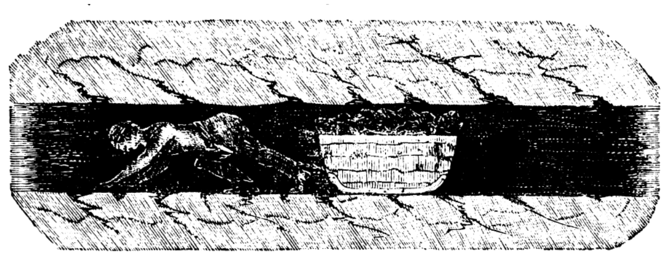
Acid Seas

Way down in the mine, your tears turn to mud
And you can't catch your breath for the dust in your lungs
Loading hillbilly gold where the sun never shines
Twelve hours a day, diggin' your grave
Way down in the mine.
– Dierks Bentley, Down in the Mine

We are blessed with a magnificent and miraculous world ocean on this planet. But we are also stressing it in ways that we are not even close to bringing under control.
– Carl Safina

During the 1800s the Western world was in the midst of the Industrial Revolution. What propelled this revolution was energy in the form of fossil fuels and in particular coal. Countless wretched hordes were employed in coal mines to extract this vital material, which was used to power industries and transportation and also to heat buildings. Poor men as well as women, prisoners, slaves and ex-slaves labored extremely long hours in horrifying conditions to extract this vital sustenance, which fed the maw of the newly unleashed and growing energy colossus. Even young children were subject to the grueling and endless drudgery in the mines.

> *William Slater: "Is six years old; draws the empty corves [small wagons for carrying coal] with a hook". Adam Widowson: "Is seven years old; has worked in a pit one year". Aram Richardson: "Is seven years old; works in the soft coal-pit; has done so for nearly a year".*[1]



Boys called carters are employed in narrow veins of coal in parts of Monmouthshire [England]; their occupation is to drag the carts or skips of coal from the working to the main roads. In this mode of labour the leather girdle passes round the body, and the chain is, between the legs, attached to the cart, and the lads drag on all-fours.

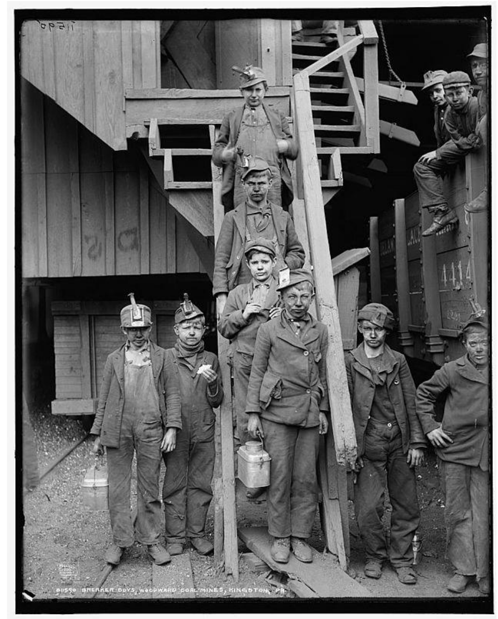
Boys as young as four years old worked naked, often in mud and water, dragging sledges filled with coal for twelve to fifteen hours a day.[2] Women and girls were harnessed to coal-carts, creeping on all fours through the cramped spaces of coal mines.[3]

> *Women and girls have been known to wear men's clothes and to take their place side by side with men in the coal and iron mines or in ditches of any kind. A day's work is often from sixteen to twenty hours in duration, rain or shine. Food is very poor, and clothes are scant.*[4]

Cities in Britain, Europe, and America consumed vast amounts of coal. By the end of the 19th century the United States and England were mining 450 million metric tons (496 million tons) of coal.[5] Coal mining was not only arduous but it was also health destroying and very often deadly. In the United

States, from 1900 to 2016 there were 104,851 recorded coal mining related fatalities.[6] Throughout the decades and all over the world large numbers of the destitute perished from falling, explosions, being crushed, drowning, suffocating, electrocution, and other horrifying ways.[7,8,9]

> *...number of persons employed in coal-mining operations the world over to be 2,500,000, we have it that on the average almost 5,000 persons are annually killed in the production of the world's coal supply.*[10]



Breaker boys, Woodward Coal Mines, Kingston, Pennsylvania, ca. 1900.

With these numbers it can be reasonably estimated that roughly ½ million people died over the more than a century of extracting coal from the ground. It's also estimated that for every death there were one hundred or so injuries, with two of them being permanently incapacitating.[11] These sobering figures show that forgotten millions sacrificed their health and lives to push the world ahead into our present fossil fuel dominated world.

