Carbon Footprint of Air Travel

August 2019

"A Breathing Planet, Off Balance" - https://www.jpl.nasa.gov/video/details.php?id=1407

CarbonSolutions
Measure. Manage. Reduce.

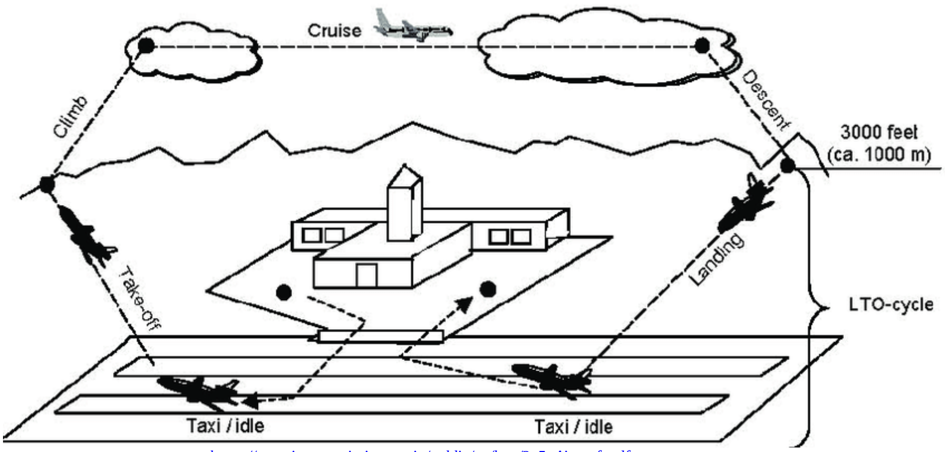
Purpose

This report is to guide you to understand and calculate emissions caused by air travel.

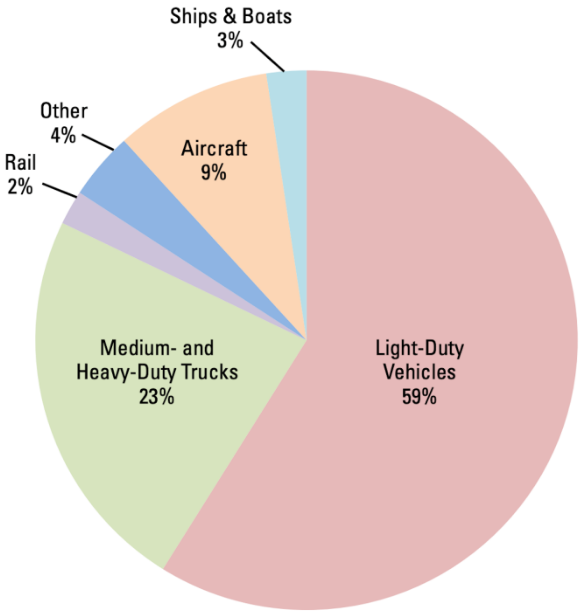
Introduction

Human activity in the atmosphere is primarily caused by air travels. They leave behind a trail of CO2 emissions. Around 2% of all human-induced carbon dioxide (CO2) emissions is from air travel. And, air travel is around 9% of CO2 emissions of all transports sources, compared to 74% from ground transportation.

Standard Flying Cycle



https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf

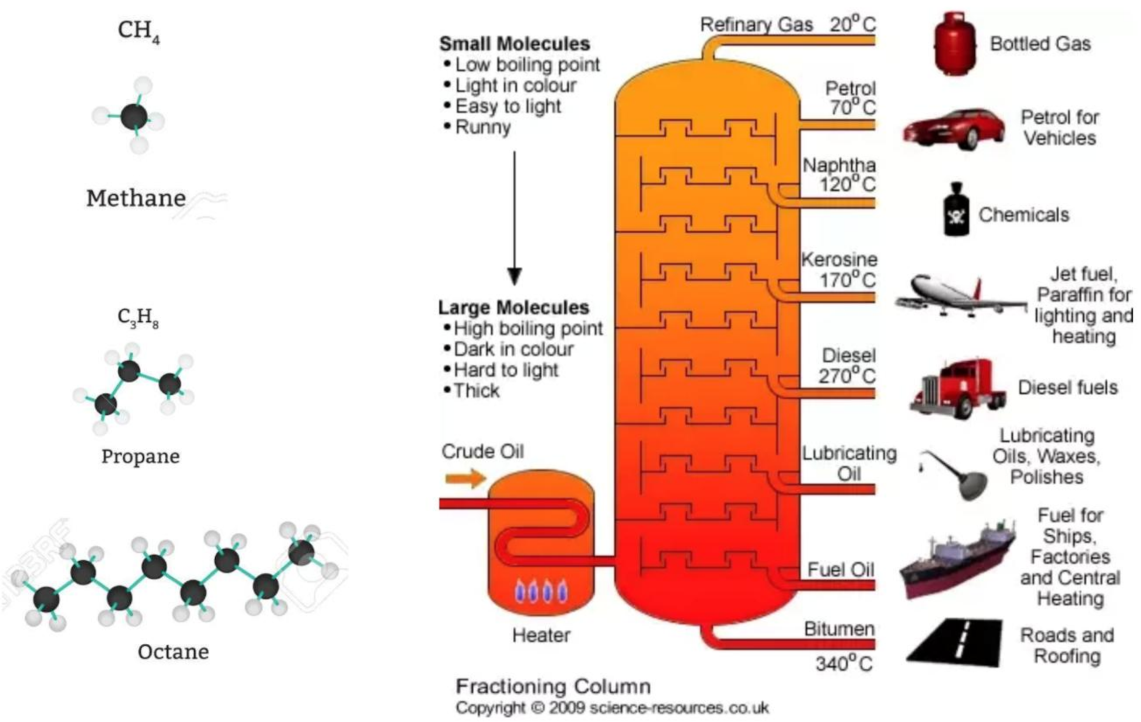


U.S. Transportation Sector GHG Emissions by Source, 2017

Fuel

Most aircraft use one of two types of fuel: gasoline and kerosene. Gasoline is used in small piston engined aircraft only. Most other aircraft run on kerosene. Both these fuels typically consist of 85% carbon, 15% hydrogen, and various additives. The fuel use and resulting emissions will be dependent on the fuel type, aircraft type, engine type, engine load and flying altitude. The exact composition of jet fuel itself can vary depending on the origin of the crude, the refining process, the climate of the area at time of flight, and some other minor factors.

Fractional Distillation of Crude Oil

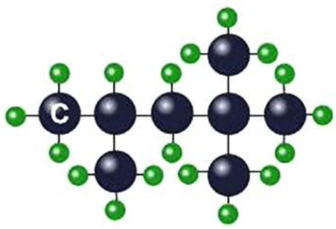


http://i-how.co/how-it-works/science/Chemistry/how-does-fractional-distillation-work.html

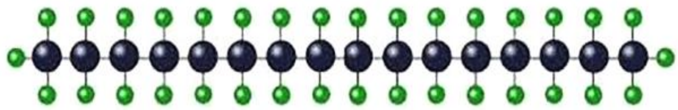
Distillation basics: thick, heavy crude oil is warmed up, small, light molecules escape first, heavier molecules follow, in the end, a sticky substance like tar is left. The lighter molecules are gases, and the longer hydrocarbon chain, the heavier the hydrocarbon products becomes.

One octane molecule, for example, becomes eight CO_2 molecules. Octo comes from ancient Greek ὀκτώ (oktṓ, “eight”) and Latin octō (“eight”).

The 87 on the Regular pump means that 87% of the fuel is octane. The 93 on the Supreme pump means that 93% of that fuel is made up of Octane molecules. The rest is typically made up of heptane molecules. A heptane has 7 carbons in the molecular chain, and comes from the Greek hepta, or ‘seven’. Aviation fuels are more kerosene like, with carbon chains ranging from 8 to 16.



Gasoline molecule, C8H18



Diesel molecule, C16H18 - diesel is heavier, and slower to burn

https://images.app.goo.gl/1dmXEovqEpGNgrC5A

The chart below describes the variable aspects of several fuels, listed in alphabetical orders.
Note that Kerosene is 85% carbon and weighs about 780 kilogram per cubic meter, and when it burns, is about 2,300 degrees Kelvin, equivalent to around 2,000 degree centigrade and 3,600 degree Fahrenheit

Fuel	Formula (state)	Density [kg/m³]	Theoretical air/fuel ratio	Higher Heating Value [MJ/kg]	Maximum adiabatic combustion temp. K	Flash point &Autoignition temperature[a] [K]	Ignition limits[b]	Maximum laminar deflagration speed [m/s]
Ethane	C_2H_6(g)	1.2	16.7 m^3/m^3	51.9	2100	140, 800	3.0..15	0.40
Ethanol	C_2H_6O(l)	790	9.0 kg/kg	29.7	2200	285, 630	3.3..21	0.80
Ether	$C_4H_{10}O$(l) (diethyl ether)	715	11.2 kg/kg	37.2		230, 440	1.8..37	
Fuel-oil	84%C10%H3%S1%N2%H2 O(l)[e]	850..990	15 kg/kg	44	2200	320, 480	0.7..5	
Gasoline	85%C15%H(l)[f]	730..760	14.7 kg/kg	48	2200	230, 650	1.3..8	0.35
n-Hexadecane	$C_{16}H_{34}$(l)	773	14.9 kg/kg	47.3	2200	400, 475	0.5..4.7	
n-Heptane	C_7H_{16}(l)	685	15.2 kg/kg	48.1	2200	269, 560	1.1..6.7	0.40
Hydrogen	H_2(g)	0.08	2.4 m^3/m^3	142	2400	-, 850	4.0..75	3.5
Kerosene Jet A-1	85%C15%H(l)[g]	780..840	15 kg/kg	47	2300	330, 500	0.7..6	0.20
Methane	CH_4(g)	0.67	9.5 m^3/m^3	55.5	2200	85, 850	4.5..16	0.45
Methanol	CH_4O(l)	790	6.5 kg/kg	22.7	2150	285, 680	6.0..37	0.50
Natural gas	CH_4(g)[h]	0.68..0.70	9.5 m^3/m^3	54	2250	-, 850	5.3..15	0.45

[g]% by weight; kerosene (or kerosene) is a distilled mixture with T_b=450..600 K (10% and 90% boiled), T_f=−40 ºC, $\nu=8\times10^{-6}$ m²/s at −20 ºC, that may be approximated by n-dodecane ($C_{12}H_{26}$) or 1-dodecene ($C_{12}H_{24}$). Commercial (Jet A-1, Jet A, and Jet B) and military (JP-4, JP-5, JP-8...) jet propulsion fuels, are basically mixtures of kerosene and gasoline (half-&-half for JP-4, 99.5% kerosene for JP-5 and JP-8, 100% kerosene for Jet A-1), plus special additives (1..2%): corrosion inhibitor, anti-icing, and anti-static compounds. Jet A-1 is the international jet fuel with T_f=−50 ºC (-47 ºC as a limit); Jet A (with T_f=−40 ºC) is a low-grade Jet A-1 only and mostly used in USA; and Jet B (T_f<−50 ºC), the commercial name of JP-4, is only used in very cold climates. They all have a lower heating value of 42.8..43.6 MJ/kg. Minimum flash point is 60 ºC for JP-5, 38 ºC for Jet A-1 and JP-8 (Jet A-1 typical value is 50 ºC, with a vapour pressure at this point of 1.5 kPa; 1 kPa at 38 ºC), and -20 ºC for JP-4. Typical density at 15 ºC is 810 kg/m³ for Jet A-1, and 760 kg/m³ for Jet B.

