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Extracted Hydrocarbon Consumption is Upsetting the Earth's Systems in a Geologic Blink of an Eye

By Dr. William Strauss[1], President, FutureMetrics

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The earth's systems are robust in geologic time. Over the many millions of years of the history of life on earth, climate fluctuations have resulted in changes in the makeup of plants and animals. Most of the evolution and adaptations that yielded the ecosphere we inhabit today were made around long cycle influences on the earth's climate.

What we are seeing today is anything but long cycle.

It is more like the sudden and extreme changes in climate that resulted from the large meteor strike 66 million years ago that wiped out about 75% of the life on earth[2]. The climate change consequences of that event were a sudden, extreme, and prolonged cooling . Today's climate crisis is a sudden and extreme heating due to the rapid release, over about about 150 years, of carbon (in the form of CO_2) that was sequestered and mineralized over hundreds of millions of years.

But will this global heating event be prolonged? The facts suggest that, given what the charts that follow below show, the answer is "yes". But perhaps, if real action is taken, the magnitude, and thus the consequences to the earth's systems, can be mitigated.

This white paper highlights the situation.

It is seriously critical!

But first, as we have discussed in many papers and presentations[3], a short note on one set of solutions that can support a better future if action is taken now.

While the term "decarbonization" is often used when contemplating the future supply of energy, that only applies to sectors that can electrify and use energy that does not rely on carbon atoms (wind, solar, hydro, and nuclear come to mind).

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[1] William Strauss has a PhD from the University of New Hampshire. He completed all the economics PhD coursework at UNH before electing to produce a multi-disciplinary dissertation within the Earth Systems Science program (from which he took additional coursework). He is trained as an economist with a deep understanding of the earth's dynamic systems. Program Summary

[2] See HERE for details.

[3] There are many free to download white papers at the FutureMetrics website.

But some sectors need transportable high energy density liquid fuels: for example, long-distance travel via aircraft. There is no conceivable battery storage solution for mitigating carbon emissions from long-distance air travel[4].

The solution is to replace the geologic carbon atoms that are the essential building block of hydrocarbons with biologic carbon[5] to produce essentially the same energy dense liquid hydrocarbon molecules.

Both traditional and sustainable aviation fuels need carbon atoms.

In other words, sustainable liquid fuels are not "decarbonized", they are "defossilized".

The same "defossilization" moniker can be applied to the replacement of coal with sustainably sourced biomass derived upgraded solid fuel for heat and power generation. FutureMetrics has focused on that solution for several decades.

But why should we care about defossilization?

The Earth's systems are signaling a sudden and rapid change.

The reason is 100% the result of fossil fuel consumption and the release in about 150 years of massive quantities of carbon that was mineralized over hundreds of millions of years.

One always must be careful not to equate correlation with causation without proof. But science is clear on the effects of carbon dioxide on the atmosphere. And the facts on CO_2 emissions from the consumption of fossil fuels are, well, facts. There is more on the direction of causation later in this paper.

[4] Energy density is critical for aviation fuel. Aircraft that travel moderate distances or more will not be battery-electric driven. The energy density per kilogram of modern Li-ion batteries is about 0.25 kWh/kg. Sustainable aviation fuel (SAF) is about 12.0 kWh/kg (nearly 50 times more energy per unit of weight). While battery efficiency per kg will likely improve in coming years, it is highly unlikely that we will see a 50x improvement! Furthermore, as SAF is consumed during flight, the aircraft gets lighter, resulting in lower fuel consumption per distance traveled. Batteries retain 100% of their weight from takeoff to landing. For example, a 4,800-km flight would require about 30 tonnes of regular aviation fuel or SAF. Batteries with the same energy would weigh about 1,500 tonnes. That is about 5 times the maximum takeoff weight of a Boeing 787 and of course leaves no room for passengers or cargo.

[5] See FutureMetrics white papers explaining how perpetually renewing sustainably source biomass derived carbon is net zero to the atmosphere in combustion.

The rest of this paper illustrates this dire situation.

Figure 1 below is the starting point.