Not only were millions of people subject to appalling and dangerous working conditions extracting coal from the Earth, but the burning of coal also had serious impacts on the environment. Cities and towns became notoriously polluted as endless smokestacks belched out dark clouds of soot and ash, making this bleak and dreary cityscape a symbol of the new modern industrial metropolis.[12] In 1880 meteorologist Rollo Russell wrote of the pollution in London:

> *In winter more than a million chimneys breathe forth simultaneously smoke, soot, sulphurous acid, vapour of water, and carbonic acid gas, and the whole town fumes like a vast crater, at the bottom of which its unhappy citizens must creep and live as best they can.*[13]

The famous London fog was not a low lying cloud of water vapor. In fact, the London fog was made up of the soot and smoke that was spewed into the air by the huge amount of coal being burned. In 1902, the daily smoke that went up household chimneys and was spewed by the 14,500 factories in London was estimated to total 7 million tons.[14] The sunshine that reached the streets of London was a fraction of what it was in the countryside, often keeping the city dark and miserable.

In London, the great fog of 1880 increased the number of deaths by 2,994 over three weeks, and in 1892 caused an excess of 1,484 deaths in one week.[15] Between 1800 and 1900, air pollution may have killed people in Great Britain at a rate four to seven times the rate it killed people worldwide.[16] A visitor from India wrote of her London experience in 1882:

> *A London fog is a thick mist -- people in our country cannot imagine what a typical foggy day is really like. Other parts of England also experience the fog, but it is not as dense and dirty as*

a London fog... London has so many mechanised wagons and factories and in winter every home spews smoke out of its chimneys, so that on particular days the smoke becomes heavier than the air, cannot rise up and therefore settles over the city and sometimes engulfs large areas and darkens almost everything. On particular days this sort of fog persists through the day and assumes different hues - sometimes ashen - sometimes black - sometimes yellow... One walks in the streets, visibility so poor that one moves almost by instinct. Darkness more horrible than that at night has descended at noon, and no artificial light can really illuminate the blackness created by a fog. It is difficult to breathe; one is suffocated by tiny black, oily particles that clog the nose.[17]

October 1919: A man braves the blinding fog to deliver ice around London. Thick smog regularly fell upon the city from the onset of winter in October until the beginning of spring.

The deadly coal burning vapors continued throughout the 1800s and into the 1900s. In October 1948 a killer smog, containing airborne pollutants emitted from nearby zinc smelting plants and steel mills, hovered over Donora, Pennsylvania, killing 20 people and making thousands ill.[18] In December 1952 a mass of dry, cold air settled over London, trapping smog and almost entirely immobilizing the city's nine million residents. Over four days 4,000 people died from the blinding and suffocating toxic gases, and many thousands more were made seriously ill.[19] In New York City an estimated 220–240 deaths were caused by the six-day 1953 smog, and an estimated 300–405 deaths were caused by the two-week 1963 smog.[20]

Science refers to the carbon cycle and often put emissions in the amount of the element carbon. However, the carbon entering the atmosphere is in the form of carbon dioxide, which is one carbon atom combined with two oxygen atoms. This means carbon dioxide (CO_2) is about 3.67 times heavier than carbon alone.

"Why do carbon dioxide emissions weigh more than the original fuel?" U.S. Energy Information Administration, https://www.eia.gov

During this metamorphosis of Western societies from agrarian to industrial, mankind attained the ability to create wondrous machines that altered the way people would live and utilize energy. The introduction of the steam engine and a series of technological advances shifted the production of goods from homes and small operations to large industrial factories, often augmenting or largely replacing manual labor. The application of predominantly coal power to the industrial processes along with the use of the railroads helped to accelerate this historic societal transformation.

In the pre-modern era communities were often unhygienic and dirty, but with the advent of new technologies life changed and improved for many as innovations such as piped water, sewer systems and electricity were introduced. Yet, with these technological and societal shifts, humans had attained the ability to also subject the environment to large scale contamination and destruction, bringing forth a new modern phenomenon of widespread and persistent environmental pollution.

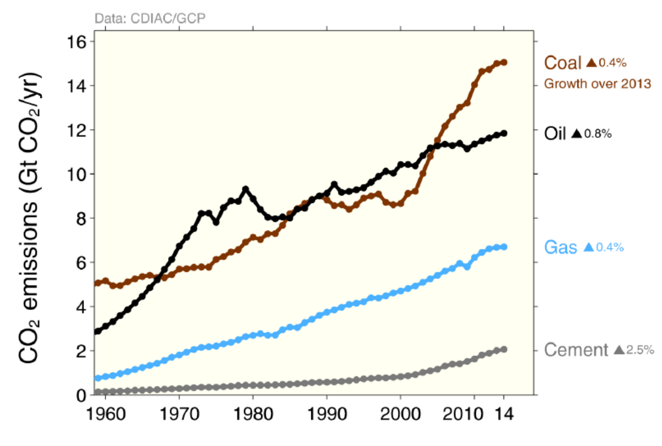
Starting in those early years of the Industrial Revolution carbon output from coal and new fossil fuels has grown and continues to increase. From 1750 to 2010 approximately 356 gigatons (1 gigaton = 1 billion tons) of carbon (1,305 gigatons of carbon dioxide or CO_2) have been released into the atmosphere, primarily from the consumption of fossil fuels and cement production throughout the world.[21] Cement is the source of about 8% of the world's CO_2 emissions. It contributes more CO_2 than aviation fuel (2.5%) and is not far behind the global agriculture business (12%).[22]

This massive amount of CO_2 that has entered the environment is equivalent to the weight of nearly 4,000,000 Empire State Buildings,[23] with more than half of industrial CO_2 pollution having been emitted since 1988.[24] Approximately 9.86 gigatons of carbon (36.2 gigatons of CO_2 equal to nearly 110,000 Empire State Buildings or over 64,500,000 Airbus A380 Passenger Jets[25]) are released by human activity into the atmosphere each year.[26] With expanding world populations and economies, the production of the major sources of CO2 global emissions (coal, oil, gas, and cement) continues to increase with no realistic end in sight.