The table below illustrates the Landing and Takeoff cycle for aircraft typically found in everyday air travel. The vast majority of climate related emissions (during the LTO cycle) are in the first column, CO2

TABLE 3.6.9
LTO EMISSION FACTORS FOR TYPICAL AIRCRAFT

	AIRCRAFT	LTO emissions factors (kg/LTO/) (12)							LTO FUEL CONSUMPTION (Kg/LTO)
		CO_2 (11)	CH_4 (7)	N_2O (9)	NO_x	CO	NMVOC (8)	SO_2 (10)	
Large Commercial Aircraft (1)(2)	A300	5450	0.12	0.2	25.86	14.80	1.12	1.72	1720
	A310	4760	0.63	0.2	19.46	28.30	5.67	1.51	1510
	737-100/200	2740	0.45	0.1	6.74	16.04	4.06	0.87	870
	737-300/400/500	2480	0.08	0.1	7.19	13.03	0.75	0.78	780
	737-600	2280	0.10	0.1	7.66	8.65	0.91	0.72	720
	737-700	2460	0.09	0.1	9.12	8.00	0.78	0.78	780
	737-800/900	2780	0.07	0.1	12.30	7.07	0.65	0.88	880
	747-100	10140	4.84	0.3	49.17	114.59	43.59	3.21	3210
	747-200	11370	1.82	0.4	49.52	79.78	16.41	3.60	3600
	747-300	11080	0.27	0.4	65.00	17.84	2.46	3.51	3510
	747-400	10240	0.22	0.3	42.88	26.72	2.02	3.24	3240

Notes:

(1) ICAO Engine Exhaust Emissions Data Bank (ICAO, 2004) based on average measured data. Emissions factors apply to LTO (Landing and Take off) only.

(2) Engine types for each aircraft were selected on a consistent basis of the engine with the most LTOs. This approach, for some engine types, may underestimate (or overestimate) fleet emissions which are not directly related to fuel consumption (eg NO_x, CO, HC).

(2) Emissions and Dispersion Modelling System (EDMS) (FAA 2004b)

(4) FOI (The Swedish Defence Research Agency) Turboprop LTO Emissions database

(5) Representative of Turboprop aircraft with shaft horsepower of up to 1000 shp/engine

(6) Representative of Turboprop aircraft with shaft horsepower of 1000 to 2000 shp/engine

(7) Representative of Turboprop aircraft with shaft horsepower of more than 2000 shp/engine

(8) Assuming 10% of total VOC emissions in LTO cycles are methane emissions (Olivier, 1991) (as in the *1996 IPCC Guidelines*).

(9) Estimates based on Tier I default values (EF ID 11053) (as in the *1996 IPCC Guidelines*).

(10) The sulphur content of the fuel is assumed to be 0.05% (as in the *1996 IPCC Guidelines*).

(11) CO_2 for each aircraft based on 3.16 kg CO_2 produced for each kg fuel used, then rounded to the nearest 10 kg.

(12) Information regarding the uncertainties associated with this data can be found in: Lister and Norman, 2003; ICAO, 1993.

Table prepared in 2005 updates will be available in the Emission Factor Data Base.

The table below shows that the percentage of LTO fuel consumption relative to the total fuel burn varies relative to the total distance of flight

Dep airport	Arr airport	Dist. (Km)	Time	Air craft fuel burn (Kg)	LTO fuel consumption (Kg/LTO)	LTO fuel percentage
Paris	London	346	0+50	2546	780	28%
Miami	New York	1756	2+36	9918	1510	15%
Incheon	Singapore	4625	5+55	38320	3600	9%

Characteristics of Jet Fuel Emissions

The UN has published a document regarding civil aviation, listing it as one category of transportation fuels. It was published in 2006 under the title of *IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories*. It states that emissions from aviation come from the combustion of jet fuel (jet kerosene and jet gasoline) and aviation gasoline. Emissions depend on the number and type of aircraft operations; the types and efficiency of the aircraft engines; the fuel used; the length of flight; the power setting; the time spent at each stage of flight; and, to a lesser degree, the altitude at which exhaust gases are emitted.

According to the recent update of the IPCC guidelines (KYOTO, Japan, May 13), the new report, the ***2019 Refinement to the 2006 IPCC Guidelines*** *for* ***National Greenhouse Gas Inventories*** includes changes in four sectors ***except*** the transportation sector. The following table thus can be used as a standard source for GHG inventory purposes. https://en.wikipedia.org/wiki/Jet_fuel

*CO2 emissions for **national inventory purposes** are expressed in kilogram relative to the energy provided - in Terajoule - as opposed to by the fuel's weight*

TABLE 3.6.4
CO_2 EMISSION FACTORS

Fuel	Default (kg/TJ)	Lower	Upper
Aviation Gasoline	70 000	67 500	73 000
Jet Kerosene	71 500	69 800	74 400

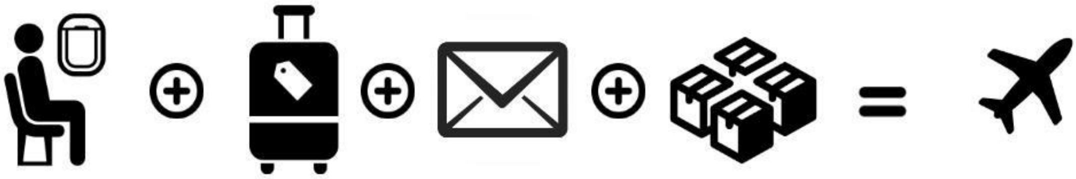
https://www150.statcan.gc.ca/n1/pub/57-601-x/00105/4173282-eng.htm

Carbon dioxide emission factors are based on the fuel type and native carbon content. National emission factors for CO2 should not deviate much from the default values because the quality of fuels is well defined. Also, CO2 should be estimated on the basis of the *full* carbon content of the fuel.

The below table illustrates emissions on a per person basis for various distances flown in common day aircraft

	Commuter	Regional	Short-haul	Medium-haul	Long-haul
kgCO2e per passenger per 100 km	11.43	8.01	6.58	6.95	7.45
max range in km	560	1220	1900	6300	13300
max kgCO2e per passenger per trip at max range of category	64	98	125	438	990
max range in miles	348	758	1181	3915	8264
kgCO2e per passenger - per mile flown	0.18	0.13	0.11	0.11	0.12

The International Civil Aviation Organization (ICAO) uses the following formula to determine the portion of an individual on a routine flight



[((No. Passengers*100Kg) + (No. of seats * 50 Kg))/1000] (tonnes) + Freight (tonnes) + Mail (tonnes)

To calculate accurate aviation emissions, you can refer to the methodology in this following document ***- ICAO Carbon Emissions Calculator Methodology Ver. 10****, page 8* ***-*** *in order to obtain the total mass of airplane*

> ### 4.4 Passenger Load Factor and Passenger to Cargo Factor
>
> As this methodology is intended to assess the passenger's aviation emissions it is necessary to deduct the flight emissions associated with the freight and mail carried on the flight from the total. This calculation will be performed on a revenue mass basis using historic freight and mail numbers specific to the city-pair being considered.
>
> The data are sourced from the ICAO TFS dataset which contains totals of number of seats and passengers, tonnes of freight, and tonnes of mail carried. In order to develop an average freight allocation an average passenger mass with baggage is assumed as 100 Kg, plus a 50 Kg add-on to account of the on-board equipment and infrastructure associated with passenger use (for example, the weight of seats, toilets, galleys and crew). The total mass is then established as:
>
> [((No. Passengers*100Kg) + (No. of seats * 50 Kg))/1000] (tonnes) + Freight (tonnes) + Mail (tonnes)
>
> Based on the historical traffic data it is then possible to establish the proportion of freight and mail mass in relation to the total mass calculated by the formula above. The resulting proportion is the fraction of the flight emissions for which the passengers should not be held accountable for. The TFS data is updated annually by ICAO for each one of the 75 route groups (see **Appendix A**).

https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v10-2017.pdf

Air Travel efficiency varies by distance flown

Commuter flights
For flights of 300 nmi (560 km)

Model	Seats	Fuel burn	Fuel efficiency per seat
ATR 42-500	48	1.26 kg/km (4.5 lb/mi)	3.15 L/100 km (75 mpg - US)
ATR 72-500	70	1.42 kg/km (5.0 lb/mi)	2.53 L/100 km (93 mpg - US)
Beechcraft 1900D (226 nm)	19	1.00 kg/km (3.56 lb/mi)	6.57 L/100 km (35.8 mpg - US)
Bombardier CRJ100	50	2.21 kg/km (7.83 lb/mi)	5.50 L/100 km (42.8 mpg - US)

Regional flights

For flights of 500–660 nmi (930–1,220 km)

Model	Seats	Sector	Fuel burn	Fuel efficiency per seat
Airbus A319neo	144	600 nmi (1,100 km)	3.37 kg/km (11.94 lb/mi)	2.92 L/100 km (80.6 mpg - US)
Airbus A220 100	115	600 nmi (1,100 km)	2.8 kg/km (10.1 lb/mi)	3.07 L/100 km (76.7 mpg - US)
Boeing 737-300	126	507 nmi (939 km)	3.49 kg/km (12.4 lb/mi)	3.46 L/100 km (68 mpg - US)
Bombardier CRJ200	50	580 nmi (1,070 km)	1.80 kg/km (6.39 lb/mi)	4.49 L/100 km (52.4 mpg - US)

Short-haul flights

For flights of 1,000 nmi (1,900 km)

Model	Seats	Fuel Burn	Fuel efficiency per seat
Airbus A220-300	160	2.56 kg/km (9.08 lb/mi)	2.00 L/100 km (118 mpg - US)
Airbus A220-300	135	2.30 kg/km (8.17 lb/mi)	1.85 L/100 km (127 mpg - US)
Boeing 737-600	110	2.77 kg/km (9.8 lb/mi)	3.15 L/100 km (75 mpg - US)
Quest Kodiak	9	0.71 kg/km (2.52 lb/mi)	6.28 L/100 km (37.5 mpg - US)

Medium-haul flights

For flights of 1,750–3,400 nmi (3,240–6,300 km)

Model	Seats	Sector	Fuel burn	Fuel efficiency per seat
Airbus A320	150	2,151 nmi (3,984 km)	2.91 kg/km (10.3 lb/mi)	2.43 L/100 km (97 mpg - US)
Boeing 737 MAX-8	168	3,400 nmi (6,300 km)	2.86 kg/km (10.1 lb/mi)	2.13 L/100 km (110 mpg - US)
Boeing 787-8	291	3,400 nmi (6,300 km)	5.26 kg/km (18.7 lb/mi)	2.26 L/100 km (104 mpg - US)
Irkut MC-21	163	1,750 nmi (3,240 km)	3.04 kg/km (10.8 lb/mi)	2.33 L/100 km (101 mpg - US)

Long-haul flights

For flights of 4,650–7,200 nmi (8,610–13,330 km)

Model	Seats	Sector	Fuel burn	Fuel efficiency per seat
Airbus A330-200	241	6,000 nmi (11,000 km)	6.4 kg/km (23 lb/mi)	3.32 L/100 km (71 mpg - US)
Airbus A380	544	6,000 nmi (11,000 km)	13.78 kg/km (48.9 lb/mi)	3.16 L/100 km (74 mpg - US)
Boeing 747-400	416	6,000 nmi (11,000 km)	11.11 kg/km (39.4 lb/mi)	3.34 L/100 km (70 mpg - US)
Boeing 787-9	294	4,650 nmi (8,610 km)	5.85 kg/km (20.8 lb/mi)	2.49 L/100 km (94 mpg - US)

For more details, please visit following web page:
https://en.wikipedia.org/wiki/Fuel_economy_in_aircraft

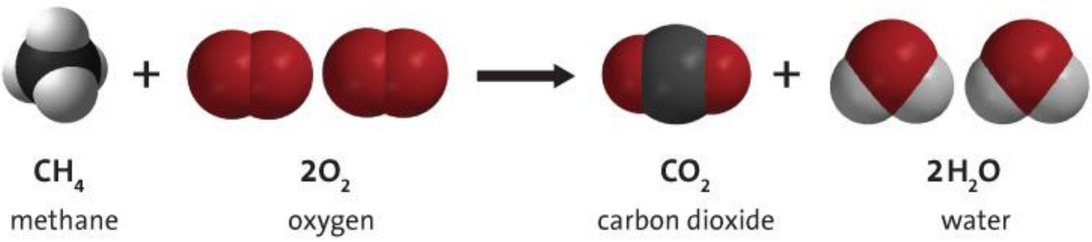
Make your own calculations

This Table can be used to calculate aviation related GHG emissions. In the first column, you enter the fuel type then the chemical formula followed by the emission rate and fuel quantity to calculate the total.