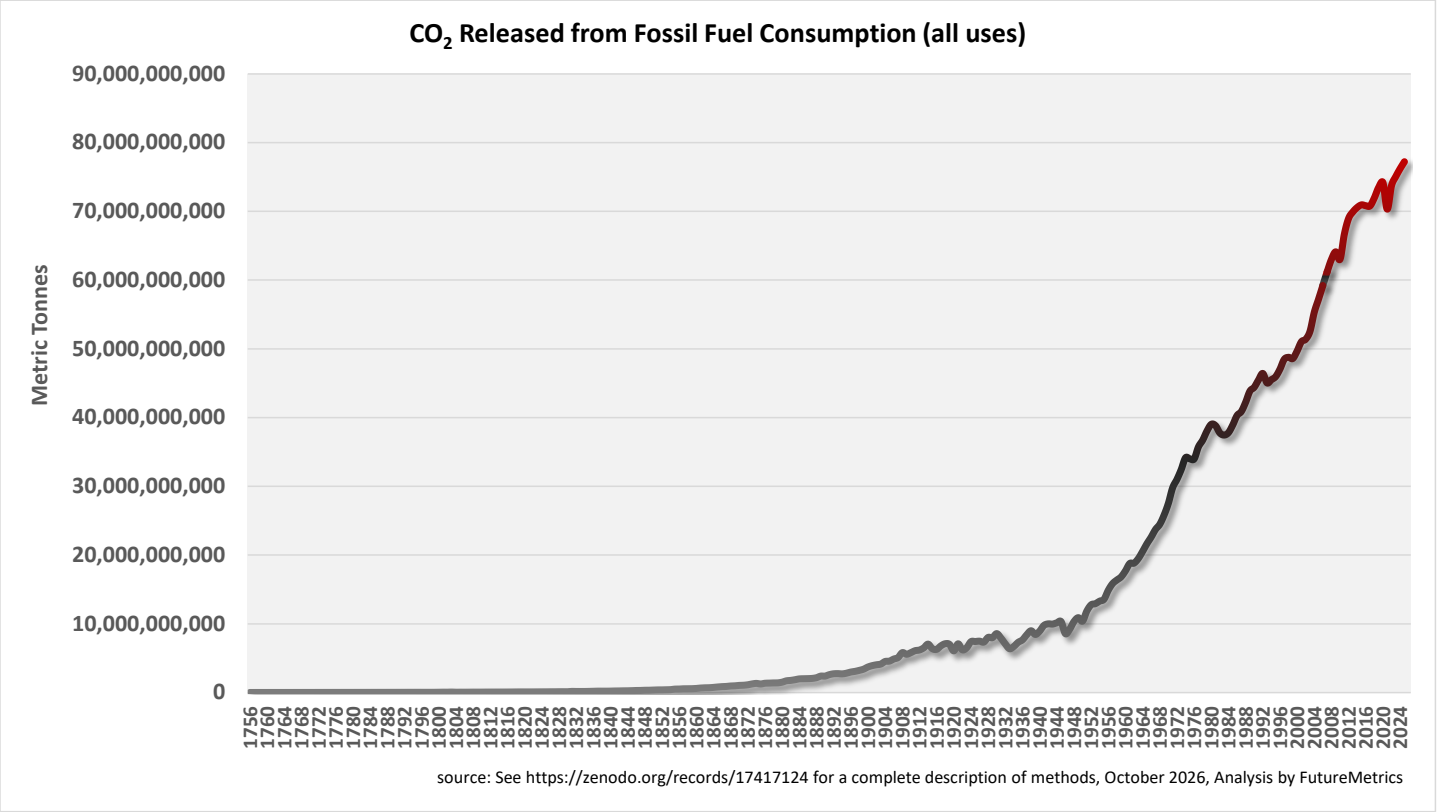

Figure 1 - CO_2 Released from Fossil Fuel Consumption

As animal power and hydropower evolved into steam power (first from wood and then coal) and internal combustion engines using petroleum based liquid fuels, the curve in Figure 1 started to creep off of the x-axis.

As the use of coal and petroleum distillates grew, all sorts of emissions from the combustion of those fuels became regulated over time. But those emissions were either visible, noxious, caused obvious consequences (like NO_x ➔ acid rain), or all of the above. CO_2 emissions are not visible, have no smell and did not, for most of the history on the chart above, have in-you-face consequences.

But it turns out that CO_2 emissions are pollution in the most basic sense[6]. As atmospheric concentrations have increased, the negative consequences are now in-you-face.

[6] https://en.wikipedia.org/wiki/Pollution

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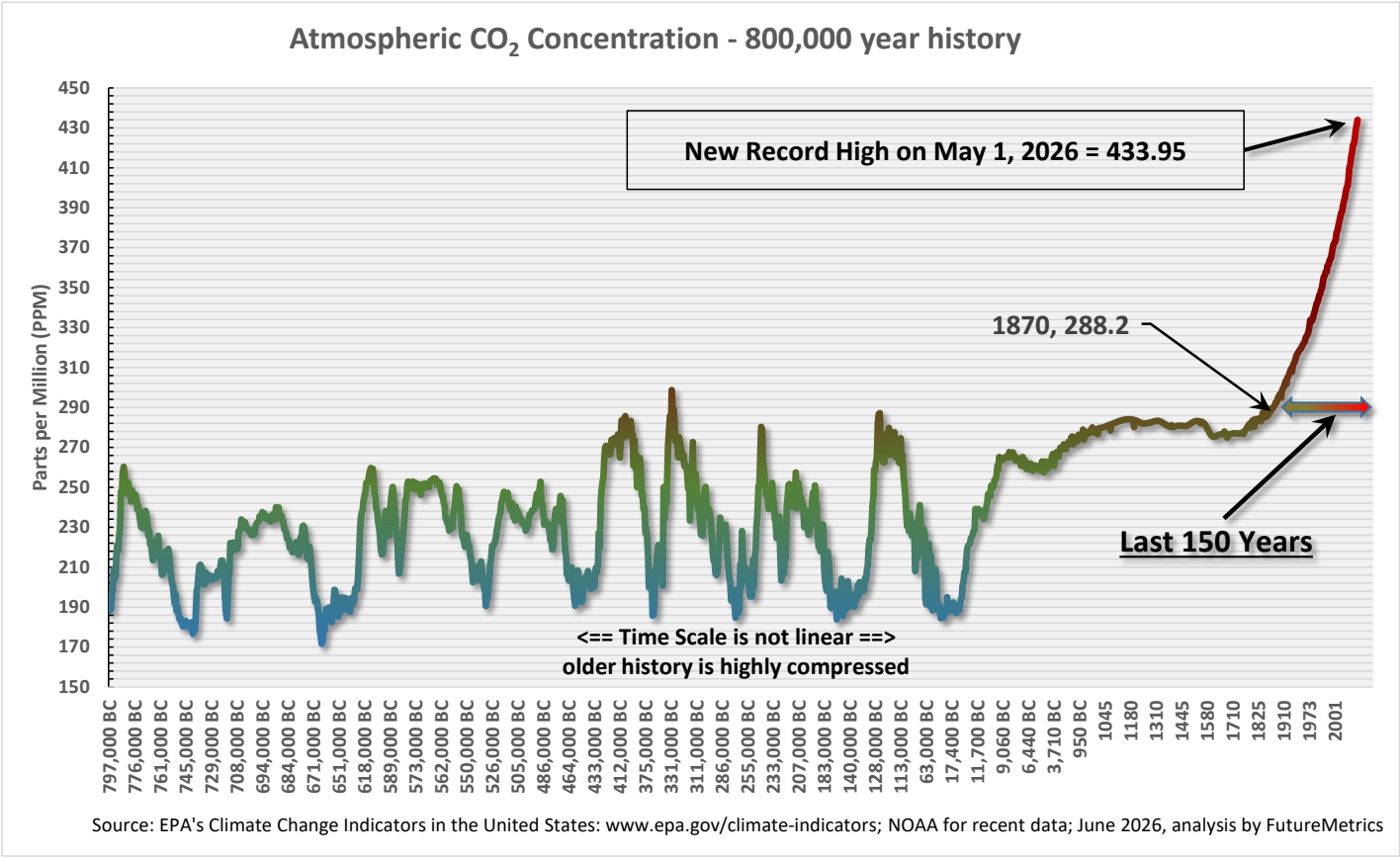