Flaring occurs when unwanted natural gas released in oil extraction is burned. While flaring only accounts for 1% of CO_2 emissions it still translates to a substantial amount.

> *The World Bank estimates that 140 billion cubic meters of natural gas produced with oil is flared at thousands of oil fields worldwide. The result: emissions equivalent to that of 77 million automobiles—or, translated into power generation, more electricity than the entire continent of Africa currently consumes.*[27]

The use of fossil fuels and other human activities have resulted in the global CO_2 atmospheric concentration increasing from approximately 277 parts per million (ppm) in 1750 to 397 ppm in 2014, hitting 400 ppm in March 2015[28] and 410 ppm in May 2018, which is the highest level seen in 800,000 years.[29]



Share of global emissions of CO_2 in 2014: coal (42%), oil (33%), gas (19%), cement (6%), flaring (1%, not shown).

If humans continue to emit greenhouse gases at current rates, scientists estimate that atmospheric carbon dioxide could reach 550 ppm to 800 ppm by 2100.[30] The rate of change in global temperature and atmospheric CO_2 over the past century are 100 to 1,000 times higher than most of the changes in the past 420,000 years.[31]

Not all of the carbon dioxide that has entered the atmosphere has remained there. Oceans have absorbed up to 30% of human-made carbon dioxide, which has increased ocean water acidity worldwide. This acidification of the oceans occurs as the carbon dioxide from fossil fuels dissolves in seawater producing carbonic acid. Carbonic acid breaks down and increases hydrogen ions (H+), which lower the pH of the water.

What is referred to as acidity of a liquid solution is the concentration of hydrogen ions (H+). This acidity is measured using the pH scale which ranges from 0 (strong acid) to 14 (strong base) and where a value of 7 is considered neutral. This scale is logarithmic so that a small change in pH is actually a large change in hydrogen ion concentration. These seemingly small changes in pH can actually have a big impact because many organisms are very sensitive to pH, requiring it to be within a narrow range.[32] For instance, human blood pH normally falls within the range 7.35–7.45. A slight variation outside of this range can result in rather serious health consequences. If a human's pH drops to 6.9 a person will be in a coma, but at 6.8 a person will die.[33]

Since pre-industrial times, the pH of the oceans has dropped from an average of 8.2 to 8.1 today, meaning the oceans are 30% more acidic.[34] Climate change projections estimate that by the year 2100, this number will drop further to around 7.8, or 170% more acidic since the start of the Industrial Revolution.[35]

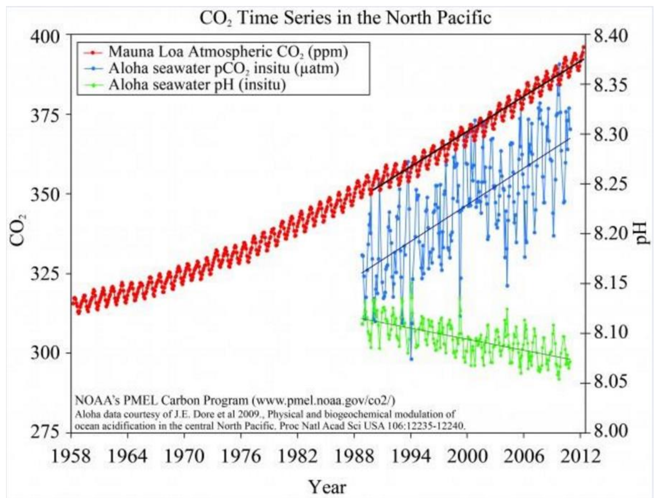
> *Ocean acidification (OA)—a result of too much carbon dioxide reacting with seawater to form carbonic acid—has been dubbed "the other CO2 problem." As the water becomes more acidic, corals and animals such as clams and mussels have trouble building their skeletons and shells. But even more sinister, the acidity can interfere with basic bodily functions for all marine animals, shelled or not. By disrupting processes as fundamental as growth and reproduction, ocean acidification threatens the animals' health and even the survival of species.*[36]

Although the amount of CO_2 that has been emitted is large, it may seem small compared to the huge volume of water that oceans contain, which is at 1.3 billion cubic kilometers (0.3 billion cubic miles).[37] However, the CO_2 in the atmosphere directly interacts with all the ocean water.

