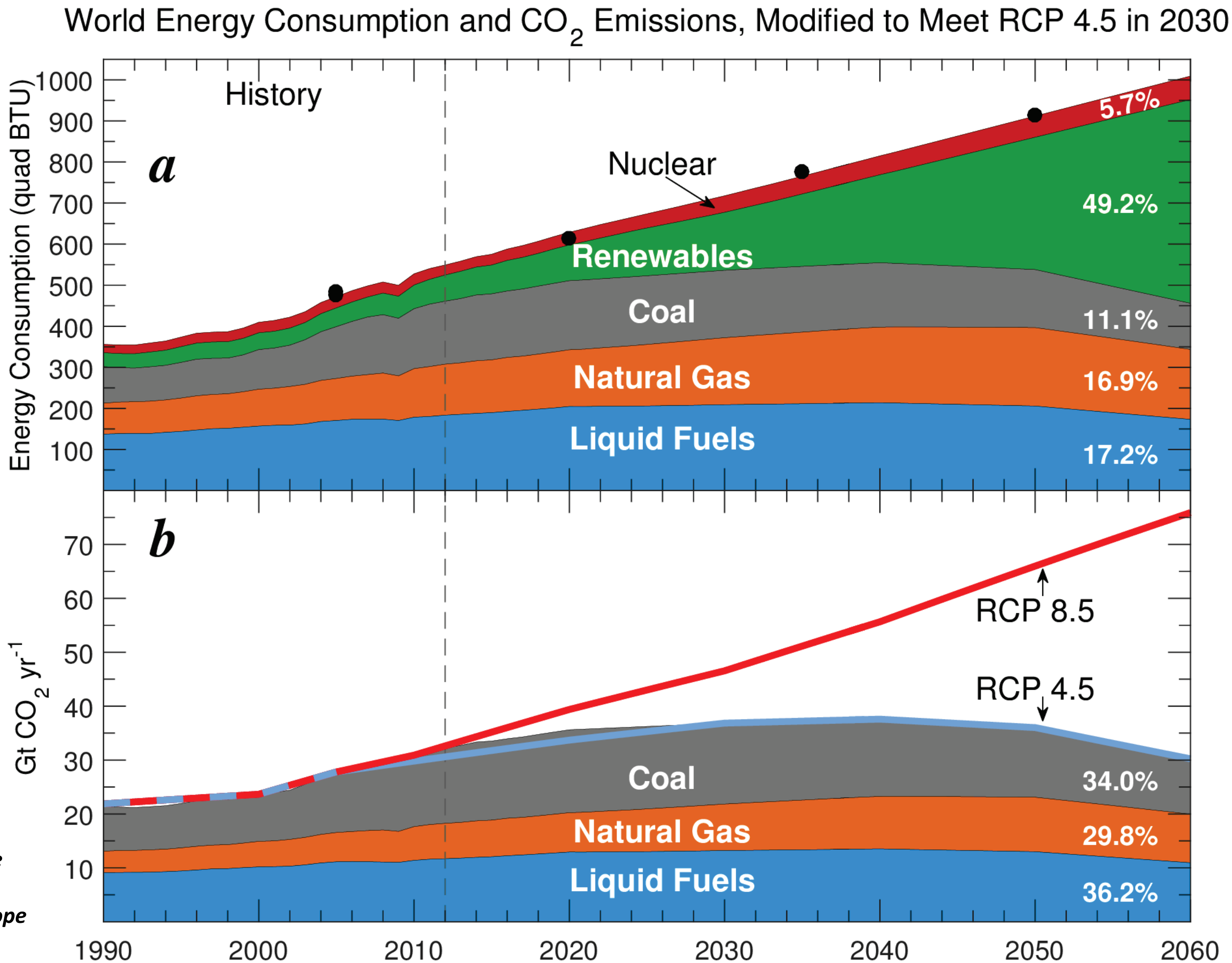


Fig 4.3
Paris Climate Agreement: Beacon of Hope

Achieving RCP 4.5 requires *half of total global energy* to be supplied by sources that do not emit GHGs by year 2060