Figure 2 - Atmospheric CO_2 Concentration

The sudden release of carbon (in the form of combustion by-products) that was captured over hundreds of millions of years by plants producing carbohydrates that were mineralized into hydrocarbons in the form of coal, petroleum, and natural gas has created a rapid increase in CO_2 concentrations in the atmosphere. Figure 2 illustrates this.

Figure 3 below plots the data in Figure 1 against the data on changes in land and sea temperatures versus a baseline. The correlation[7] is 0.94.

As noted above, correlation does not prove causation. But read on…

[7] https://en.wikipedia.org/wiki/Correlation

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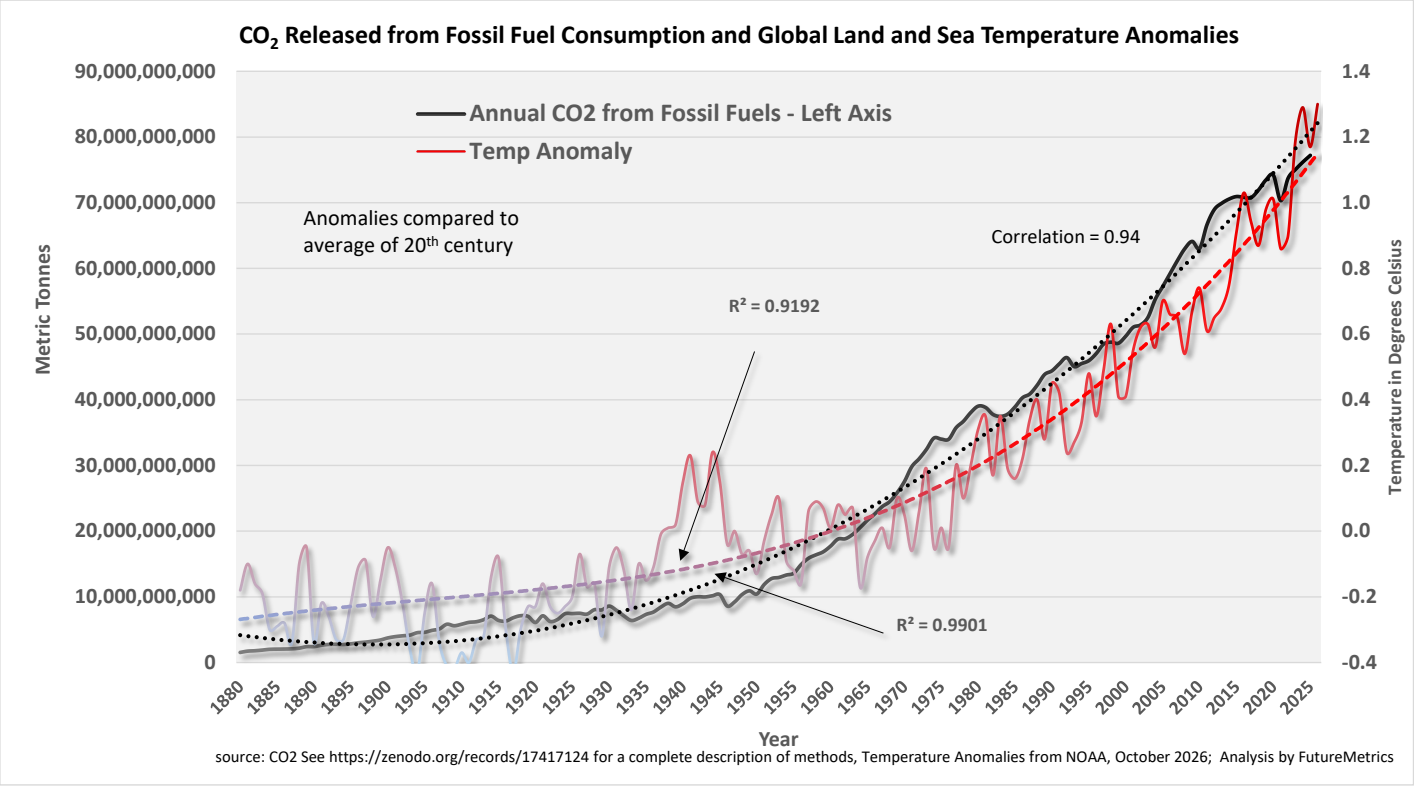

Figure 3 - CO_2 and Temperature Anomalies

The curves are increasing at an increasing rate (for math geeks, the second derivative of the curve function is positive). The challenge is to change the slopes and rates of slope change for both of those curves.

But there is more to the story than just the annual emissions. The accumulation of those annual emissions is the actual stock of CO_2 in the atmosphere. The mechanisms for atmospheric CO_2 removal take time. In other words, if we stop all CO_2 emissions tomorrow, the impact of what has already been done will linger for a very long time.

> "Carbon dioxide does not have a single, fixed lifespan; instead, between 15% and 40% of an emitted pulse remains in the atmosphere for over 1,000 years. Unlike other greenhouse gases like methane—which break down through chemical reactions within roughly a decade—CO_2 relies on an interconnected web of natural carbon sinks with drastically different removal timelines." Source.