Fuel Type	Formula	kgCO2/L	Fuel Quantity (L)	Resulting kgCO2
Gasoline	C8H18	2.3		
Kerosene (JP-1A/4/8, etc.)	C12H26	2.48		

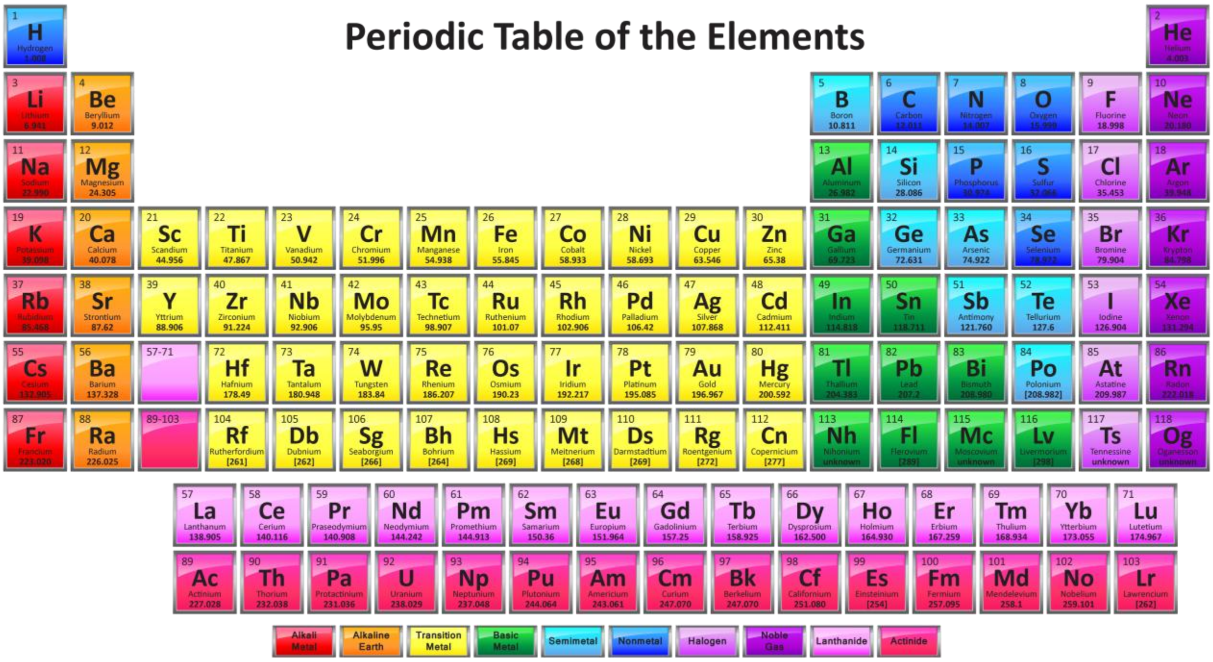
CO2 on a molecular level

The below sequence shows how one molecule of Methane - commonly known as Natural Gas - recombines with Oxygen to become one Carbon Dioxide and two Waters



https://images.app.goo.gl/v9V1TG4fJKXiXHPj6

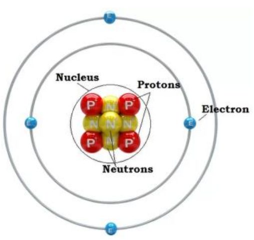
The table below shows the progression of atoms as they gain electrons and become bigger.
*Note that Carbon is identified with the capital **C** and Oxygen with the capital **O***

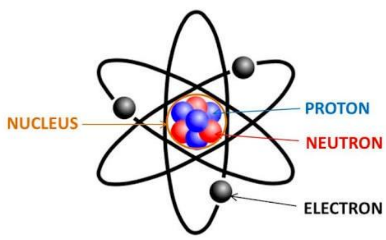


https://sciencenotes.org/2016-2017-colorful-periodic-table-118-element-names/

Weight of Oxygen atom is 15.9994 => 16

The number 8 denotes the quantity of protons in the nucleus, which is matched by the number of electrons in the outer shells - 16 is the weight of the neutrons and the protons combined, making up the nucleus, whereas the electrons weigh almost nothing.





https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Atomic_Theory/Atomic_Structure

There are 2 Oxygen and 1 Carbon in CO_2 > 16 + 16 + 12 = 44. The majority of the weight comes from the Oxygen. Carbon has an atomic weight of 12, Oxygen has an atomic weight of 16.

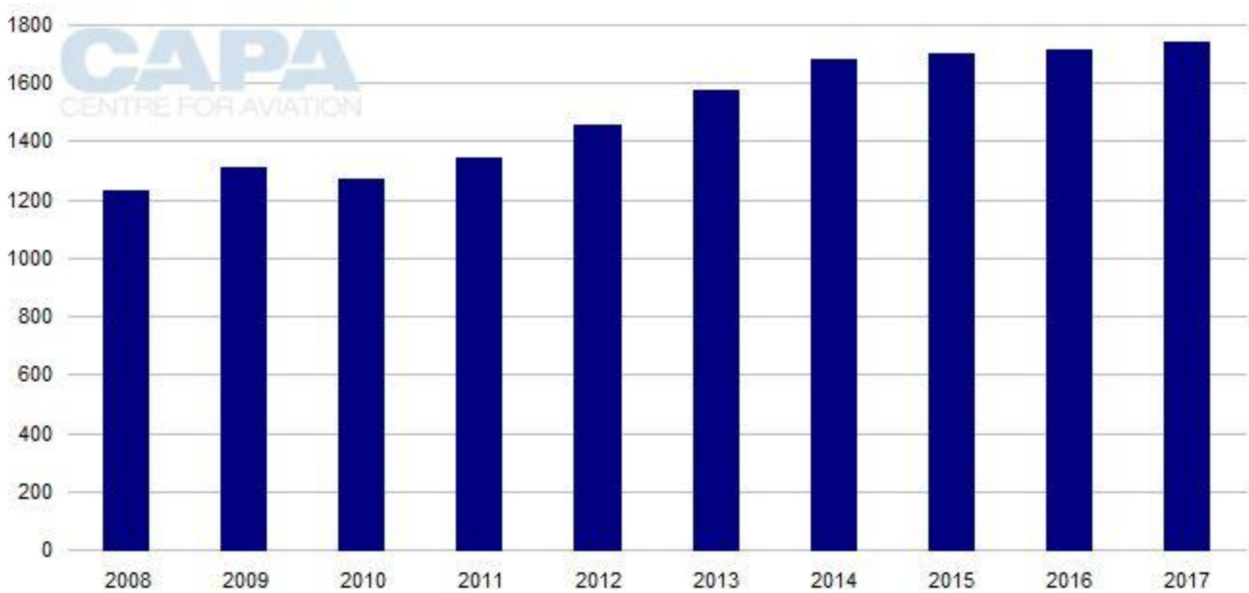
44 is the atomic weight of CO_2 - because 12 is of carbon and 32 is of oxygen > therefore, 44/12 or 3.67 is the ratio of carbon dioxide to carbon.

Aircraft Emissions - a global view

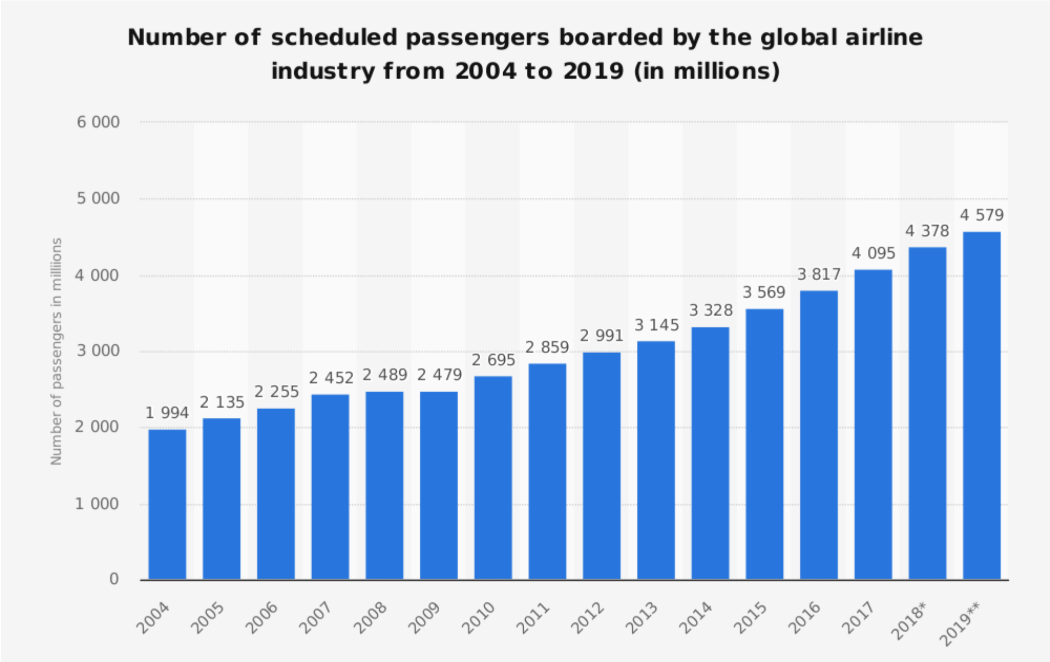
The number of flights performed globally by the airline industry has been steadily increasing since the early 2000s and is expected to reach 40 million annual in 2019. This figure represents an increase of over 50 percent from a decade prior. Since 1990, CO_2 emissions from international aviation have increased 83 per cent. Globally, aviation is responsible for around 2% of anthropogenic CO_2 emissions, but its impact is projected to rise by 200% to 360% by 2050.

Airliners.net, an aviation enthusiast website, states that there are about 39,000 planes in the world – including all commercial and military planes. According to the CAPA Fleet Database, the total number of commercial aircraft delivered in 2017 reached another record high. The database recorded 1,740 deliveries in 2017, which was 1.5% more than the 1,714 aircraft delivered in 2016. This was the seventh consecutive year of rising delivery numbers.