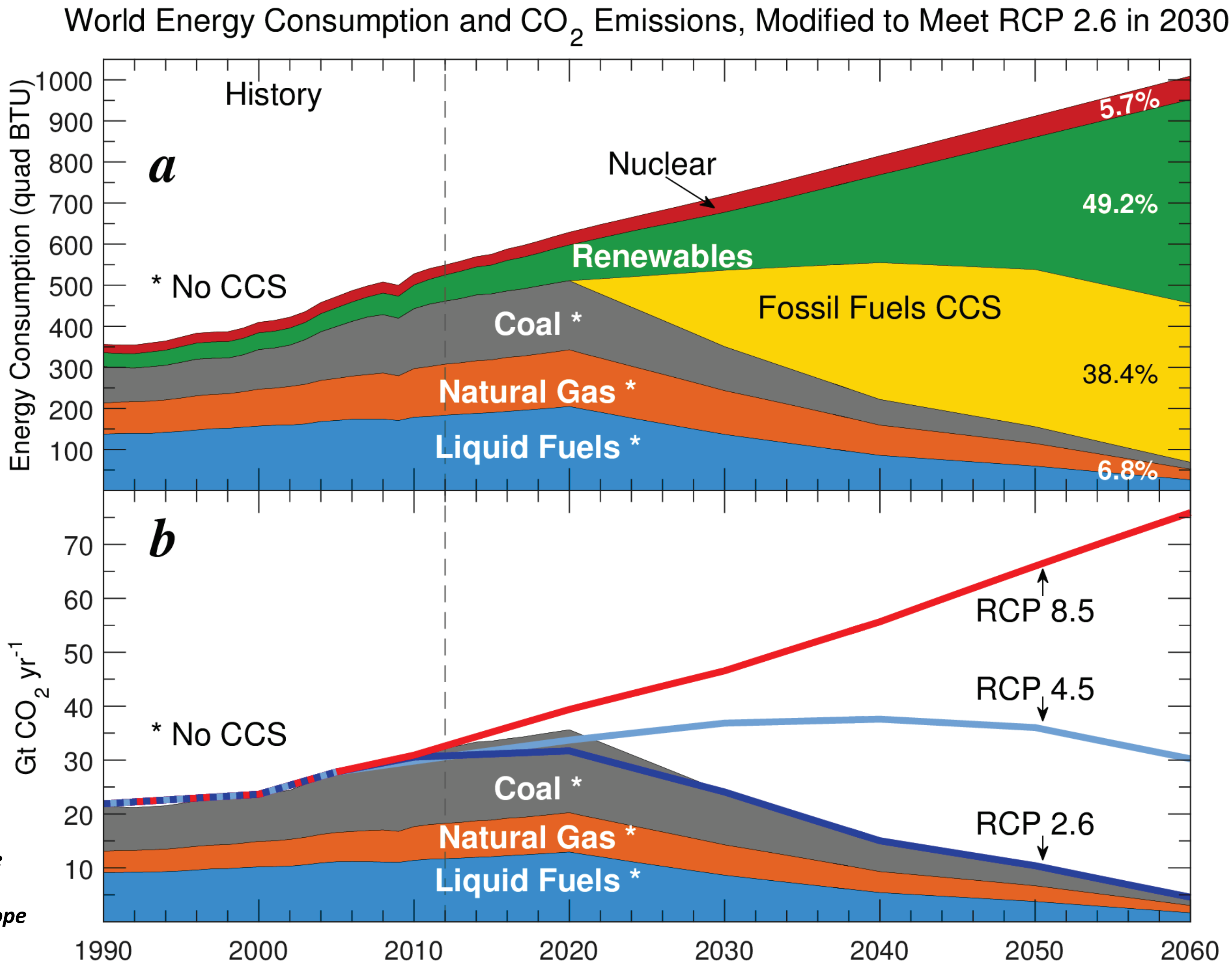
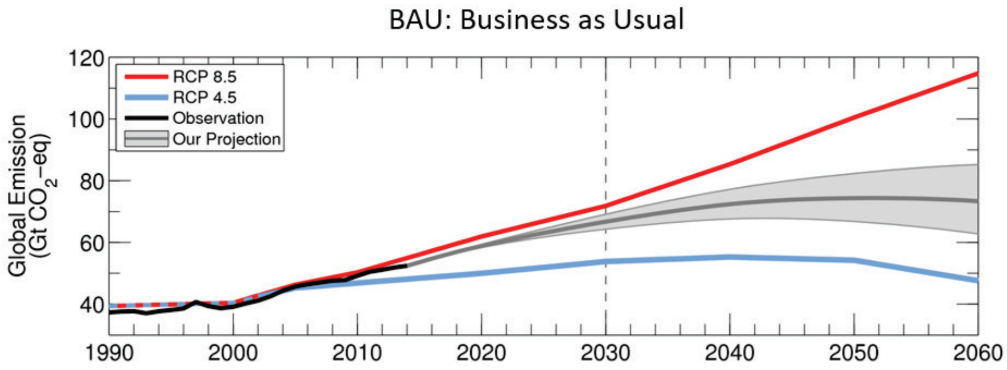


Fig 4.5
Paris Climate Agreement: Beacon of Hope

Achieving RCP 2.6 requires *half of total global energy* to be supplied by renewables/nuclear by 2060 coupled with massive Carbon Capture and Sequestration (CCS)

GHG Emission Projection



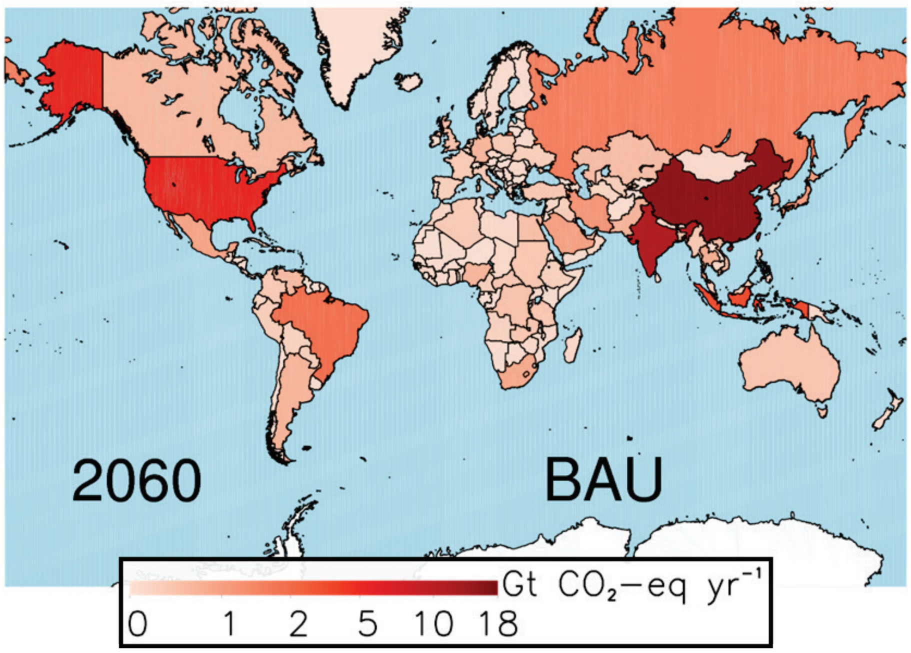


Fig 3.8 & 3.13
Paris Climate Agreement: Beacon of Hope

CO_2-eq: Considers emissions of CO_2, CH_4, & N_2O

RCP 4.5 & 8.5: GHG scenarios with 2.6., 4.5, and 8.5 W m^{-2} RF of climate in 2100