Figure 4 illustrates the three major phases of natural CO_2 removal. The chart is based on an IPCC model and shows the percent of an initial release that is permanently removed over the first 15 years after its addition to the atmosphere. Below Figure 4 on the next page is an explanation of the fast, intermediate, and long-term sinks[8].

Based on the modeling behind the chart, about 61% of the initial release remains in the atmosphere at year 15.

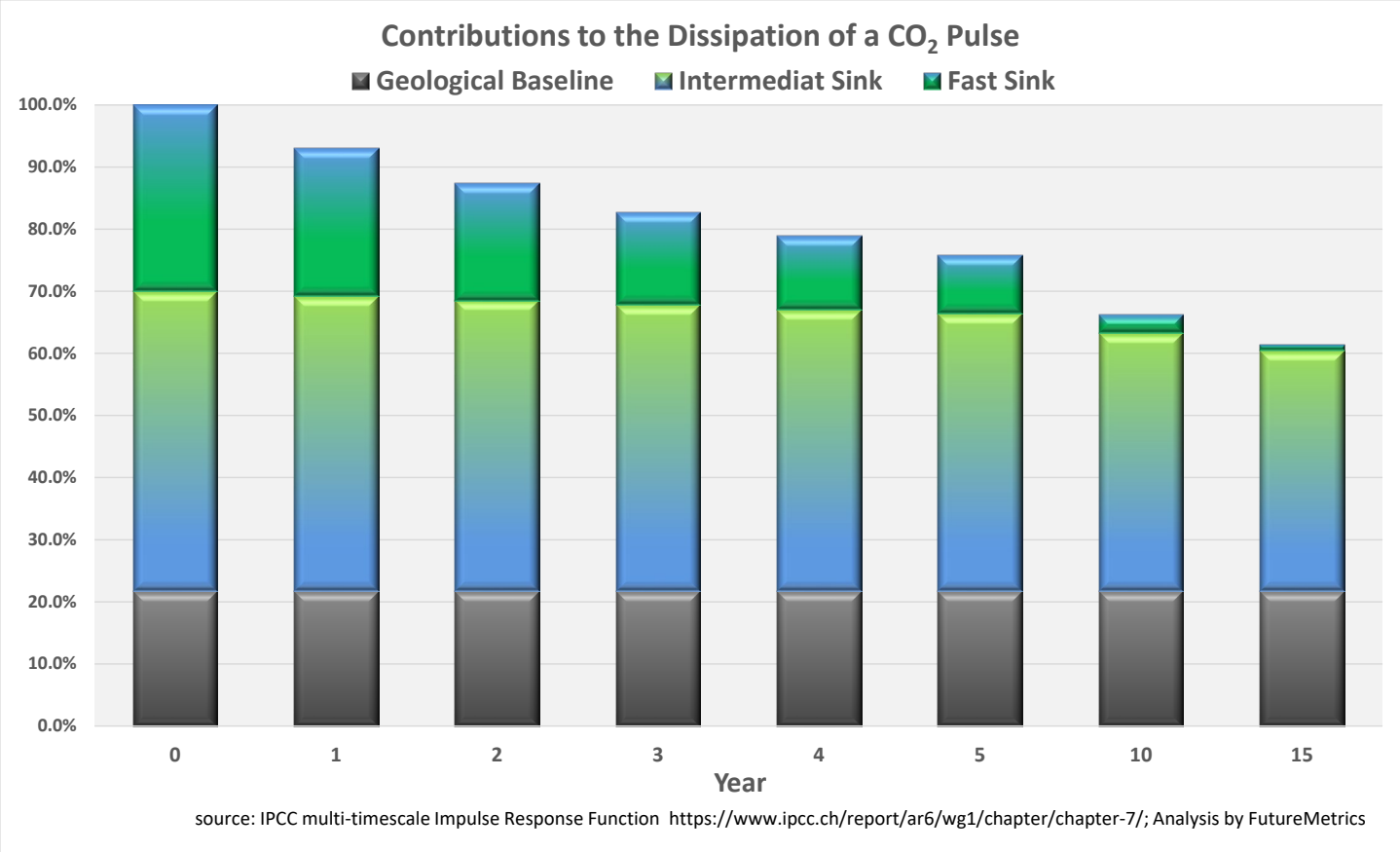

Figure 4 - Contributions to the Dissipation of a CO_2 Pulse

[8] The explanations on the next page are from a query on Claude. They describe the IPCC Fifth Assessment Report (AR5) model that uses a multi-exponential Impulse Response Function (IRF). See the appendix for a math note.

In Figure 4 the fast sink pool exhibits a rapid decay. The physical infrastructure behind this pool includes:

- Terrestrial photosynthetic uptake: Rapid sequestration by land flora and seasonal vegetation via primary productivity cycles.
- Surface ocean equilibrium: Direct gas-liquid phase diffusion at the atmosphere-ocean boundary layer, establishing a fast equilibrium with the surface mixed layer. There is a consequence – ocean acidization[9].

The intermediate pool is represents carbon migrating into deep marine and terrestrial stores:

- The marine solubility pump: Thermohaline[10] downwelling and polar overturning circulation transporting carbon-saturated surface water down into deep abyssal oceans.
- The biological carbon pump: Marine organisms fixing carbon into particulate organic matter which sinks to the ocean floor upon senescence.
- Structural biosphere sequestration: Accumulation within long-lived woody biomass structures (old-growth forests) and highly stable deep-soil organic matrices.

The geological baseline is a permanent atmospheric removal fraction. It has an infinite modeled lifetime factor. This baseline remains trapped (perhaps until millions of years into the future when the next intelligent life on earth discovers so-called fossil fuels!).