Global commercial aircraft annual deliveries : 2008 to 2017



Source: CAPA Fleet Database



Total distance traveled by air

How many airplanes fly each day in the world? , There are around **102,465 flights** per day. The average which we are going to use for this calculations is a medium-haul flight, which based on Eurocontrol, is about 2300 km so 1430 miles.

So everyday planes travel:

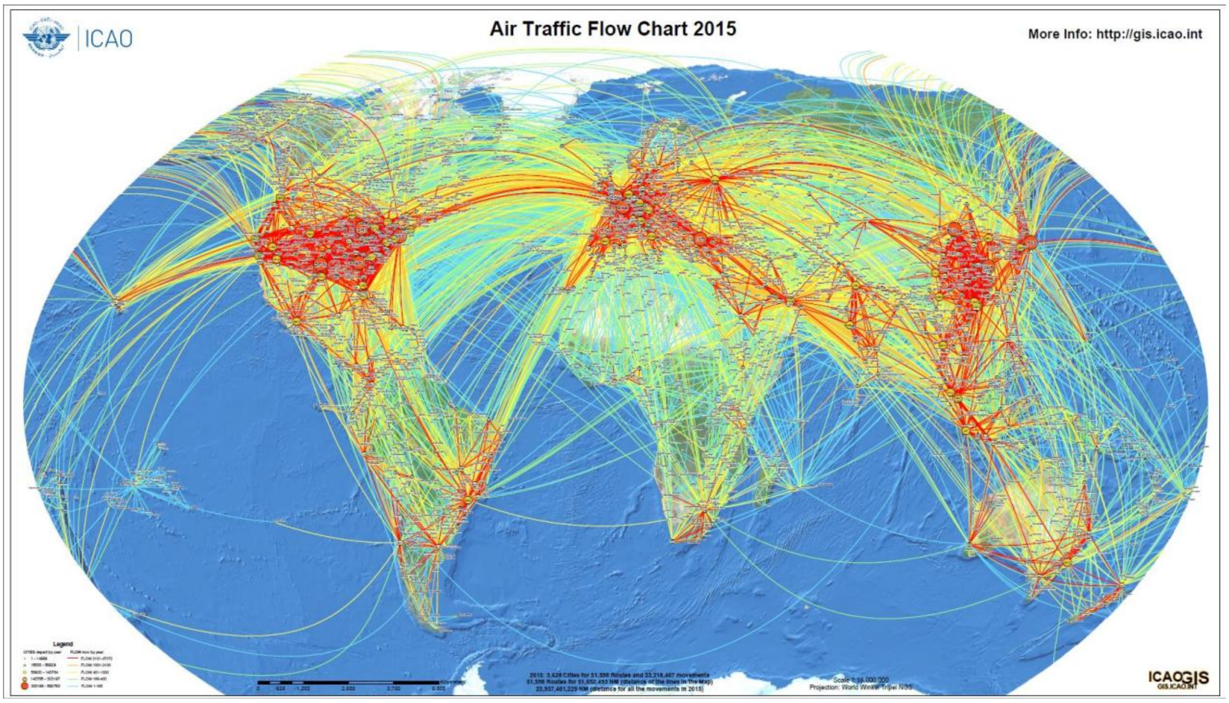
1,430 x 102,465 = **146,524,950 miles per day**

But your question was per year so in that case:

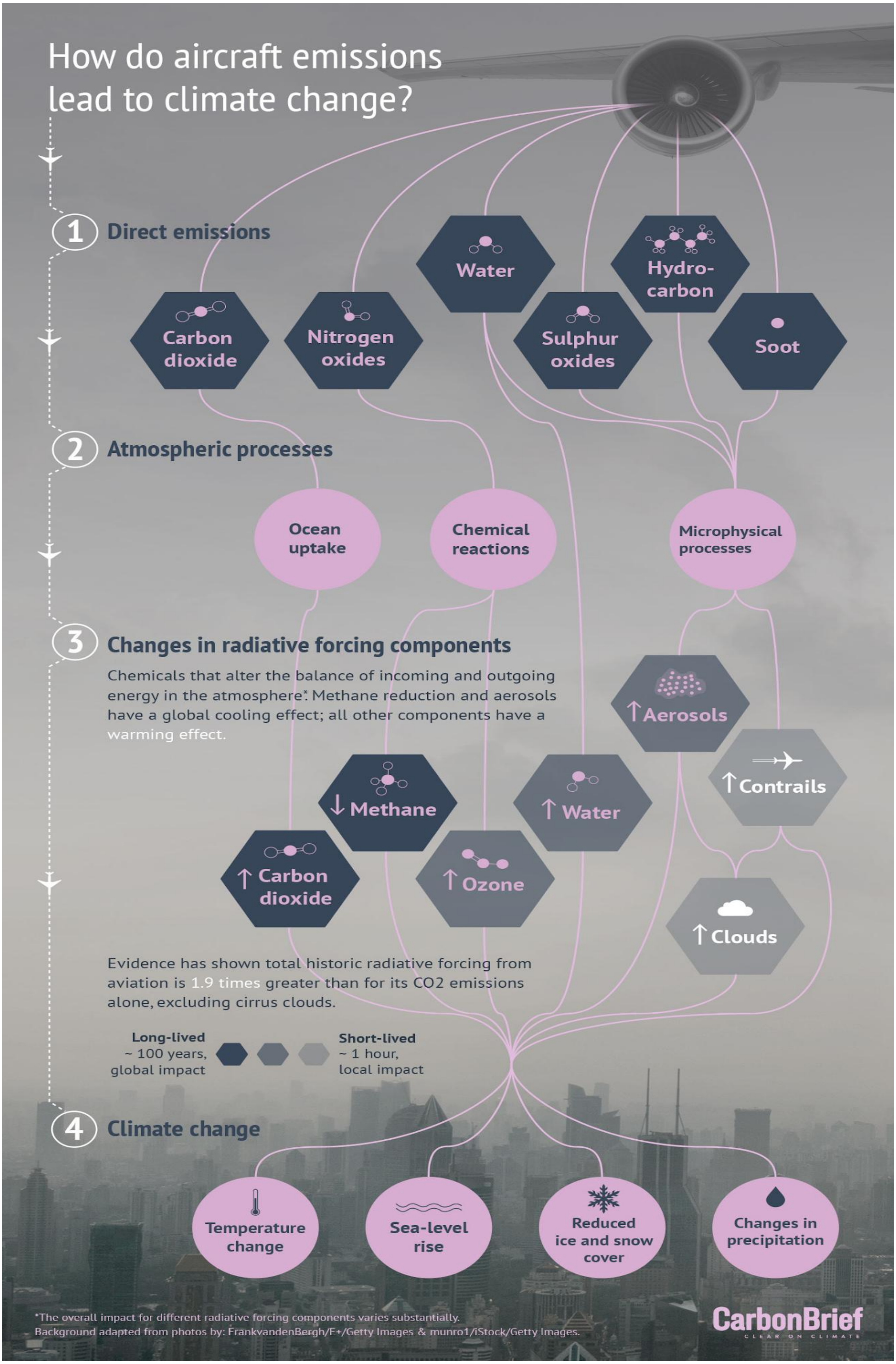
146,524,950 miles per day x 365 days = 53,481,606,750 miles per year – 53 billion miles per year

http://www.travelweek.ca/news/exactly-many-planes-world-today/
https://www.telegraph.co.uk/travel/travel-truths/how-many-planes-are-there-in-the-world/