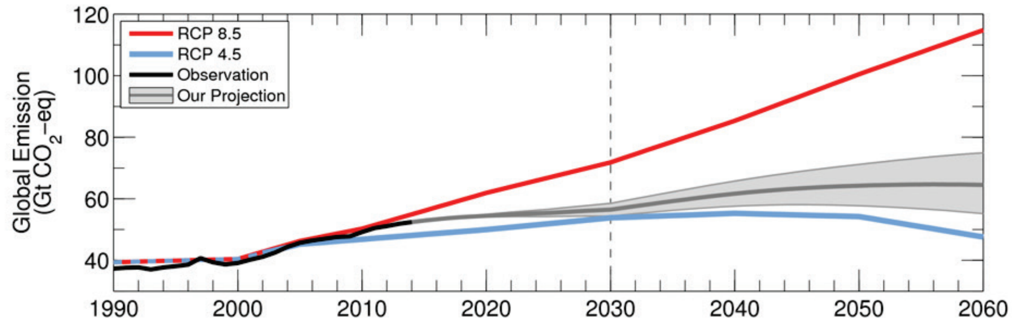
Uncertainty in "Our Projections" due to various population forecasts

Emissions for big 3 (U.S., China, & India) use Full Kaya Identity, whereas Simplified Kaya Identity used for other nations

https://en.wikipedia.org/wiki/Kaya_identity

GHG Emission Projection

Attain & Hold, all Unconditional NDCs



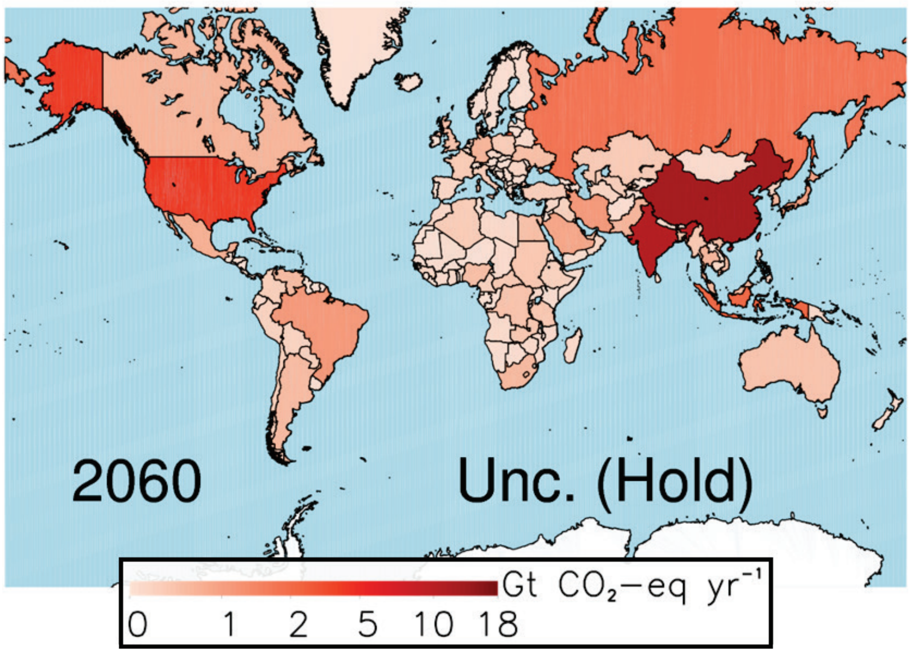
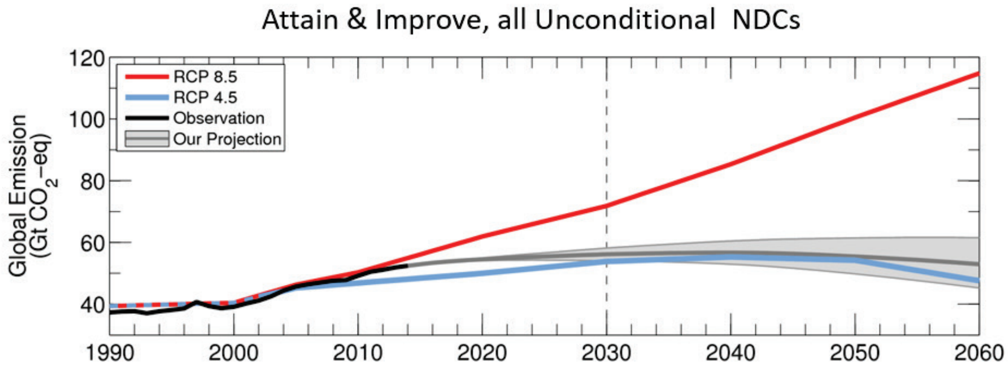


Fig 3.9 & 3.13
Paris Climate Agreement: Beacon of Hope

CO_2-eq: Considers emissions of CO_2, CH_4, & N_2O

NDC: Nationally Determined Contribution (to reduce emissions of GHGs)
Unconditional: We promise, no matter what, to follow our NDC