The surface layer of the ocean, which is in direct contact with the atmosphere, is mixed by wave action to a depth of typically about 100 meters (300 feet). Exposed to the sun, this top layer is warmer and less dense than the water beneath it, which makes it resistant to mixing with the bulk of deeper water. With an average ocean depth of about 3700 meters (2.3 miles), this top ocean layer can be compared to the less than ½ inch thickness of the icing on top of an 18 inch tall wedding cake. It's at this top thin layer where the exchange of atmospheric CO_2 occurs, with movement of surface layer CO_2 to the deep ocean taking centuries. It is in this upper layer of the ocean that pH has decreased, with the deeper oceans remaining virtually unchanged.[38]

When combined with CO_2, the pH of the ocean surface drops to levels that will potentially compromise or prevent calcium carbonate ($CaCO_3$) accretion (gradual growth) by a wide range of organisms, including reef corals and calcifying algae. Many organisms depend on the relatively stable ocean pH, which has endured for millions of years until the onset of the Industrial Revolution.[39]

The California Current Large Marine Ecosystem (CCLME) is an oceanic ecosystem in the eastern North Pacific Ocean spanning nearly 3,000 kilometers (1,864 miles) from southern British Columbia, Canada to Baja California, Mexico.[40] This area is among the most productive in the world, supporting 20% of global fishery yield.[41]



CO_2 Time Series in the North Pacific from the Mauna Loa observatory in Hawaii showing that as atmospheric CO_2 levels have increased ocean pH has decreased.

Across the CCLME, scientists have observed near-shore pH that fell well below current global mean surface ocean pH of 8.1. The pH reached as low as 7.43 at the most acidified site, and up to 18% of the values recorded by scientists fell below 7.8 during the upwelling season. These levels are among the lowest reported to date for the surface ocean and match levels not projected for the global surface ocean until atmospheric CO_2 exceeds 850 ppm, which is almost double present day levels of around 400 ppm. Ocean deoxygenation and increasing upwelling from growing offshore winds may be accelerating the rising acidity levels near-shore. In the most severely acidic spots, suboptimal conditions for calcifying organisms encompassed up to 56% of the summer season.[42]The ever increasing acidic and hypoxic coastal waters is an escalating threat to the CCLME and other coastal waters, with severe consequences for marine ecosystems and the fisheries they support.

Many scientific studies have unequivocally shown that a wide range of marine organisms are sensitive to pH changes, and their physiology, fitness and survival are almost always affected in a negative way.[43] Laboratory and field experiments along with observations of naturally high CO_2 marine environments have shown lower rates of growth, survival or other performance measures for many organisms in acidified waters, although with considerable variation between species.[44]

Declining pH of upper seawater layers, due to absorption of increasing atmospheric CO_2 has been added to the list of coral reef threats that include land-based sediment discharges, coral predators, sea surface temperatures, and overfishing. In general, corals do not appear to have the capacity to adapt fast enough to these relatively sudden environmental changes.

> *Coral reefs provide food and livelihood security for some 500 million people worldwide. Significant reef loss would, therefore, impact marine biodiversity, threaten the survival of coastal communities through reduced food sources and reduce the capacity of nearby coastlines to buffer the impact of sea level rise, including increased storm surges.*[45]

Coral bleaching is often associated with increased ocean temperatures. However, studies show that ocean acidification alone can also create bleaching in certain reef organisms.

> *Our results indicated that prolonged CO_2 dosing causes bleaching (loss of symbiotic algae) in two key groups of reef-building organisms. The bleaching results indicate that future predictions of bleaching in response to global warming must also take account of the additional effect of acidification.*[46]

Corals require an environment where they can form their skeletons. Studies show that coral calcification decreases with declining pH, which has hindered the ability of reefs to build their skeletons. Research suggests that this reduction in growth is a response to ocean acidification.[47]

> *Seawater acidification partially results from an increase of atmospheric CO_2, and is thought to reduce a reef coral's calcification ability. For example, coral calcification rates in the Great Barrier Reef have reduced by 14%–21% since the 1990s; which is unprecedented in at least the last 400 years.*[48]

A 2009 study showed that growth and calcification of massive Porites, a genus of stone coral, in the Great Barrier Reef (GBR) is declining. If Porites calcification is similar to other reef-building corals, then maintenance of the calcium carbonate structure that is the foundation of the GBR will be severely compromised, causing widespread ecosystem degradation.[49] As atmospheric CO_2 levels rise, the resulting decline in pH in the oceans may make coral reefs unsustainable.[50]

> *These organisms [corals] are central to the formation and function of ecosystems and food webs, and precipitous changes in the biodiversity and productivity of the world's oceans may be imminent.*

Phytoplankton are microscopic marine single-cell plants. They form the base of several aquatic food webs by directly providing food for a wide range of herbivorous marine creatures. Other creatures in turn eat these herbivores, from small predators like sardines and up the food chain to top predators like sharks and humans. Phytoplankton use energy from the sun to convert carbon dioxide and nutrients into complex organic compounds through a process known as photosynthesis. As these plants die and sink to the ocean floor a small portion of their organic carbon is buried. The carbon remains there for millions of years in the form of substances like oil, coal and shale, until it is converted into energy through human activity and released back into the atmosphere

A 2015 study, published in the journal Nature Climate Change, reported that by the year 2100 increased ocean acidification will cause changes in phytoplankton. Some species will die out and some will flourish, although it is hypothesized that an increase in CO_2 could be an overall benefit to phytoplankton.[51] However, this will still alter the balance of phytoplankton around the entire world. Stephanie Dutkiewicz, a principal research scientist in MIT's Center for Global Change Science, noted that:

> *"The fact that there are so many different possible changes, that different phytoplankton respond differently, means there might be some quite traumatic changes in the communities*

> *over the course of the 21st century. A whole rearrangement of the communities means something to both the food web further up, but also for things like cycling of carbon."*[52]

The study also predicted that as the oceans warm many phytoplankton species will move toward the poles, creating an ocean environment that may look quite different than today. These significant changes at the bottom of the food web may have big ramifications further up the food chain.