- Chemical buffer satiation: The exhaustion of the ocean's immediate chemical carbonate buffering capacity leaves a portion of carbon stuck in atmospheric equilibrium.
- Continental silicate weathering: Carbonic acid precipitation breaking down continental silicate rock structures over tens of thousands of years.
- Mineral carbonate precipitation: Runoff ions reacting in the marine environment to produce calcium carbonate ($CaCO_3$) deposits, permanently embedding carbon into seafloor sedimentary limestone layers.

Thus, CO_2 emitted today has a long-lasting impact. Figure 5 on the next page shows how much CO_2 is removed from a given addition to the atmosphere over the next 1000 years. The modeling uses the same parameters that are used in Figure 4.

Note that the curve in Figure 5 will approach zero; but only after tens to hundreds of thousands of years have passed.

[9] Read THIS for explanation and discussion of consequeses.
[10] https://en.wikipedia.org/wiki/Thermohaline_circulation

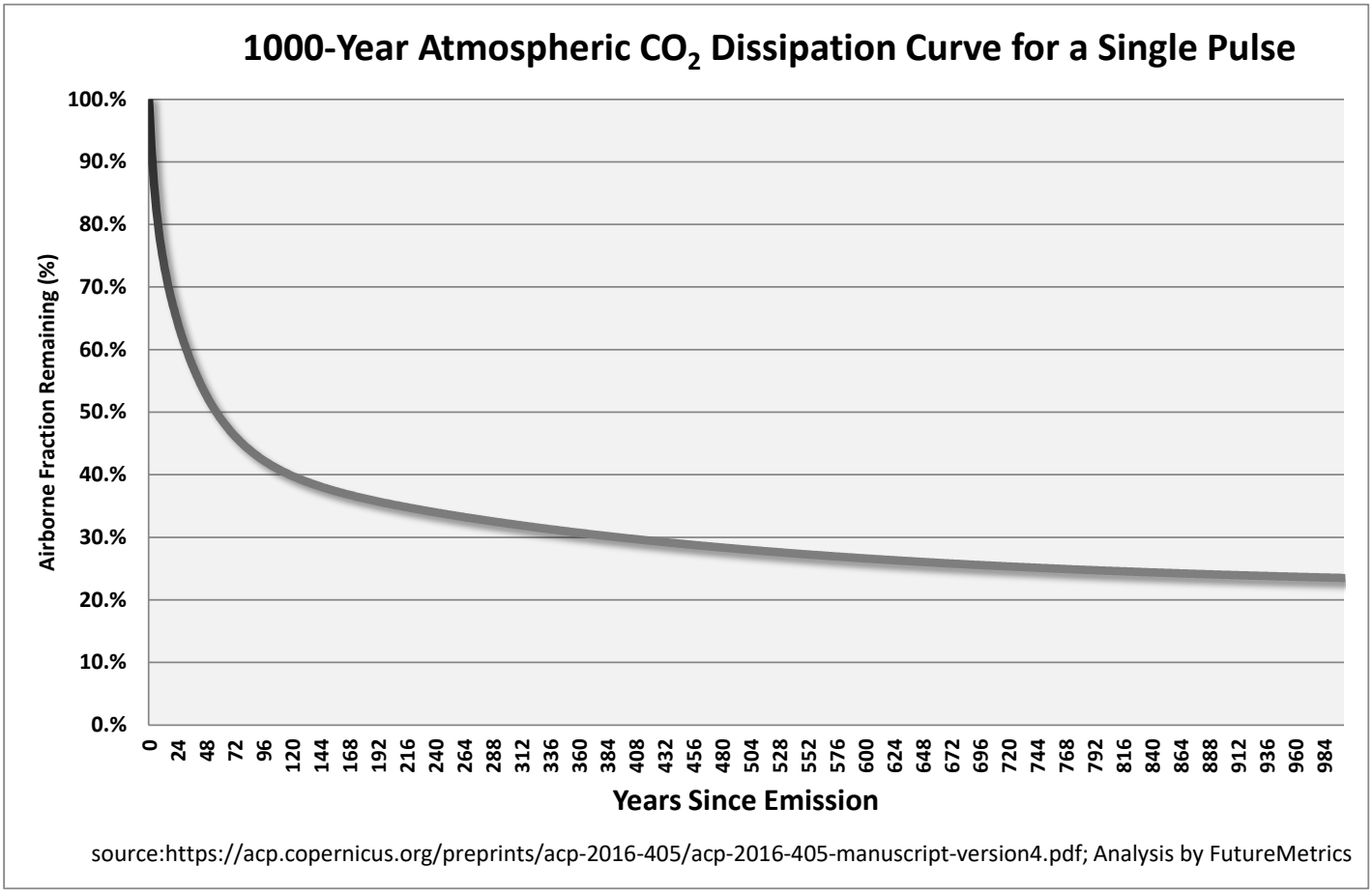

Figure 5 - CO_2 Dissipation Curve

Applying the dissipation model to the annual emissions data, we get the curve in Figure 6 which estimates the total stock of CO_2 in the atmosphere.