GHG Emission Projection



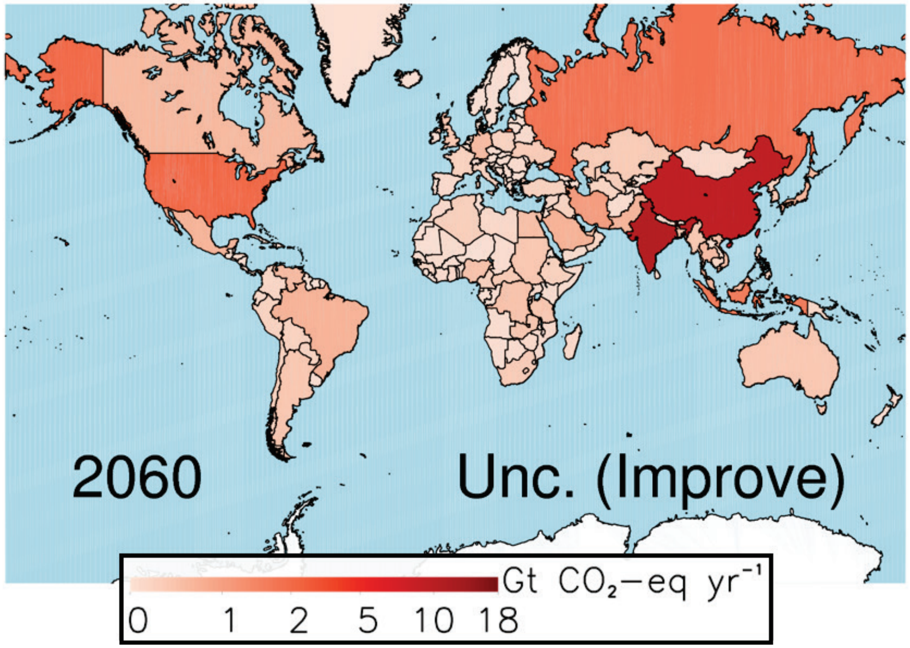


Fig 3.10 & 3.13
Paris Climate Agreement: Beacon of Hope

CO_2-eq: Considers emissions of CO_2, CH_4, & N_2O

NDC: Nationally Determined Contribution (to reduce emission of GHGs)
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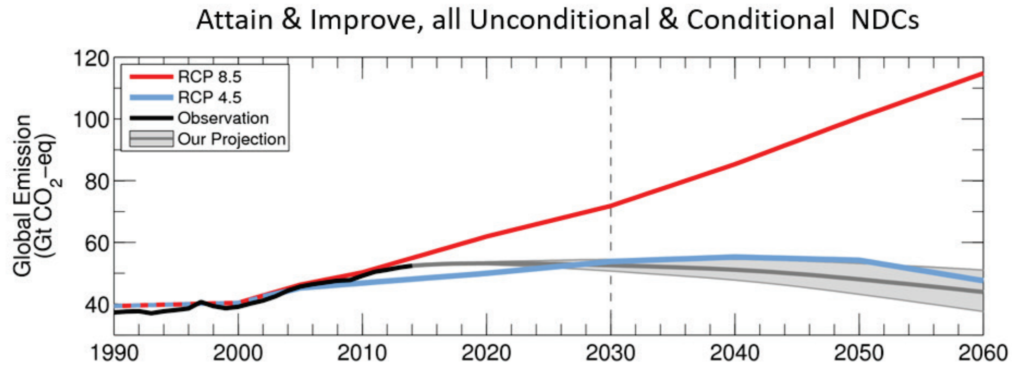
GHG Emission Projection