> *"Generally, a polar bear eats things that start feeding on a diatom [common type of phytoplankton]…" Dutkiewicz says. "The whole food chain is going to be different."*[53]

The studies investigating the effects of high CO_2 on phytoplankton growth, that have in some cases shown that certain phytoplankton seemed to benefit from high CO_2 concentrations, had been conducted under high-iron conditions. However, a study published in 2018 found that the rising concentrations of atmospheric CO_2, that acidifies the ocean and decreases carbonate, affected the ability of phytoplankton to obtain enough of the key nutrient iron needed for growth.[54] The drop in carbonate concentrations made it harder for the phytoplankton to utilize iron and to grow. Consequently, these high concentrations of atmospheric CO_2 could have more of a negative effect on phytoplankton growth than was originally thought.

> *"Ultimately our study reveals the possibility of a 'feedback mechanism' operating in parts of the ocean where iron already constrains the growth of phytoplankton," said Jeff McQuaid, lead author of the study who made the discoveries as a PhD student at Scripps Oceanography. "In these regions, high concentrations of atmospheric CO_2 could decrease phytoplankton growth, restricting the ability of the ocean to absorb CO_2 and thus leading to ever higher concentrations of CO_2 accumulating in the atmosphere."*

Bryozoans are a family of small filter feeding invertebrates that live as colonies, superficially similar, but not related, to corals. They are abundant in California kelp forests and they build their honeycomb-shaped skeletons from calcium carbonate. A 2017 study showed that when these animals were exposed to warmer water and increased acidity they dissolved in as little as two months. Lead author Dan Swezey was surprised by these results.

> *"We thought there would be some thinning or reduced mass, but whole features just dissolved practically before our eyes."*[55]

A three-year study published in 2017 by Oregon State University found that the pH levels off the California and Oregon coasts were among the lowest ever recorded. Team member and marine ecologist Francis Chan found the results concerning because acidified ocean water is having impacts on coastal species.[56]

> *"The oyster industry is who really sounded the alarm," he said. "About 10 years ago, they stopped being able to successfully grow the seed oysters they need for their industry. It turns out the water had absorbed so much carbon dioxide."*

For several years the Pacific Northwest oyster industry has struggled with significant losses. Oyster larvae encountered higher mortality rates sufficient to make production economically unworkable.

Researchers at Oregon State University have documented why oysters appear so sensitive to increasing ocean acidification.[57] The acidity level isn't high enough to dissolve adult shells. Rather it is a case of water high in CO_2 altering shell formation rates, energy usage and, ultimately, the growth and survival of the young oysters. Under exposure to increasingly acidified water it becomes more energetically expensive for organisms to build shells. Adult oysters and other bivalves may grow slower when exposed to rising CO_2 levels, but larvae in the first two days of life do not have the luxury of delayed growth.

> *"They must build their first shell quickly on a limited amount of energy – and along with the shell comes the organ to capture external food more effectively," said Waldbusser, who is in OSU's College of Earth, Ocean, and Atmospheric Sciences. "It becomes a death race of sorts. Can the oyster build its shell quickly enough to allow its feeding mechanisms to develop before it runs out of energy from the egg?"*

Oyster hatcheries have now altered their working practices so that they avoid using very low pH seawater, either by recirculating their seawater or treating their water during upwelling events. With these new practices, the north-west coast oyster hatcheries are producing near to full capacity again.[58] However, in 2018 academics in England found oysters in New South Wales have become smaller and fewer in number because of coastal acidification.[59] As CO_2 levels in the atmosphere continue to rise, ocean water will become even more acidic creating more problems for shellfish. By the year 2100 mussels are expected to calcify their shells 25% slower than they currently do, and oysters 10% slower.[60]

An eight-year study by more than 250 international researchers found that infant sea creatures will be especially harmed by changes in ocean pH. They determined that the number of baby cod maturing to adulthood could fall to 25 to 8% of today's numbers by the year 2100.[61] The study's lead author, Professor Ulf Riebesell from the GEOMAR Helmholtz Centre for Ocean Research in Kiel Germany, is a world authority on ocean acidification. Riebesell noted:

> *"Acidification affects marine life across all groups, although to different degrees. Warm-water corals are generally more sensitive than cold-water corals. Clams and snails are more sensitive than crustaceans. And we found that early life stages are generally more affected than adult organisms. But even if an organism isn't directly harmed by acidification it may be affected indirectly through changes in its habitat or changes in the food web. At the end of the day, these changes will affect the many services the ocean provides to us."*[62]

The Earth has weathered five mass extinction events. The most famous extinction event is the one that annihilated the dinosaurs some 66 million years ago. However, the worst mass extinction event called the Permo-Triassic Boundary (PTB), also known as The Great Dying, happened 251 million years ago over the course of 60,000 years. During this mass extinction 96% of all species were lost, and today's life descended from just the remaining 4% of the surviving species.