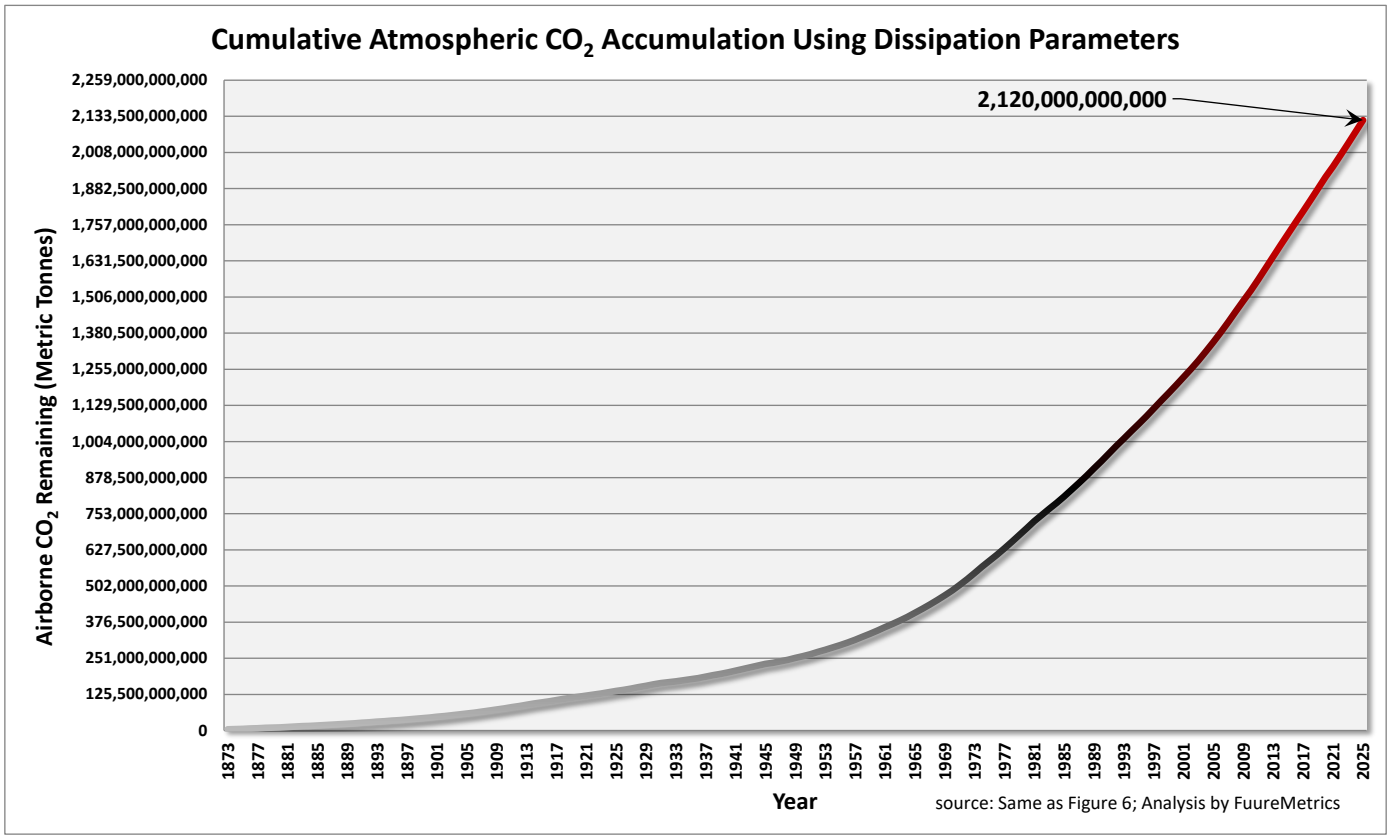

Figure 6- Cumulative Atmospheric CO_2 Accumulation using Dissipation Model

Based on the data used in this paper, human activity, vis-à-vis the use of coal, oil, and natural gas (methane), even considering the continuous removals, since the start of the fossil fuel age in the mid-1800's have added about 2.12 trillion metric tonnes of carbon dioxide to the atmosphere that was (and is) produced from mined hydrocarbons.

The higher CO_2 levels, as is illustrated in Figure 3, correlate tightly with the rising temperatures across the planet.

The direction of causation is clearly shown in Figure 7 on the next page by the relationship between how much solar heat the planet retains and the concentrations of so-called greenhouse gases. The values in Figure 7 are not conjecture. They are based on chemistry and physics.

Figure 7 is the basis for the direction of causation: higher levels of CO_2 ➔ heat trapped on the planet.