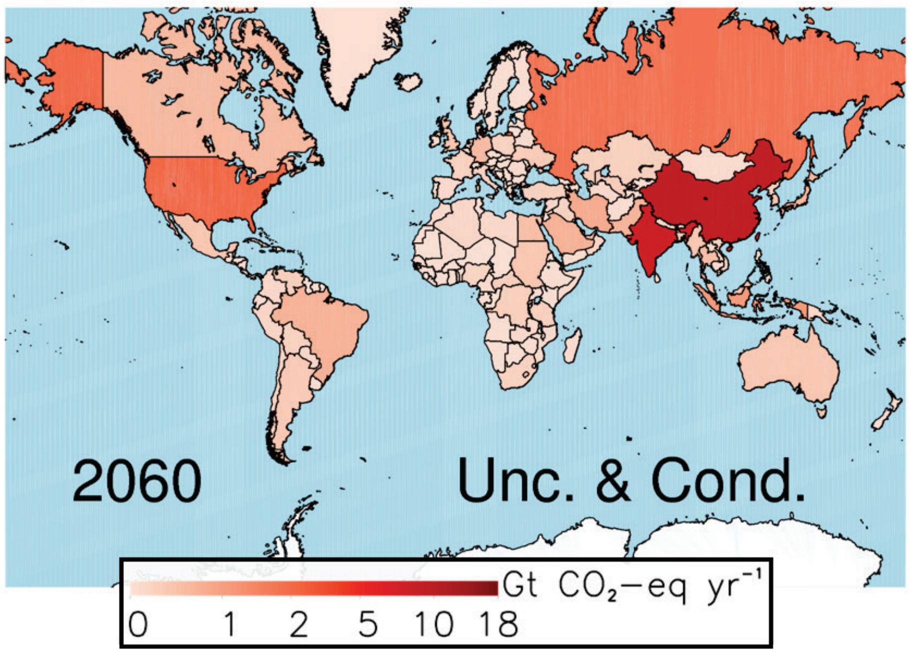


Fig 3.11 & 3.13
Paris Climate Agreement: Beacon of Hope

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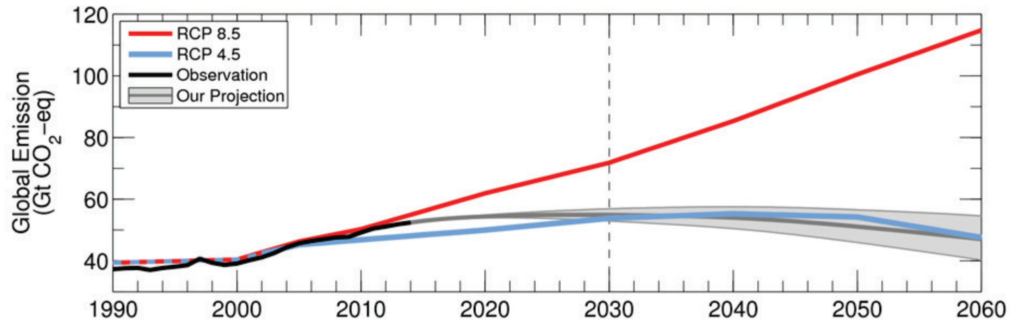
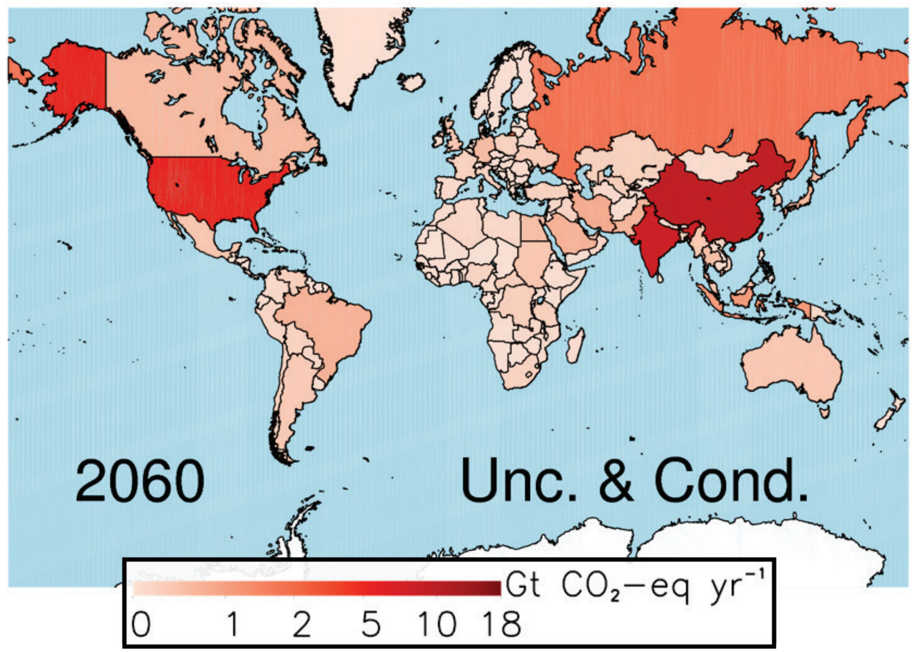
Conditional: GHG reductions contingent on financial and/or technology transfer

Attain & Improve, all Unconditional & Conditional NDCs

Except US BAU





New Work

CO_2-eq: Considers emissions of CO_2, CH_4, & N_2O

NDC: Nationally Determined Contribution (to reduce emission of GHGs)

Unconditional: We promise, no matter what, to follow our INDC and keep ***improving the carbon efficiency of our economy***

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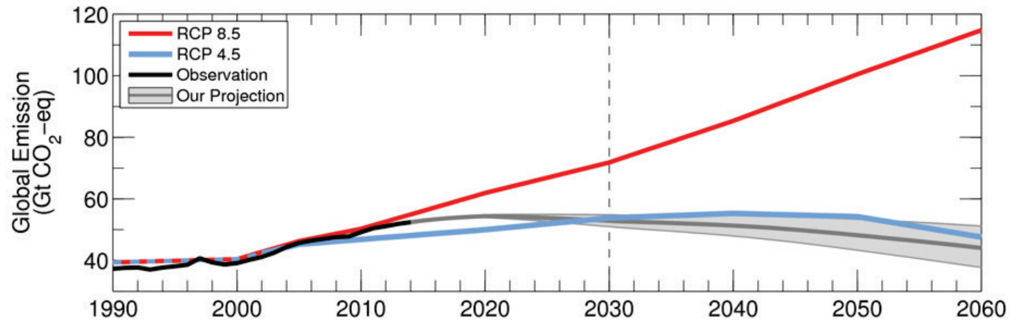
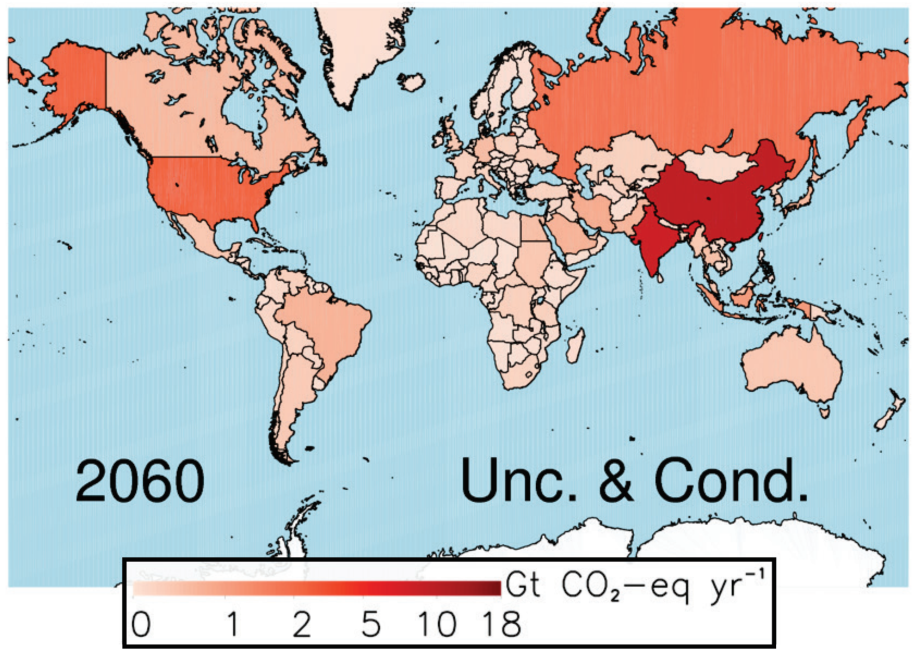
Attain & Improve, all Unconditional & Conditional NDCs

Except US 4 year delay





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Unconditional: We promise, no matter what, to follow our INDC and keep ***improving the carbon efficiency of our economy***