This cataclysm was caused by enormous volcanic eruptions that filled the air with carbon dioxide, driving warming and causing the oceans to become more acidic.[63] While the amount of carbon released into the atmosphere today does not reach the level of The Great Dying, the rate that it is being injected into the atmosphere is similar to what it was then. Matthew Clarkson of the University of Edinburgh noted:

> *"Scientists have long suspected that an ocean acidification event occurred during the greatest mass extinction of all time, but direct evidence has been lacking until now. This is a worrying finding, considering that we can already see an increase in ocean acidity today that is the result of human carbon emissions."*[64]

Marine life today has not experienced such a rapid shift in ocean pH in millions of years.[65] Ocean acidification is currently occurring at a geologically unparalleled rate, subjecting marine organisms to an additional and increasing environmental stress. While some species will not be directly affected by increasing acidity, some will be severely impacted with insufficient time to adapt.[66] Human generated increases in atmospheric CO_2 and alterations to ocean chemistry will take tens to hundreds of thousands of years to return to preindustrial values.[67]

> *Eventually, the sediments in the oceans will buffer these chemical changes but chemical recovery from such events may take tens of thousands of years while a return to the biological status quo, even if possible, could take millions of years.*[68]

Increasingly, scientists recommend limiting atmospheric CO_2 to prevent dangerous levels of global temperature increases. However, limiting output of CO_2 should be set with the effects on ocean acidification in mind as well. We've emitted so much carbon dioxide that it is being absorbed by the ocean and it is changing the very chemistry of the seawater. Persistent and increasing acidification could completely restructure marine ecosystems with domino effects across the entire food chain.

Ocean acidification is occurring in concert with other climate-related stressors, such as ocean warming and sea-level rise. In conjunction with other non-climate related impacts, including overfishing and pollution, acidification is adding pressure to already strained marine ecosystems which provide food for human consumption. Fish stocks, which are already declining in many areas due to overfishing and habitat destruction, are now faced with the new threats posed by ocean acidification.

Coral reefs, that create the habitat for 25% of all marine life on the planet, are already at serious risk and are especially delicate and prone to the effects of ocean acidification. If CO_2 levels keep increasing, coral reef erosion will outpace building even if other coral reef damaging issues are addressed. Since over 400 million people worldwide live within 100 kilometers of coral reefs, with many reliant on them for their livelihoods and food security, the health of coral reefs is of paramount concern.

The impacts of ocean acidification are beginning to be felt in some places, but future forecasts indicate even more widespread deleterious impacts if action is not taken. The obvious solution to the potential threats posed by ocean acidification is to make rapid and substantial cuts to anthropogenic CO_2 atmospheric emissions and hence, oceanic CO_2 concentrations. Ocean acidification is not a short-lived problem and could take many thousands of years to return to preindustrial levels even if carbon emissions are curbed. Unfortunately, it is now nearly a certainty that within the next 50 to 100 years, continued anthropogenic carbon dioxide emissions will further increase ocean acidity to levels that will have mostly detrimental widespread impacts on marine ecosystems.

Pictures:

Parliamentary Papers, Great Britain. Parliament. House of Commons. Reports from Commissioners. Children's Employment (Mines). Volume 15, 1842, p. 98.

Breaker boys, Woodward Coal Mines, Kingston, Pennsylvania, ca. 1900., History of coal mining in the United States, http://www.wikiwand.com/en/History_of_coal_mining_in_the_United_States

Smith, Jennifer, "Foggy London Town: Eerie photographs show the capital in grip of smog during the gloomy winter months in the early 20th Century," Daily Mail, August 31 2013, http://www.dailymail.co.uk/news/article-2407768/Eerie-images-London-fog-Grim-mid-winter-pictures-capital-early-20th-century.html

Global Carbon Budget, International Geosphere-Biosphere Programme, December 7 2015

"Climate Change and Ocean Impacts," Institute of Climate Studies, USA, http://www.icsusa.org/pages/articles/2016-icsusa-articles/june-2016---climate-change-and-ocean-impacts.php

This is one chapter from an upcoming book – Moving Back from Midnight – A World in Peril.

If you have feedback or you would like to help with working on this book in any way please contact us at movingbackfrommidnight@gmail.com. Our planet is under major threats and it will take all of us taking action to reverse course and make it a sustainable world.