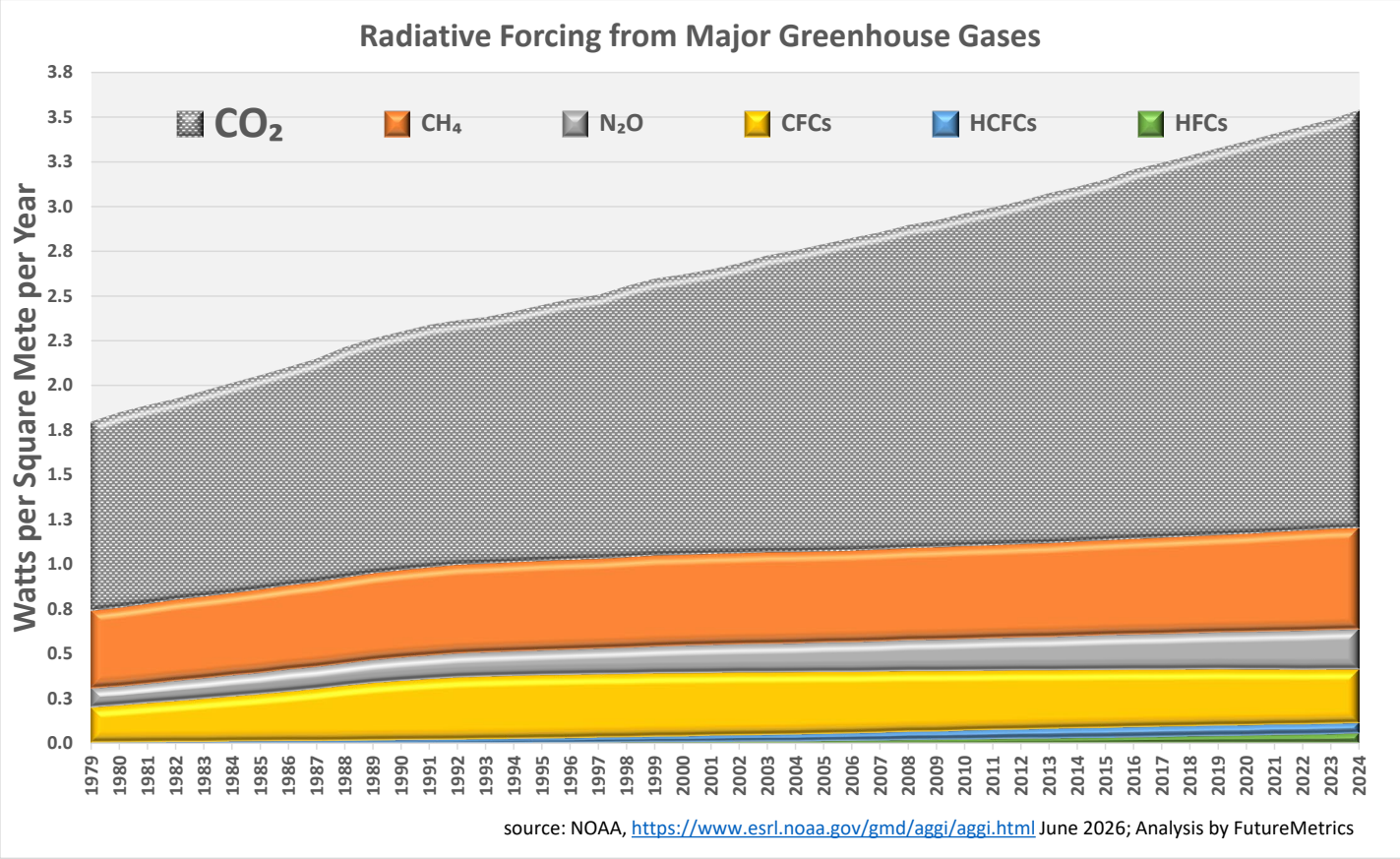

Figure 7 - Radiative Forcing from Major Greenhouse Gases

The chart shows the increase in energy in watts per year per square meter that the earth's surface has to absorb each year. The increase is dramatic.

> "The extra 3.54 W m^{-2} of heat retained in 2024 by the increases measured in long-lived greenhouse gas abundances since pre-industrial time represents an increase of 1.47% in the amount of heat retained in the Earth system from the sun on an ongoing basis (240 W m^{-2}) after accounting for the energy being reflected back to space (Bond albedo = 0.294; Williams, 2024)."[11]

The last two charts of this paper show two measures of the consequences.

[11] https://gml.noaa.gov/aggi/aggi.html

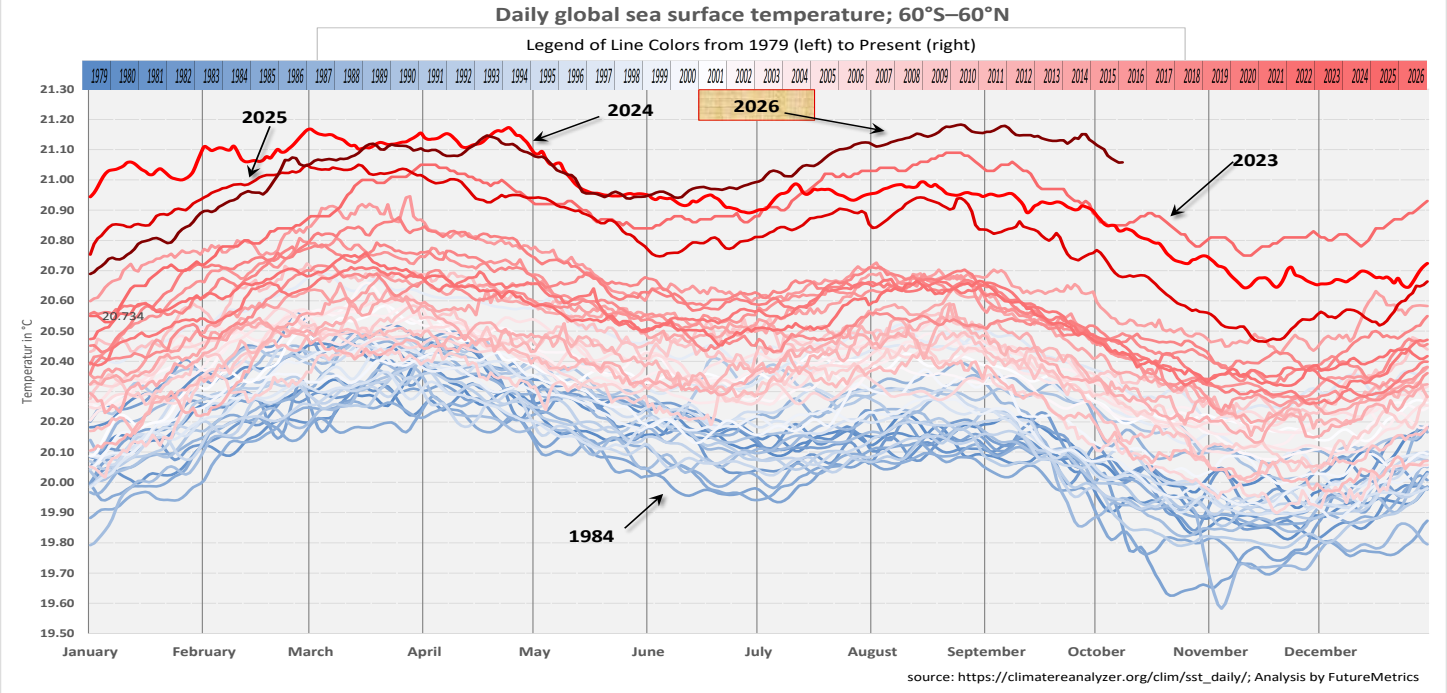

Figure 8 - Global Sea Surface Temperatures - 1979 to Present

Figure 8 shows how the land and sea temperatures are getting higher at a faster rate. The recent sudden jumps, and now 2026's excursion, exhibit one major "code red" warning sign.