Conditional: GHG reductions contingent on financial and/or technology transfer

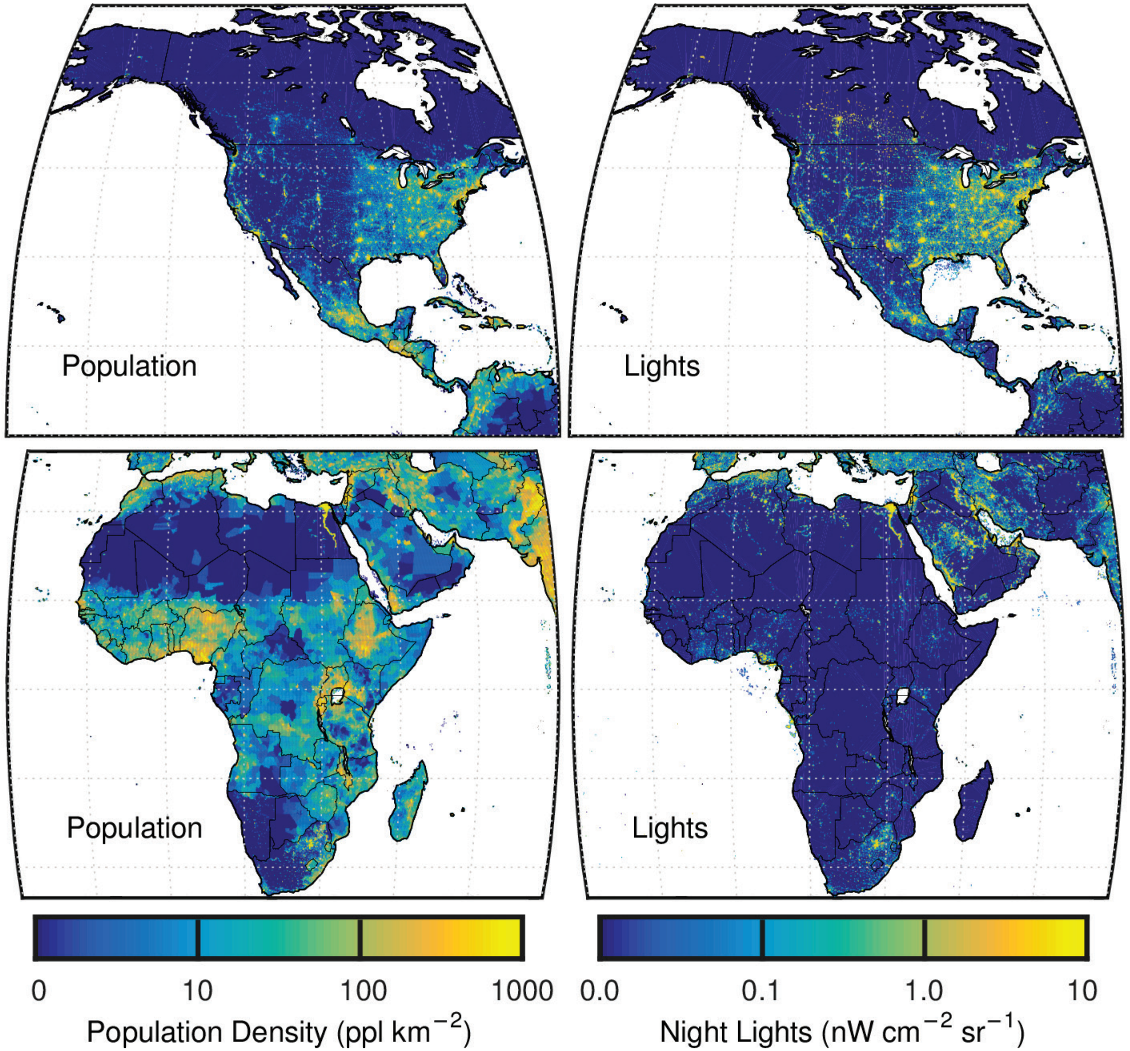


Fig 4.7
Paris Climate Agreement: Beacon of Hope

Limiting global warming to 2°C will require a massive transition to renewables and/or implementation of carbon capture and sequestration in the developed world and initial electrification of developing world by renewables (i.e., must bypass fossil fuels)