[1] Parliamentary Papers, Great Britain. Parliament. House of Commons. Reports from Commissioners. Children's Employment (Mines). Volume 15, 1842, p. 11.
[2] "The Modern Union," The Blacksmiths Journal, October 1904, vol. V., no. 10, p. 4.
[3] Carlton J. H. Hayes, A Political and Social History of Modern Europe, Volume 2, 1920, The Macmillan Company, p. 85.
[4] Negro Slavery in America, The Review of Reviews, January 15, 1900, p. 90.
[5] Coulson, Michael, The History of Mining - The events, technology, and people involved in the industry that forged the modern world, 2012, Harriman House Ltd., p. 161.
[6] Coal Fatalities for 1900 Through 2016, United States Department of Labor - Mine Safety and Health Administration, https://arlweb.msha.gov/stats/centurystats/coalstats.asp
[7] Reports on the gases and explosions in collieries, 1847, London.
[8] Mines and Quarries. Reports of Arthur H. Stokes Esq., H. M. Inspector of Mines for the Midland District, 1896, London.
[9] Parliamentary Papers, Great Britain. Parliament. House of Commons. Reports from Commissioners. Children's Employment (Mines). Volume 15, 1842, p. 136.
[10] Hoffman L., Frederick, "Fatal Accidents in Coal Mining in 1903," The Engineering and Mining Journal, December 22, 1904, p. 990.
[11] McIvor, Arthur and Johnston, Ronald, Miner's Lung - A History of Dust Disease in British Coal Mining, 2007, p. 42.
[12] Cavert, William, The Smoke of London - Energy and Environment in the Early Modern City, 2016, Cambridge University Press, p. 5.
[13] Trish Ferguson, Victorian Time - Technologies, Standardizations, Catastrophes, 2013.
[14] "The Treatment of Smoke: A Sanitary Parallel," Nature, vol. 66, no. 1722, October 30, 1902, p. 669.
[15] American Medicine, "Smoke a Sanitary, Not Only Esthetic Nuisance," American Medicine, May 17, 1902, vol. 3, no. 20, p. 800.
[16] Jacobson, Mark, Atmospheric Pollution - History, Science, and Regulation, 2002, Cambridge University Press, p. 84.
[17] Gupta, Jayati, "London Through Alien Eyes," Literary London: Interdisciplinary Studies in the Representation of London, March 2003, vol. 1 no. 1.
[18] "Killer smog claims elderly victims," https://www.history.com/this-day-in-history/killer-smog-claims-elderly-victims
[19] Gunn, Angus, Encylopedia of Disasters - Environmental Catastrophes and Human Tragedies, 2008, p. 425
[20] "1966 New York City smog," https://en.wikipedia.org/wiki/1966_New_York_City_smog
[21] Christoff, Peter and Eckersley, Robyn, Globalization and the Environment, 2013, Rowman & Littlefield Publishers, Inc., p. 86.
[22] Rodgers, Lucy, "Climate change: The massive CO2 emitter you may not know about," BBC, December 17, 2018, https://www.bbc.com/news/science-environment-46455844
[23] Empire State Building Fact Sheet, http://www.esbnyc.com/sites/default/files/esb_fact_sheet_4_9_14_4.pdf
[24] Frumhoff, Peter, "Global Warming Fact: More than Half of All Industrial CO2 Pollution Has Been Emitted Since 1988," Union of Concerned Scientists Blog, December 15, 2014, http://blog.ucsusa.org/peter-frumhoff/global-warming-fact-co2-emissions-since-1988-764
[25] Airbus A380 Specs, http://www.modernairliners.com/airbus-a380/airbus-a380-specs
[26] Trends in Global CO2 Emissions 2016 Report, PBL Netherlands Environmental Assessment Agency, The Hague, 2016, p. 43.
[27] Friedman, Lisa, "Landmark Deal Curbs Flaring Pollution - Top oil-producing nations and companies pledge to eliminate the waste of natural gas that also exacerbates global warming," Scientific American, April 17, 2015, https://www.scientificamerican.com/article/landmark-deal-curbs-flaring-pollution
[28] Global Carbon Budget, International Geosphere-Biosphere Programme, December 7, 2015