The last chart, on the next page, is the historical data on El Nino[12]. The ocean surface temperature in the mid-pacific zone fluctuates around a longer-term average (shown on the chart). This year, so far, the event is exhibiting super extreme conditions. Another "code red" warning.

The energy that the oceans absorb from the increased radiative forcings does not magically disappear. This year energy stored in the pacific is being released into the atmosphere at unprecedented levels.

The facts point to a sudden, extreme, and prolonged event. Can life on earth as we know adapt fast enough? You can work out your own version of the times ahead. But our dreams for a better future will not be what they are supposed to be in. We may still have time to move quickly to defossilzed and mitigate the consequences of business-as-usual. If not, it will likely be a world of increased uncertainty, seriously negative growth, collapses of all sorts of systems we take for granted, and social and economic chaos.

We must try now to do better.

FutureMetrics' team continues to be proud of its part in trying effect change.

[12] To learn more about El Nino, see HERE.

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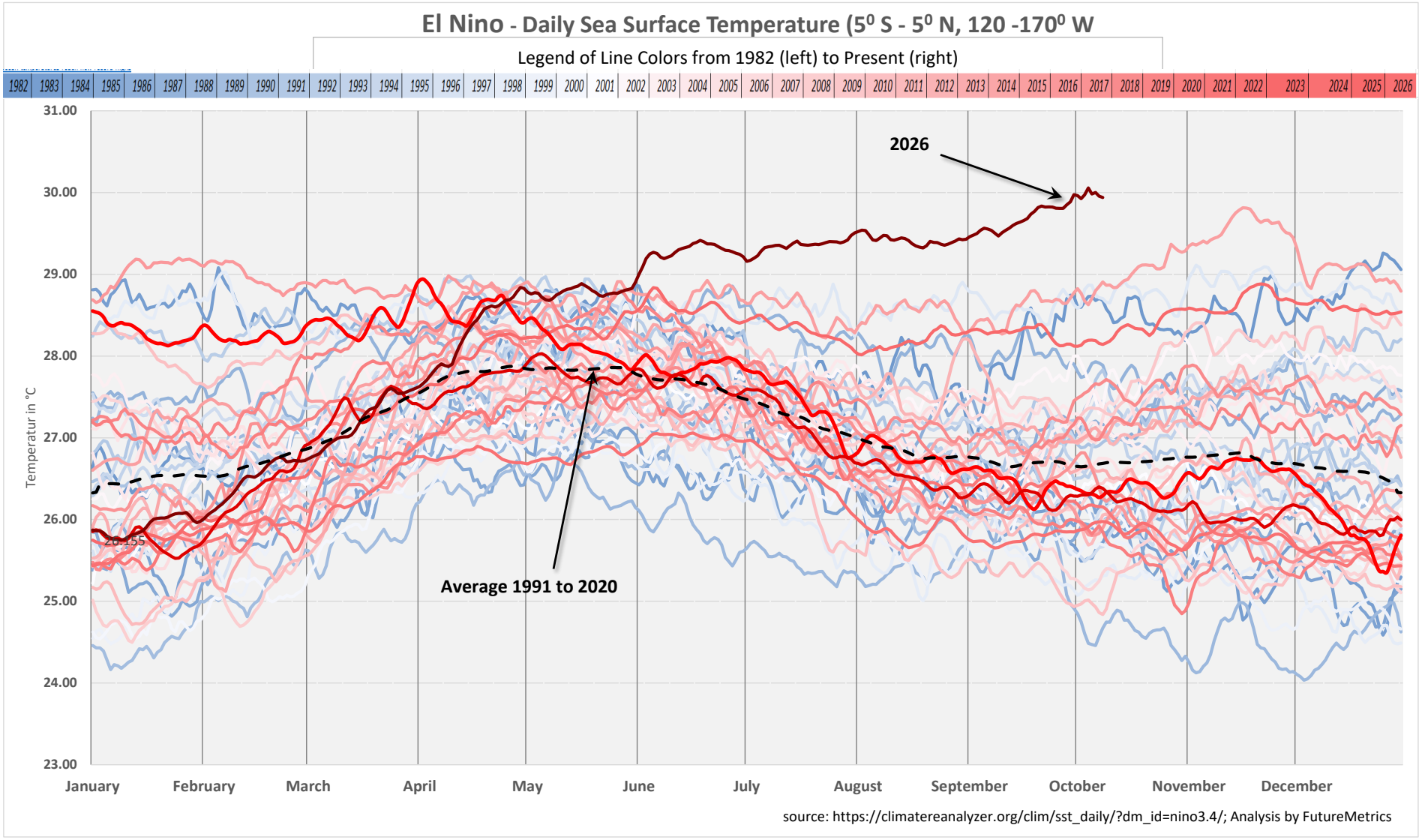

Figure 9 - El Nino - Daily Sea Surface Temperatures - 1982 to Present

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Appendix

IPCC AR5 CO_2 Dissipation Function & Parameters

The atmospheric lifetime of carbon dioxide is modeled in the IPCC Fifth Assessment Report (AR5) using a multi-exponential Impulse Response Function (IRF). This function simulates how a single pulse of CO_2 decays as it is redistributed simultaneously into multiple parallel natural sinks over time.

The function is:

$$IRF(t) = a_{0+} \sum_{i=1}^{3} a_i \cdot e^{-\frac{t}{d_i}}$$

Where t equals the year, and:

Pathway Component	Index (i)	Coefficient (a_i)	Decay Constant (d_i)
Geological Baseline	a_0	0.2173	∞ (No Decay)
Intermediate (Slow Overturning)	a_1	0.224	394.4 Years
Intermediate (Medium Overturning)	a_2	0.259	36.54 Years
Fast Sink	a_3	0.2997	4.304 Years

Table 1 Dissipation Function Parameters

One can quibble about the exact parameter values, but that does not change the general conclusion that it will take a very very long time for a significant proportion of the carbon dioxide in the atmosphere to be removed by natural processes.