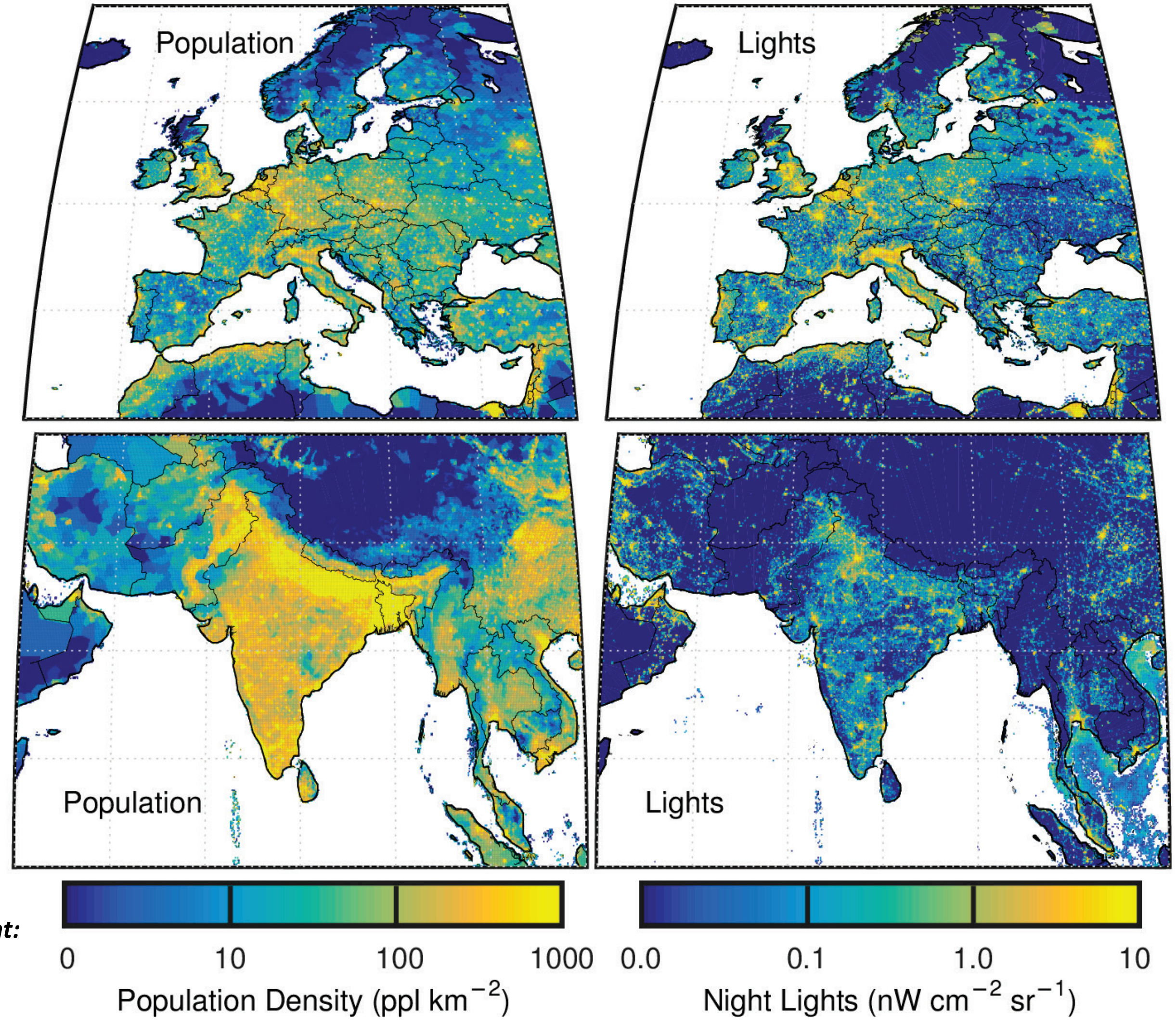
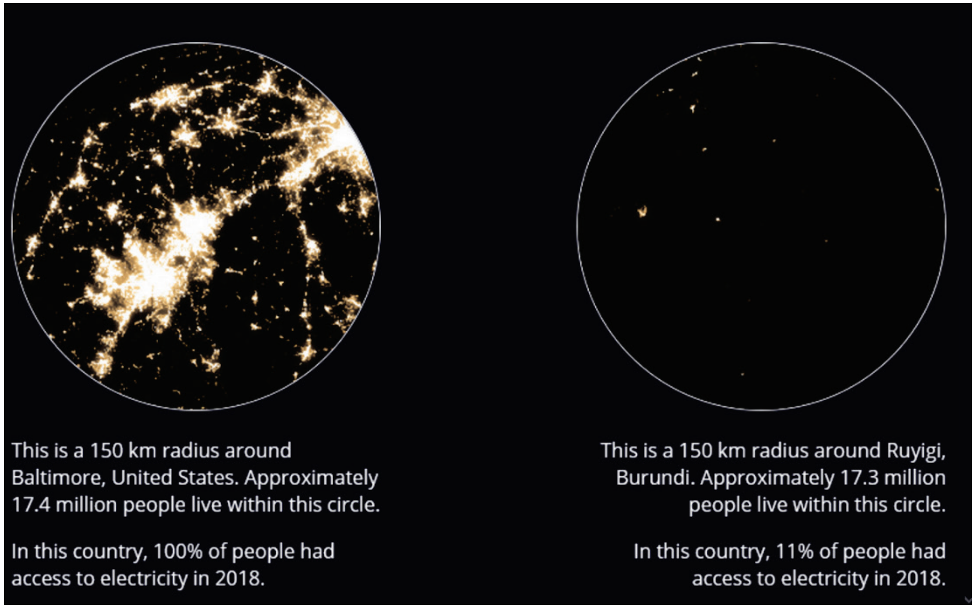
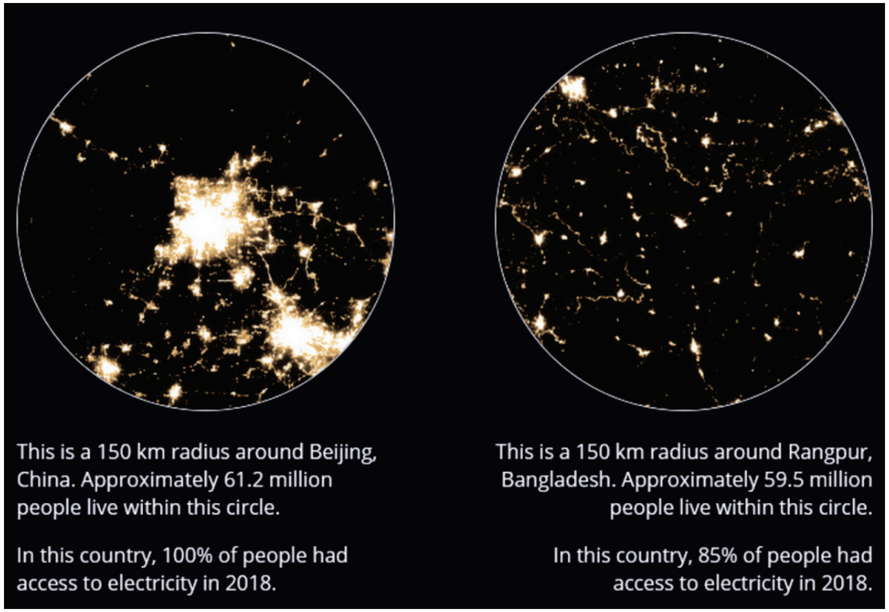


Fig 4.8
Paris Climate Agreement: Beacon of Hope

Limiting global warming to 2°C will require a massive transition to renewables and/or implementation of carbon capture and sequestration in the developed world and initial electrification of developing world by renewables (i.e., must bypass fossil fuels)





https://datatopics.worldbank.org/sdgatlas/goal-7-affordable-and-clean-energy

Limiting global warming to 2°C will require a massive transition to renewables and/or implementation of carbon capture and sequestration in the developed world and initial electrification of developing world by renewables (i.e., must bypass fossil fuels)

Energy and Power

Simple equation connects energy and power

Energy = Power × Time

Size of a **power** plant is commonly measured in units of power:

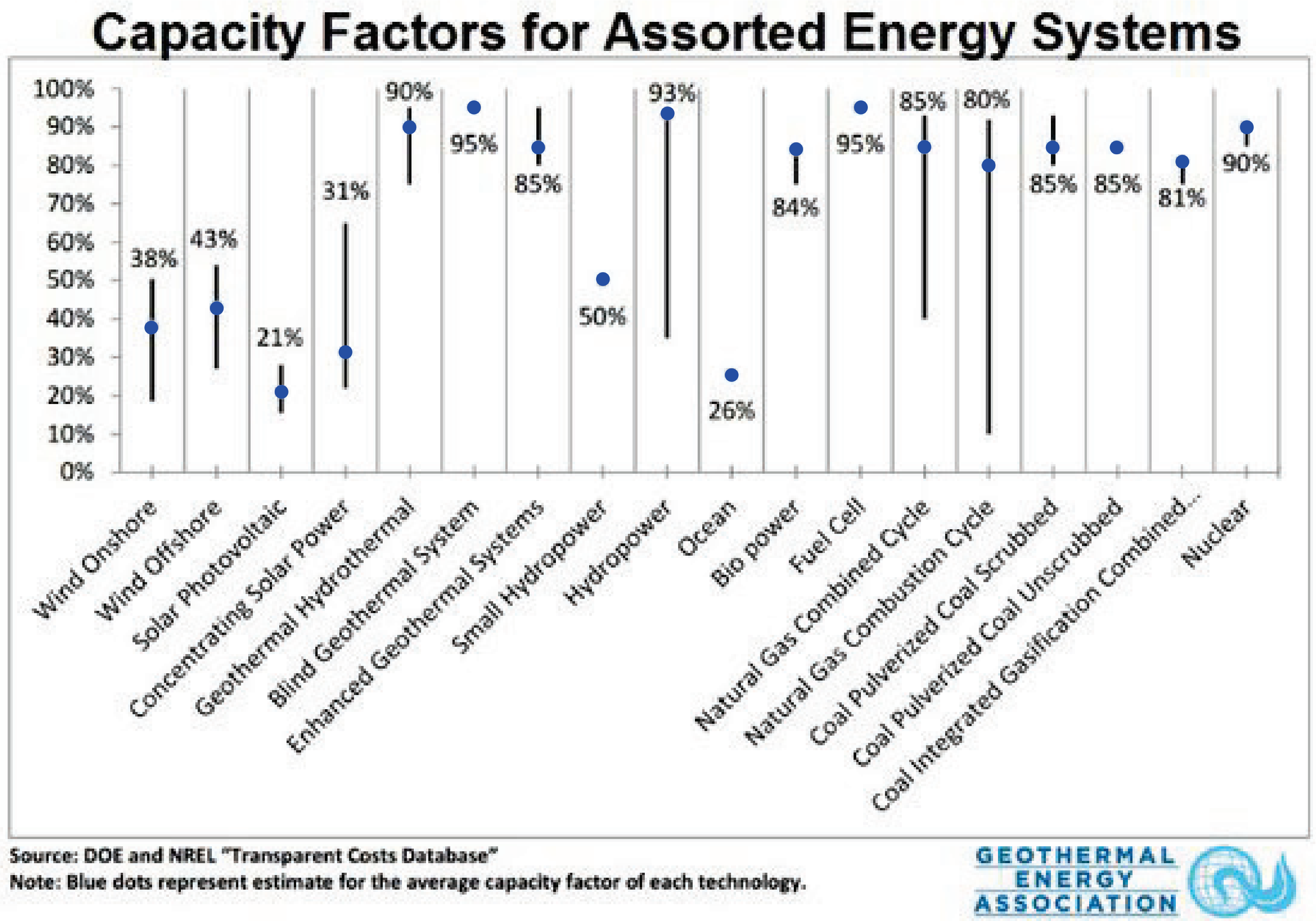
kW (kilo: 10^3 Watts): Home solar
MW (mega: 10^6 Watts) Industrial
GW (giga: 10^9 Watts): Massive Hydroelectric
TW (terra: 10^{12} Watts): Large Nation and/or Global

Output of a **power** plant in units of energy:

kWh (kilo: 10^3 W hour)
MWh (mega: 10^6 W hour)
GWh (gig: 10^9 W hour)

Capacity Factor: actual output of a power plant (energy) divided by maximum output, if power plant could run 24/7/365 ***at full capacity***

Please see https://energyeducation.ca/encyclopedia/Energy_vs_power for a nice explanation of Energy & Power



https://www.pinterest.com/pin/4292562121285998

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

Total Source	GW (year 2010)
Coal	1594
Natural Gas	1360
Hydro-electric	897
Solar	38
Wind	180
Nuclear	**375**
Liquid Fossil Fuel	291
Other Renewable (Biomass)	71
Geothermal	10
Total	4816

Source: https://www.eia.gov/outlooks/ieo/tables_ref.php

In 2010, **32.6%** of global electricity generating capacity did not release prodigious GHGs to the atmosphere

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

Total Source	GW (year 2020)
Coal	2154
Natural Gas	1662
Hydro-electric	1262
Solar	700
Wind	646
Nuclear	**374**
Liquid Fossil Fuel	297
Other Renewable (Biomass)	121
Geothermal	13
Total	7229

Source: https://www.eia.gov/outlooks/ieo/tables_ref.php

In 2020, **43%** of global electricity generating capacity does not release prodigious GHGs to the atmosphere

World Installed ***Electricity*** Generating ***Capacity***:

Power (Energy/Time)

Total Source	ΔGW (2020–2010)
Coal	560
Natural Gas	302
Hydro-electric	**365**
Solar	**662**
Wind	**466**
Nuclear	**–1**
Liquid Fossil Fuel	**6**
Other Renewable (Biomass)	**50**
Geothermal	**3**
Total	2413

Source: https://www.eia.gov/outlooks/ieo/tables_ref.php

Between 2020 and 2010, **64%** of the increase in global electricity generating capacity occurred by fuel sources that do not release prodigious GHGs to the atmosphere