Number of flights / day / year - passenger airborne now / year / miles flown

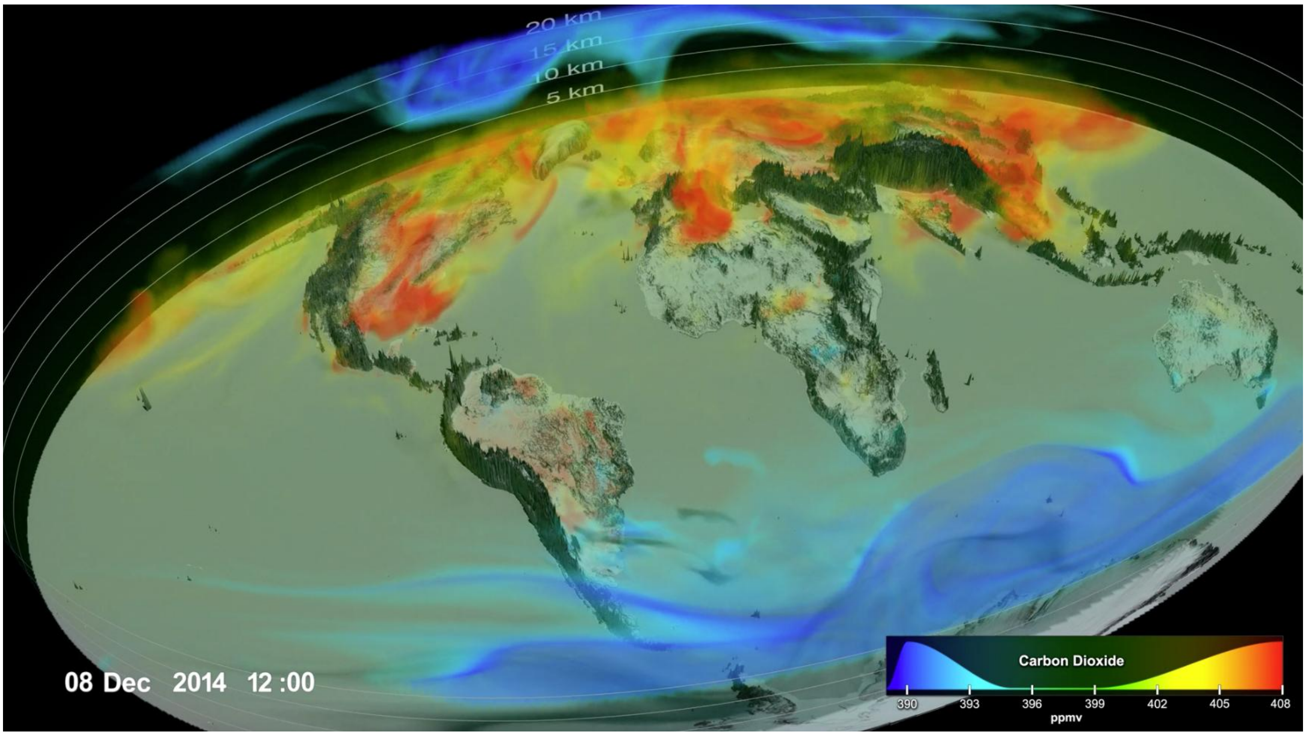


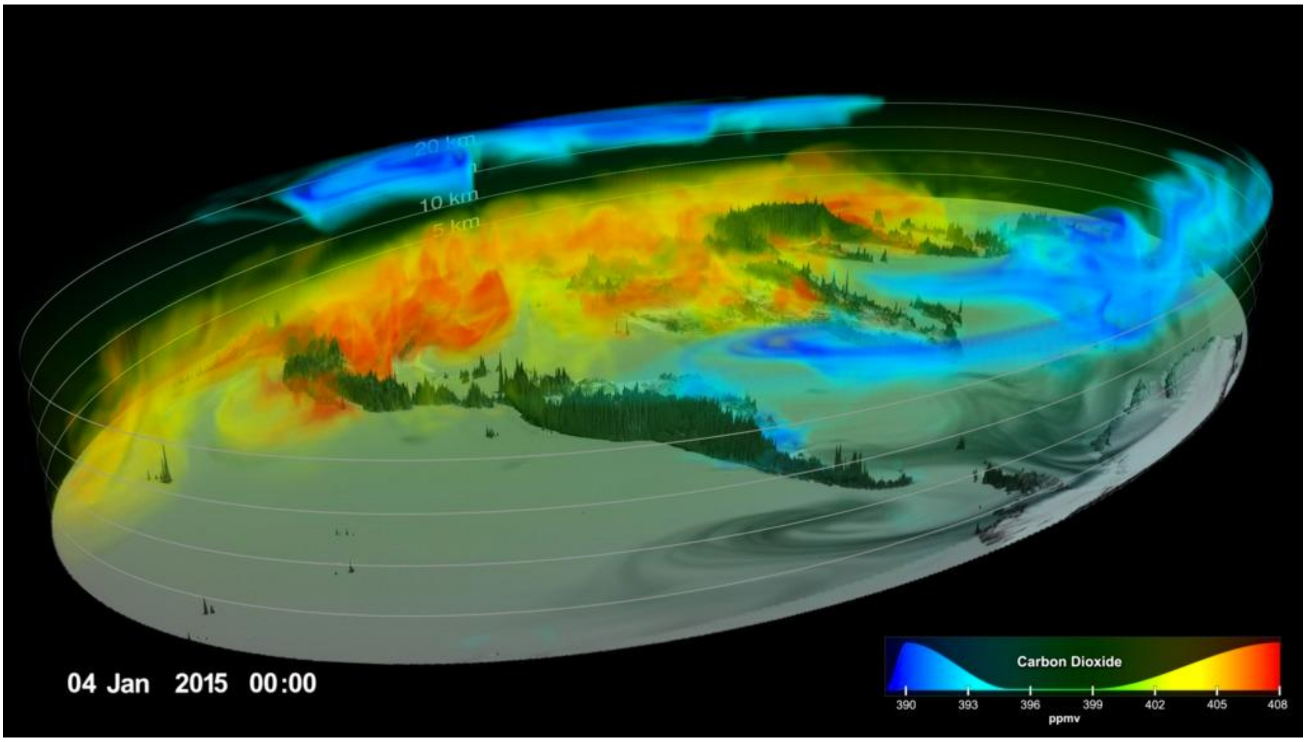
Aircraft Types	
	
Passenger Airplane	**Private Airplane**
	
Agricultural Airplane	**Rescue Helicopter**
	
Military Jet	**Cargo Airplane**


How do aircraft emissions lead to climate change?
1 Direct emissions
Carbon dioxide
Nitrogen oxides
Water
Sulphur oxides
Hydro-carbon
Soot
2 Atmospheric processes
Ocean uptake
Chemical reactions
Microphysical processes
3 Changes in radiative forcing components
Chemicals that alter the balance of incoming and outgoing energy in the atmosphere*. Methane reduction and aerosols have a global cooling effect; all other components have a warming effect.
↑ Aerosols
↑ Contrails
↓ Methane
↑ Water
↑ Carbon dioxide
↑ Ozone
↑ Clouds
Evidence has shown total historic radiative forcing from aviation is 1.9 times greater than for its CO2 emissions alone, excluding cirrus clouds.
Long-lived ~ 100 years, global impact
Short-lived ~ 1 hour, local impact
4 Climate change
Temperature change
Sea-level rise
Reduced ice and snow cover
Changes in precipitation
*The overall impact for different radiative forcing components varies substantially.
Background adapted from photos by: FrankvandenBergh/E+/Getty Images & munro1/iStock/Getty Images.
CarbonBrief
CLEAR ON CLIMATE

Visualization of CO_2 in the earth's atmosphere (Released by NASA)

Notice that the concentration of Carbon Dioxide is much higher in the northern hemisphere.





NASA, 3D Simulation, Carbon Dioxide (CO2), Goddard Space Flight Center, Greenhouse Gas, OCO-2, Jet Propulsion Laboratory, Global

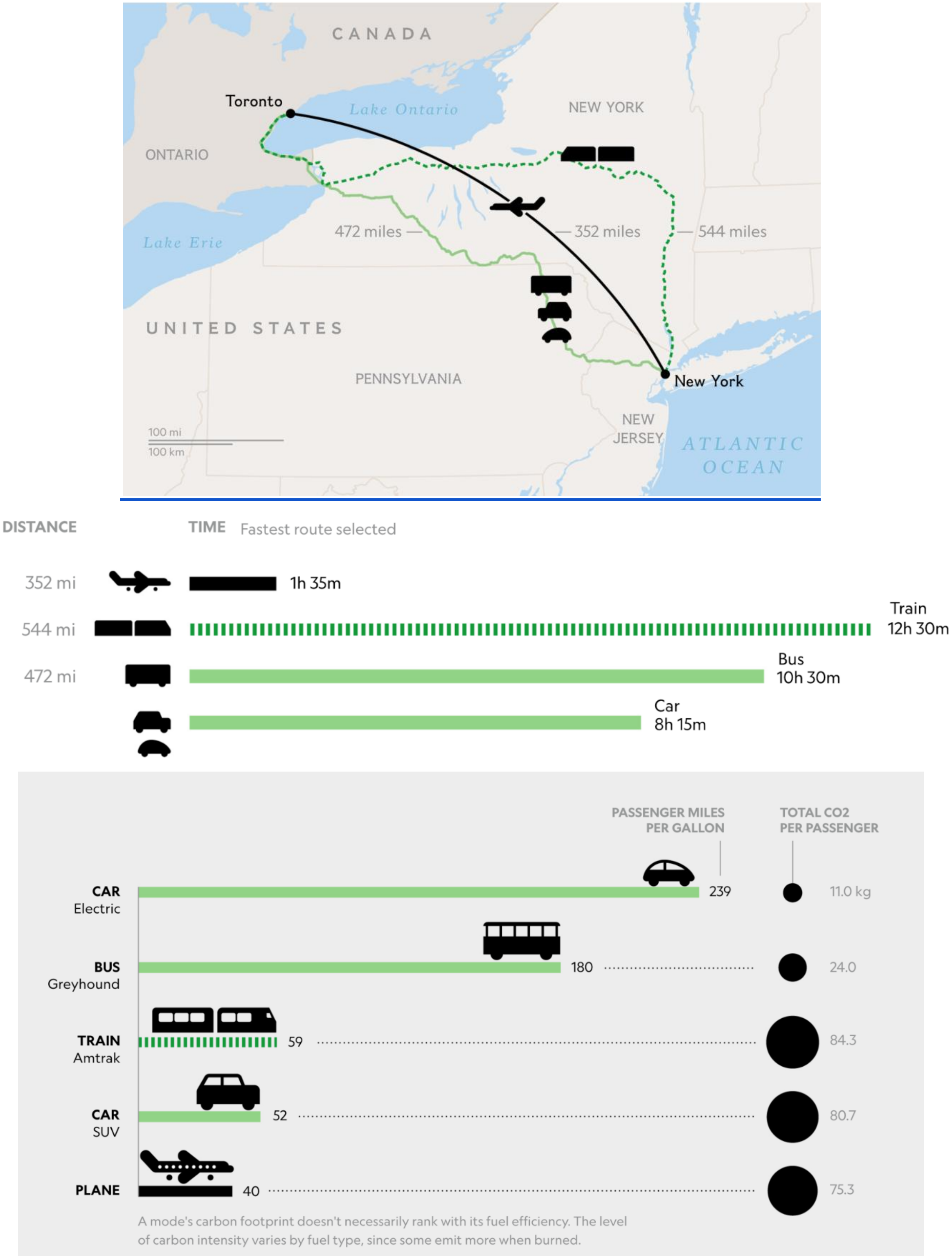
"Following Carbon Dioxide Through the Atmosphere"

YouTube https://youtu.be/syU1rRCp7E8

Flying vs. Other Transportation

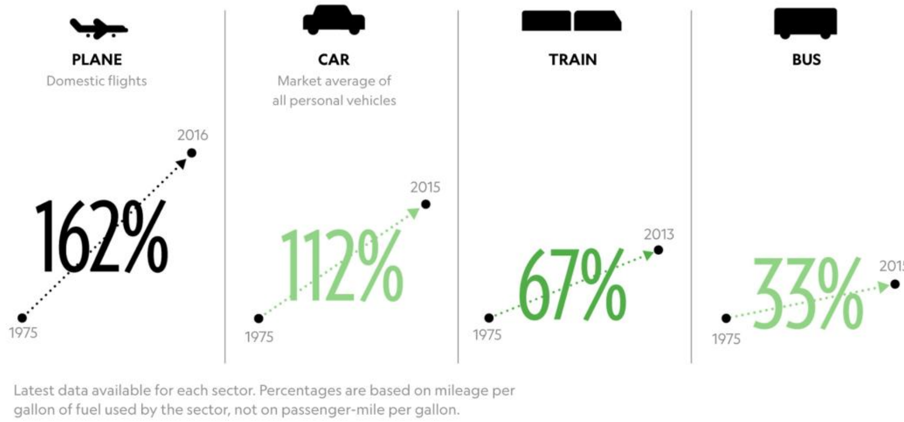
The mode of transportation we choose can have a big impact. It can affect time, comfort, cost, and other factors. But how we travel can also have a big impact on the planet. In this graphic, we break down the most efficient ways to travel on a typical trip:

New York to Boston



The fuel economies across transit modes can be compared with a metric known as passenger miles per gallon. The bus is the most energy-efficient way to travel between Toronto and New York.

Lighter materials, improved aerodynamic design, and more fuel-efficient engines have increased the distance each mode can travel on one gallon of fuel.

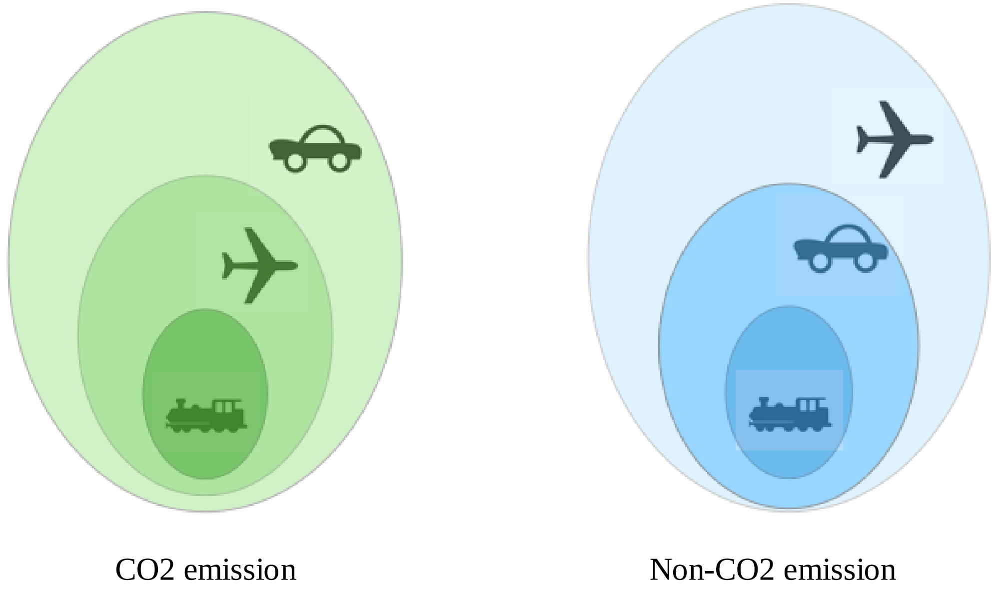


Non-CO2 emissions

The calculations above don't take into account the radiative forcing – the impact on the overall energy balance of the planet – caused by non-CO2 warming pollutants, such as water vapor, aerosols and nitrogen oxides.