[29] Farand, Chloe, “Carbon dioxide levels in Earth’s atmosphere reach ‘highest level in 800,000 years’,” The Independent, May 5, 2018, https://www.independent.co.uk/environment/carbon-dioxide-concentration-atmosphere-highest-level-800000-years-mauna-loa-observatory-hawaii-a8337921.html
[30] Marah J. Hardt and Carl Safina, “How Acidification Threatens Oceans from the Inside Out,” Scientific American, August 9, 2010
[31] O. Hoegh-Guldberg, et al., Coral Reefs Under Rapid Climate Change and Ocean Acidification, Science, December 14, 2007, vol. 318, pp. 1737-1742.
[32] “A primer on pH,” NOAA, https://www.pmel.noaa.gov/co2/story/A+primer+on+pH
[33] Jacob, Kirsten, “How Our Bodies Go To Extraordinary Lengths To Maintain Safe pH Levels,” Forbes, March 11, 2016, https://www.forbes.com/sites/quora/2016/03/11/how-our-bodies-go-to-extraordinary-lengths-to-maintain-safe-ph-levels
[34] UNEP Emerging Issues: Environmental Consequences of Ocean Acidification: A Threat to Food Security, 2010, p. 2.
[35] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 11.
[36] Marah J. Hardt and Carl Safina, “How Acidification Threatens Oceans from the Inside Out,” Scientific American, August 9, 2010
[37] “Ocean's Depth and Volume Revealed,” Live Science, May 19, 2010, https://www.livescience.com/6470-ocean-depth-volume-revealed.html
[38] Ocean Chemistry, American Chemical Society (ACS), https://www.acs.org/content/acs/en/climatescience/oceansicerocks/oceanchemistry.html
[39] Majit S. Kang and Surinder S. Banga, Combating Climate Change - An Agricultural Perspective, 2013, CRC Press, p. 20.
[40] “About California Current,” NOAA, https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/about.html
[41] F. Chan, J. A. Barth, et al., “Emergence of Anoxia in the California Current Large Marine Ecosystem,” Science, February 15, 2008, vol. 319, p. 920.
[42] F. Chan, J. A. Barth, et al., “Persistent spatial structuring of coastal ocean acidification in the California Current System,” Scientific Reports, May 2017, doi:10.1038/s41598-017-02777-y
[43] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014.
[44] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 54.
[45] UNEP Emerging Issues: Environmental Consequences of Ocean Acidification: A Threat to Food Security, United Nations Environment Programme (UNEP), 2010, p. 5.
[46] K. R. N. Anthony, et al., “Ocean acidification causes bleaching and productivityloss in coral reef builders,” PNAS (Proceedings of the National Academy of Sciences), November 11, 2008, vol. 105, no. 45, pp. 17442-17446.
[47] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 57.
[48] YU KeFu, “Coral reefs in the South China Sea: Their response to and records on past environmental changes,” Science China Earth Sciences, August 2012, vol. 55, no. 8, p. 1219, doi: 10.1007/s11430-012-4449-5
[49] Glenn De’ath, Janice M. Lough, and Katharina E. Fabricius, “Declining Coral Calcification on the Great Barrier Reef,” Science Magazine, January 2, 2009, vol. 323, pp. 116-119.
[50] Herr, Dorothée, The Ocean and Climate Change: Tools and Guidelines for Action, 2009, p. 14.
[51] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 65.
[52] Chu, Jennifer, “Ocean acidification may cause dramatic changes to phytoplankton - Study finds many species may die out and others may migrate significantly as ocean acidification intensifies,” MIT (Massachusetts Institute of Technology) News, July 20, 2015, http://news.mit.edu/2015/ocean-acidification-phytoplankton-0720

[53] Chu, Jennifer, “Ocean acidification may cause dramatic changes to phytoplankton - Study finds many species may die out and others may migrate significantly as ocean acidification intensifies,” MIT (Massachusetts Institute of Technology) News, July 20, 2015, http://news.mit.edu/2015/ocean-acidification-phytoplankton-0720
[54] “Key biological mechanism is disrupted by ocean acidification,” phys.org, March 14, 2018, https://phys.org/news/2018-03-key-biological-mechanism-disrupted-ocean.html
[55] “Canary in the kelp forest: Sea creature dissolves in today's warming, acidic waters,” Science Daily, April 19, 2017, https://www.sciencedaily.com/releases/2017/04/170419131935.htm
[56] Nair, Roshini, “Ocean acidity increasing along Pacific coast, study finds,” CBC News, June 4, 2017, http://www.cbc.ca/news/canada/british-columbia/ocean-acidity-increasing-along-pacific-coast-study-finds-1.4144786
[57] “Study: Ocean acidification killing oysters by inhibiting shell formation,” Oregon State University (OSU) News and Research Communications, June 11, 2013, http://oregonstate.edu/ua/ncs/archives/2013/jun/study-ocean-acidification-killing-oysters-inhibiting-shell-formation-0
[58] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 82.
[59] McGowan, Michael, “Sydney rock oysters getting smaller as oceans become more acidic,” The Guardian, August 15, 2018, https://www.theguardian.com/australia-news/2018/aug/16/sydney-rock-oysters-getting-smaller-as-oceans-become-more-acidic
[60] “Ocean Acidification Predicted To Harm Shellfish, Aquaculture,” Science News, March 18, 2007, https://www.sciencedaily.com/releases/2007/03/070318133722.htm
[61] “Ocean Acidification threatens cod recruitment in the Atlantic,” August 24, 2016, https://www.geomar.de/en/news/article/ocean-acidification-threatens-cod-recruitment-in-the-atlantic
[62] Harrabin, Roger, “More acidic oceans ‘will affect all sea life’,” BBC News, October 23, 2017, http://www.bbc.com/news/science-environment-41653511
[63] “Timeline Of Mass Extinction Events On Earth,” http://www.worldatlas.com/articles/the-timeline-of-the-mass-extinction-events-on-earth.html
[64] Kahn, Amina, “Ocean acidification triggered devastating extinction, study finds,” Los Angeles Times, April 9, 2015, http://www.latimes.com/science/sciencenow/la-sci-sn-ocean-acidification-mass-extinction-20150409-story.html
[65] Marah J. Hardt and Carl Safina, “How Acidification Threatens Oceans from the Inside Out,” Scientific American, August 9, 2010
[66] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014
[67] An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity, United Nations Environmental Programme (UNEP), 2014, p. 32.
[68] UNEP Emerging Issues: Environmental Consequences of Ocean Acidification: A Threat to Food Security, United Nations Environment Programme (UNEP), 2010.