The impacts of non-CO2 aircraft emissions at high altitudes came to prominence back in 1999 following publication of a special report by the International Panel on Climate Change (IPCC) on aviation. This estimated the total historic impact of aviation on the climate to have been two to four times higher than for CO2 emissions alone.

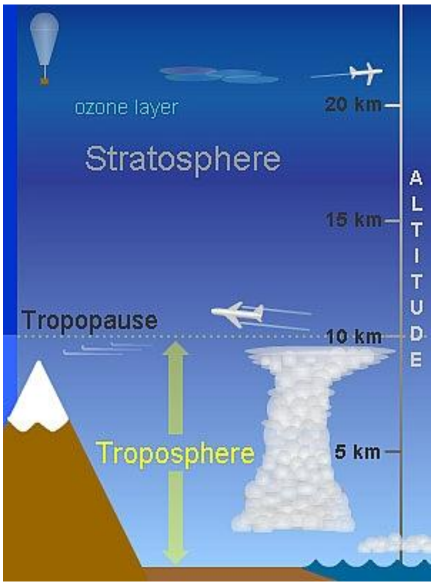
But while it has been well established for more than a decade that air traffic affects the climate through emissions other than just CO2, putting a number on the overall effect of these emissions has proven tricky.



CO_2 emissions at altitude

The atmosphere above the cloud deck is silent, cold, and has 1/5th the molecules we experience on the ground. The air moves in a mostly consistent, wide and uniform manner, without obstruction, such as a mountain range or afternoon thunderstorm. Aircraft bring to that layer the carbon rich fuel whose powerful brew traps wavelengths of a certain size - 100,000 flights a day - in flight corridors several miles wide, a thousand or so meters high.

The movement of aircraft through tunnels designed for efficiency, optimal ground control and cost considerations, results in bands of emissions strapping the atmosphere between popular coordinates. Like a belt that gets thicker every day, the continuous injection of high density molecules in a low density environment is altering its morphology.



This is a new science, challenging to study, and one where no nation or organization has taken a clear lead. Emissions at altitude are increasing day by day - and more and more understood as something that is fundamentally altering the chemistry - likely irreversibly - of a transparent, vacuus, subzero layer of planet earth.

https://youtu.be/A5H1qmWSubY
https://multimedia.scmp.com/news/world/article/2165980/flight-paths/index.html
https://en.wikipedia.org/wiki/Stratosphere

Definitions of specialist terms

Carbon dioxide equivalent (CO2e) a term for describing different greenhouse gases in a common unit

nmi A nautical mile is a unit of measurement defined as exactly 1852 meters (about 6,076 feet or 1.1508 statute miles)

mpg a measure of the average distance traveled per unit of energy consumed

kg basic unit of mass in the metric system. A kilogram is very nearly equal (it was originally intended to be exactly equal) to the mass of 1,000 cubic cm of water. The pound is defined as equal to 0.45359237 kg, exactly

LTO cycle Landing and Take-off cycle

Parts per million (ppm) the number of units of mass of a contaminant per million units of total mass

Reference

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). (2006). *2006 IPCC guidelines for national greenhouse gas inventories* (Vol. 5). Hayama, Japan: Institute for Global Environmental Strategies.

Rypdal, K. (2000). AIRCRAFT EMISSIONS-Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories-IPCC.

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http://i-how.co/how-it-works/science/Chemistry/how-does-fractional-distillation-work.html √

https://images.app.goo.gl/zsFrDjxZ5NsPa3JG8
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https://images.app.goo.gl/hDirmFJpzQAoHSs56

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https://www.nationalgeographic.com/travel/features/carbon-footprint-transportation-efficiency-graphic/

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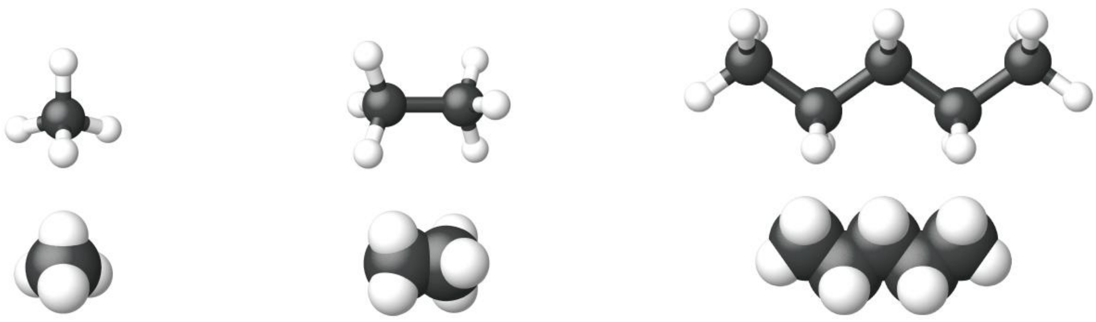
https://en.wikipedia.org/wiki/Keeling_Curve

https://www.engineeringtoolbox.com/co2-comfort-level-d_1024.html

https://www.forbes.com/sites/kevinmurnane/2016/12/20/nasas-spectacular-new-video-shows-previously-unseen-changes-in-CO2-in-the-atmosphere/#16602a555055

http://www.carbonify.com/carbon-calculator.htm

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



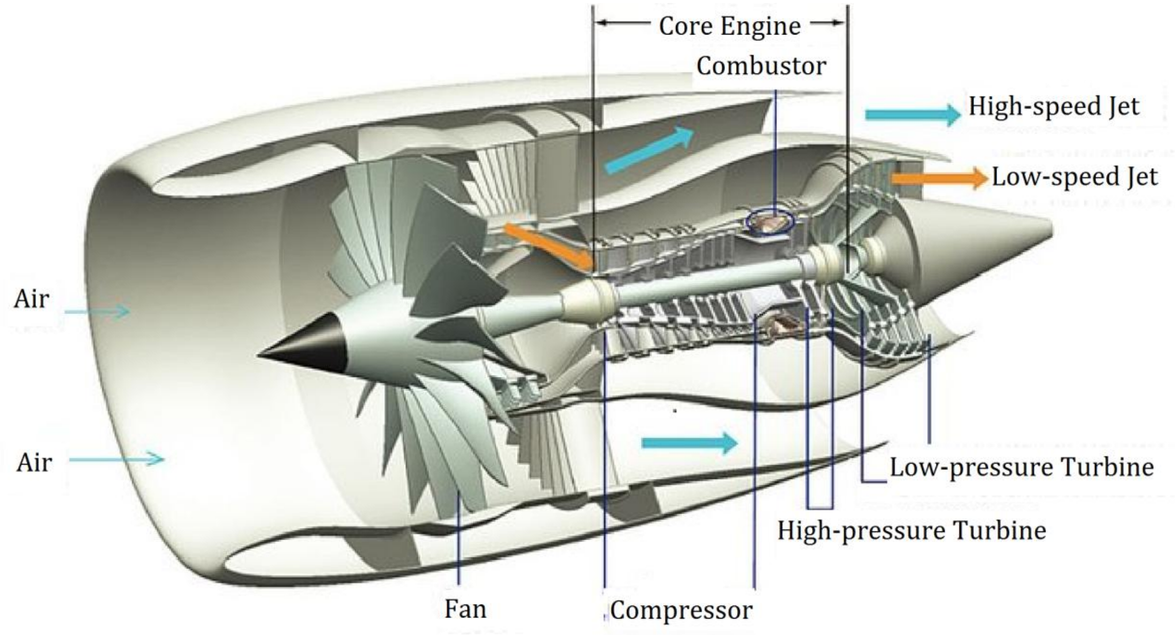
methane CH_4 | ethane CH_3CH_3 or C_2H_6 | pentane $CH_3CH_2CH_2CH_2CH_3$ or C_5H_{12}

https://images.app.goo.gl/KZ69YrMxzSsQuLR99

How does a jet engine work?

The engine sucks air in at the front with a fan. A compressor raises the pressure of the air. The compressor is made with many blades attached to a shaft. The blades spin at high speed and compress or squeeze the air. The compressed air is then sprayed with fuel and an electric spark lights the mixture. The burning gases expand and blast out through the nozzle, at the back of the engine. As the jets of gas shoot backward, the engine and the aircraft are thrust forward. As the hot air is going to the nozzle, it passes through another group of blades called the turbine. The turbine is attached to the same shaft as the compressor. Spinning the turbine causes the compressor to spin.

YouTube https://youtu.be/KjiUUJdPGX0



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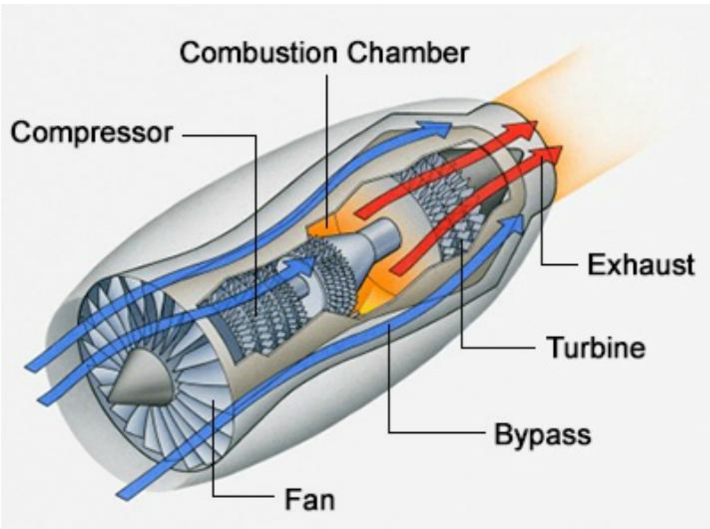
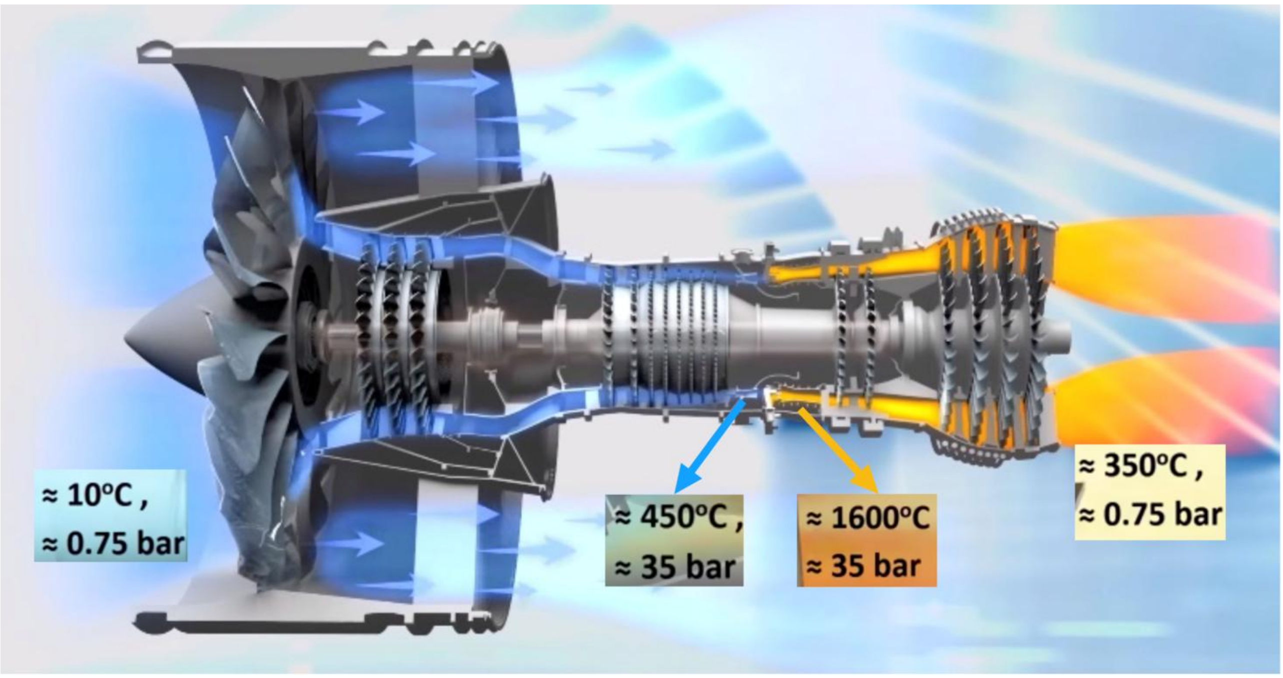
	The air temperature at cruising altitude is around -44 degree Celsius. Oxygen at that altitude is sparse, and drops to 5% from 21% at ground level

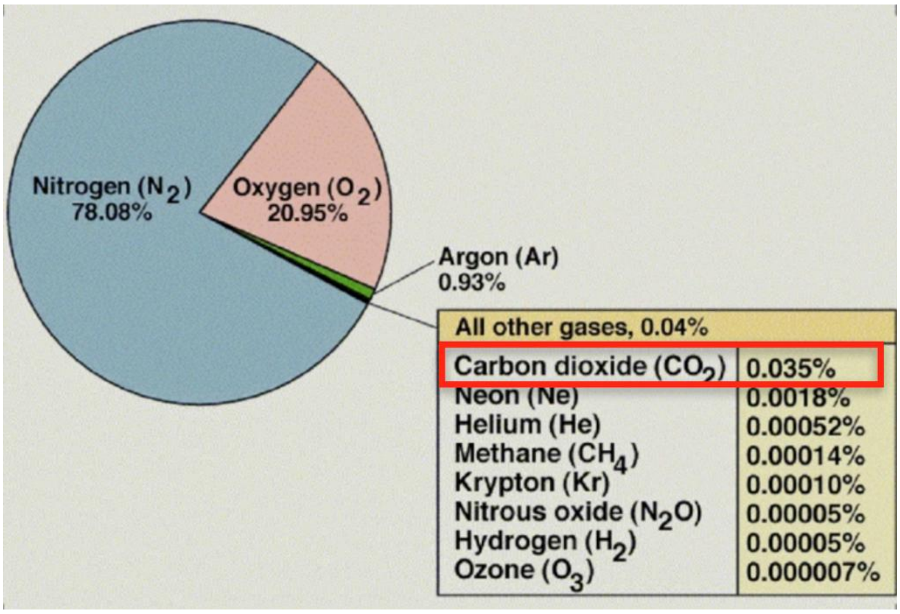
https://www.researchgate.net/figure/Atmospheric-and-partial-pressures-of-oxygen-at-different-altitudes_tbl1_8601541

Temperature and air density levels in the image below are based on the atmosphere at sea-level



https://images.app.goo.gl/Q6atatJGYLBBp6MB9

Notice that 99% of atmosphere consists of nitrogen and oxygen



Carbon Dioxide (CO2) is the first molecule in the atmosphere made up of three elements.

The elements are held together by a strong molecular bonds.

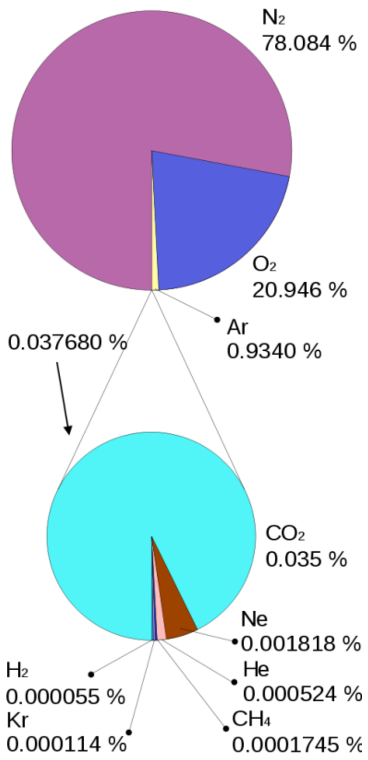
It is those bonds that enables CO2 to snare infra red waves traveling through our atmosphere.

When infrared waves are caught and bounced back, the energy inside the wave stays in our atmosphere, as opposed to traveling into space.

https://images.app.goo.gl/aLVinFnBenVwjaxW8

http://www-users.math.umn.edu/~mcgehee/Seminars/ClimateChange/presentations/2013-1Spring/20130212ThermalIRandCarbonDioxideintheAtmosphere.pdf

http://www.physics.upenn.edu/~pcn/Ms/18PhysTeacher.pdf



https://climate.ncsu.edu/edu/Composition

Note that the Turquoise - Neon Aqua Blue - is Carbon dioxide - the first real molecule present in our atmosphere.

As a molecule, it has unique characteristics. The feature most important to heat retention in our atmosphere, comes from molecular strength and wobbly nature between the carbon and the two oxygens.

This flexible strength prevents infrared radiation from leaving our atmosphere. Were it not for the bonds between oxygen and carbon, our planet would be beautiful white ball of ice spinning around the sun.

Sliding table

The atmosphere is composed of a mix of several different gases in differing amounts. The permanent gases whose percentages do not change from day to day are nitrogen, oxygen and argon. Nitrogen accounts for 78% of the atmosphere, oxygen 21% and argon 0.9%. Gases like carbon dioxide, nitrous oxides, methane, and ozone are trace gases that account for about ***a tenth of one percent*** of the atmosphere. Carbon dioxide is the first real molecule in the atmosphere.

Explain CO2 level today vs 1919 - one 100 year ago

Note that the concentration of CO2 rises around 100 parts per million - ppm - in the last 100 years. Today it is a bit over 400ppm, and 100 years ago it was a bit over 300ppm.

This is equivalent 7.76 billion tonnes of CO2 per ppm. Thus, in the last 100 year, the atmosphere has absorbed and retained from the terrestre 212 billion tonnes of carbon, resulting in 776 billion tonnes of additional carbon dioxide.

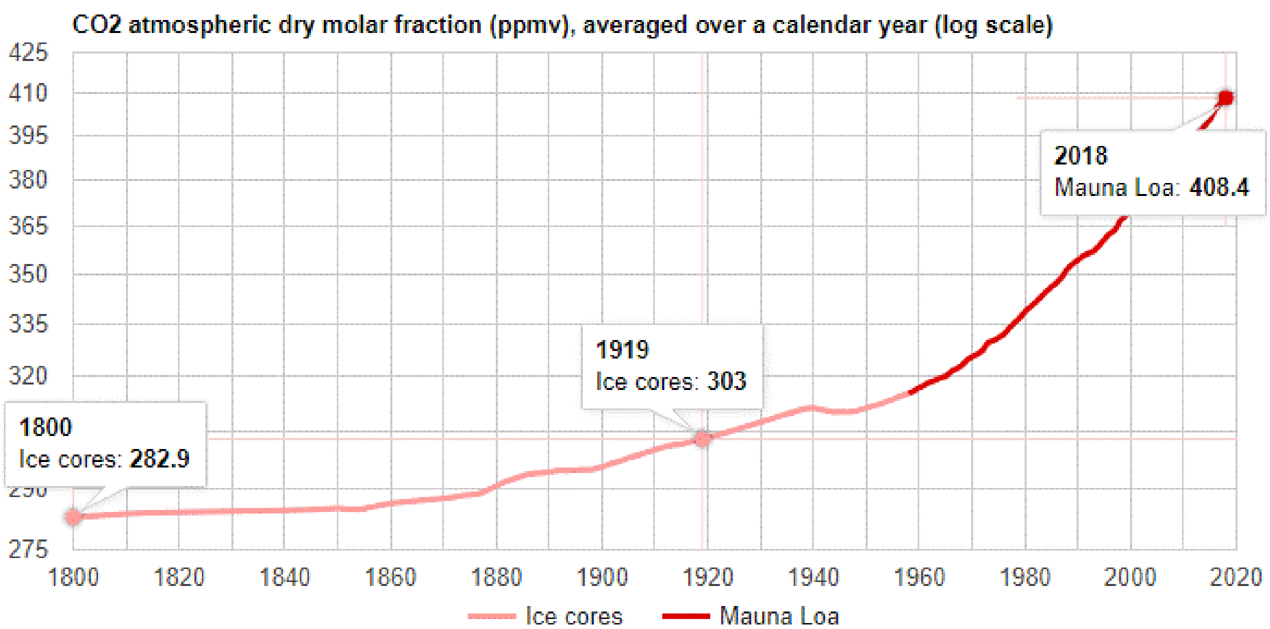
2.12	1	**IPCC and Gilbert Masters**
one tonne carbon	becomes 44/12 tonne CO2	
1	3.67	
2.12 gigatonne carbon	equals 2.12 x 44/12 GtCO2	
2.12	7.77	
one part per million of CO2	**equals 7.7 billion tonnes of CO2**	
1	**7.77**	
ppm CO2 above 'normal'	GtCO2 above 'normal'	
100	777	
number of people on earth, in billion	amount of 'extra' CO2, in billion	
7.5	777	
number of people on earth	extra tonne CO2	
7,500,000,000	777,333,333,333	
extra tonne CO2 per person		
104		

CarbonSolutions. Measure. Manage. Reduce.

Coefficients assembled by Mark van Soestbergen - 080719
mark@icbe.com - 352.284.8221 mobile

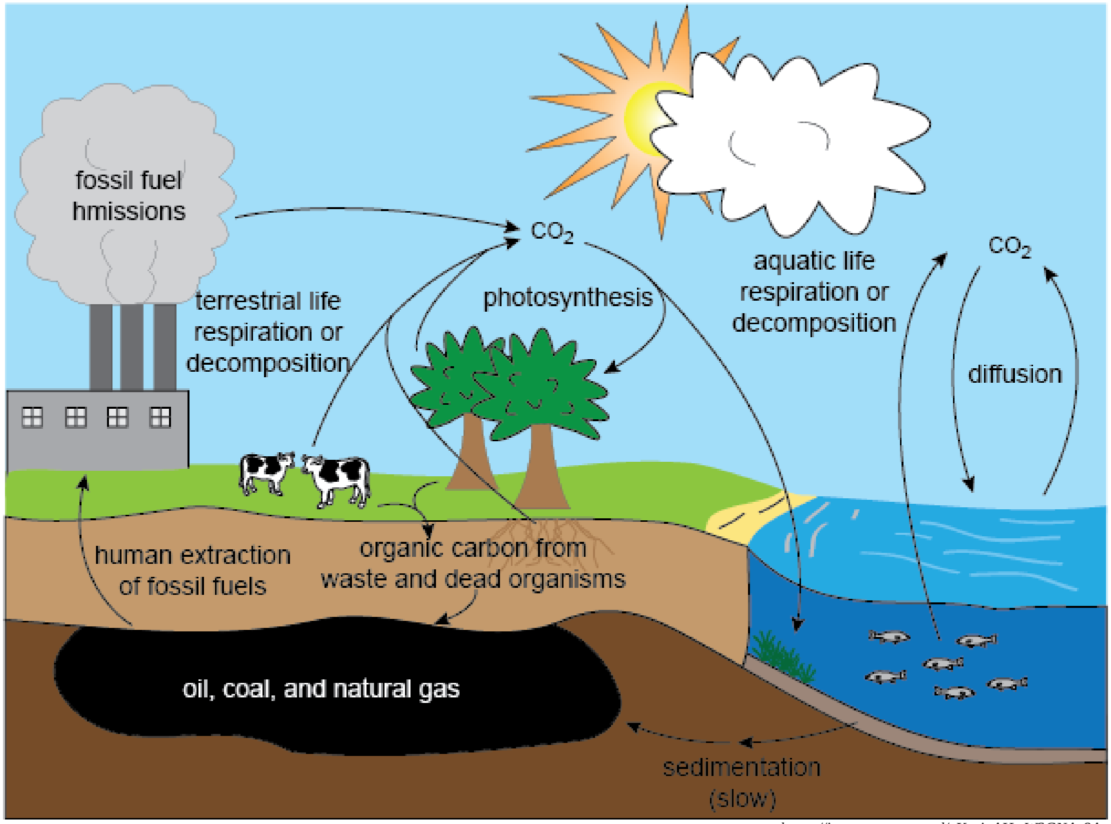
https://cdiac.ess-dive.lbl.gov/pns/faq.html
http://www.grisanik.com/blog/how-much-carbon-is-in-the-atmosphere/
https://scied.ucar.edu/carbon-dioxide-400-ppm-diagrams

In the Word version of this document - the table above can be tapped to generate a formulated Excel sheet



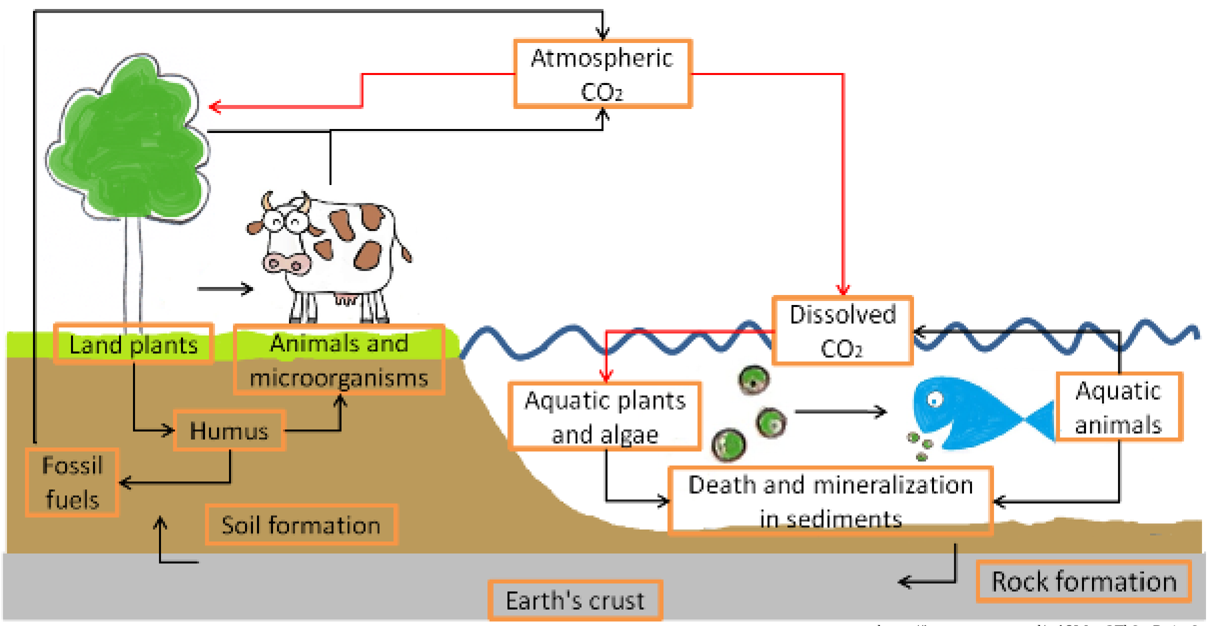
https://images.app.goo.gl/R7mExHEpJCTLGoEA8

The below image shows CO2 from factories being absorbed by trees and oceans with the help of the energy from the sun.



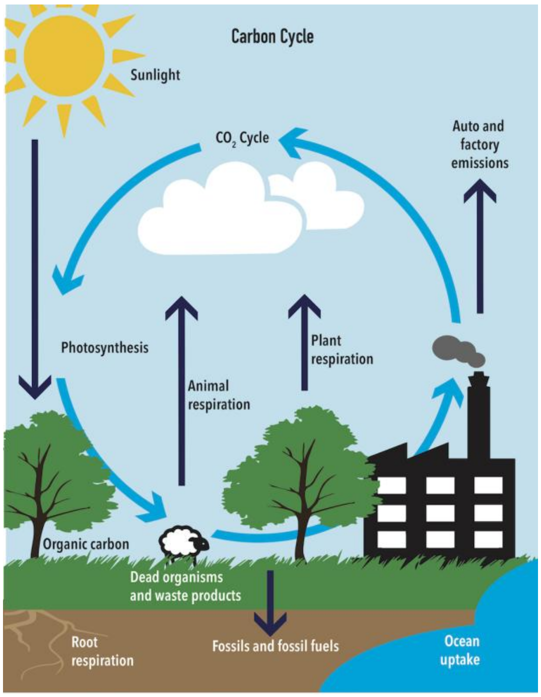
https://images.app.goo.gl/xKvxivAHwWSGNAs8A

This picture shows how land and sea play in an important role in the management of CO2 as it circulates from the air to the water and the land.



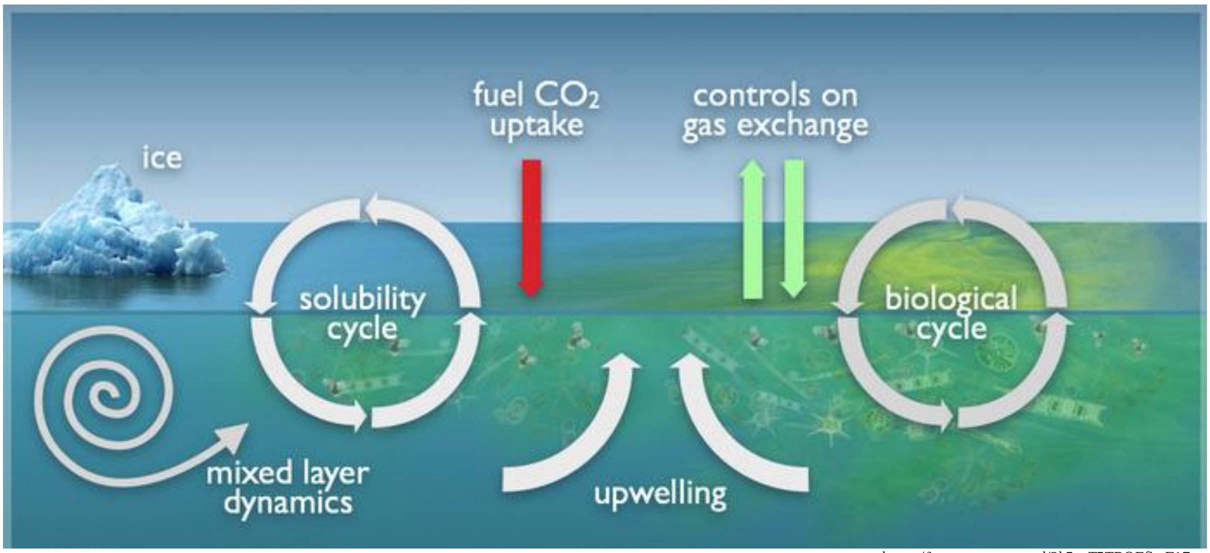
https://images.app.goo.gl/wA8Wqm2Tk6cyPn1m6

Carbon is essential for life on this planet.
Carbon is found in every life form on the land, in the soil, in the ocean, and in the air.



https://images.app.goo.gl/sM9wjxGcVhBHUe5r5

This shows the interaction How the oceans absorb carbon dioxide is critical for predicting climate change.



https://images.app.goo.gl/2k5nzT5TBQEfjmF17

"The carbon cycle"

YouTube https://youtu.be/E8Y6L5TI_94

"NASA's Earth Minute: Gas Problem"

YouTube https://youtu.be/K9kga9c0u2I

A Breathing Planet, Off Balance

YouTube https://www.jpl.nasa.gov/video/details.php?id=1407

How many trees it would take to offset the emissions caused by an air travel from Paris to London?

Aircraft **:** Boeing 747 - about 500 passengers including cargo (freight and mail) weight
Total distance flown **:** 215 miles / 345 kilometer
Total tonnes of CO_2 produced by 747 **:** 5.238 tonnes

Total tonnes CO_2 per passenger : 0.0105
No. of trees to offset per 1 passenger : 0.5238 - tree breathing for one year
Total no. of trees breathing one year to offset per flight (Paris - London, OW) : 0.5238 x 500 = **262 trees**

Paris —> London

262 Trees

https://www.sciencedirect.com/science/article/pii/S008207840400061X
http://irina.eas.gatech.edu/EAS8803_Fall2009/Lec6.pdf
https://scied.ucar.edu/carbon-dioxide-absorbs-and-re-emits-infrared-radiation

About this Report / Research Paper

This paper was generated in late Spring and early Summer of 2019.

The researcher and author is Kyuyong Shim, a student at the University of Florida, pursuing a Master's in Mechanical Engineering. Kyuyong applied for an academic internship with a local entity, and selected to combine his professional experience with the project research goals; to enhance the understanding of man's role in earth's climate.

http://www.mae.ufl.edu/

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Kyuyong is a Major in the Korean Air Force, and team pilot of the 53rd Air Demonstration Group, nicknamed Black Eagles, the flight display team of the Republic of Korea Air Force based at Wonju AB, Gangwon Province.

He currently resides in Gainesville, with his wife and sport loving son, who is also a talented and prolific author of Man-wha.

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We'd like to also thank Randy Wells, Director of the Greater Gainesville International Center, who organized the study locale and access to meeting space, the Innovation Hub at the University of Florida for their fantastic outdoor balcony views, Curia on the Drag and Volta Coffee, for the delicious ambiance and creative atmosphere.

About CarbonSolutions

CarbonSolutions was founded in 1998 as the consulting arm of the International Carbon Bank and Exchange, Inc. Since then we have helped numerous national and international clients establish greenhouse gas inventories, certify emission reduction projects and generate climate strategies.

081419

This exercise was an eye opener for me, had never really looked at the idea of spray painting the top layer of the Troposhere, Kyu-Yong did a stellar job, so glad that we have access to such genuine talent here in the GNV.

I have a sneaky feeling this paper will help us in the journey forward.

- Mark

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"This is the coolest summer for the rest of our lives."
Director Stephen Humphrey, SNRE, 2019