BEFORE THE ENVIRONMENTAL PROTECTION AGENCY

PETITION FOR RULEMAKING PURSUANT TO SECTION 21 OF THE TOXIC SUBSTANCES CONTROL ACT, 15 U.S.C. § 2620, CONCERNING THE REGULATION OF CARBON DIOXIDE

Credit: NOAA

CENTER FOR BIOLOGICAL DIVERSITY

DONN J. VIVIANI, PhD

PETITIONERS

June 30, 2015

NOTICE OF PETITION

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The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy and environmental law. The Center has over 800,000 members and online activists throughout the United States and around the world. The Center's Oceans Program and its supporters are specifically concerned with the conservation of marine species, the preservation of ocean ecosystems and the effective implementation of U.S. environmental laws, including the Toxic Substances Control Act. The Center submits this petition on its own behalf and on behalf of its members and staff with an interest in protecting the marine environment.

Donn J. Viviani, PhD, is a retired U.S. Environmental Protection Agency scientist. He was the Director of the Climate Policy Assessment Division in the Office of Policy, Economics and Innovation. He also served as Chairman of the Great Lakes Water Board's Toxic Substances Committee and as a member of the Science Coordinating Committee for the International Joint Commission for the Great Lakes. Dr. Viviani enjoys the ocean and submits this petition, in part, so his grandchildren will be able to enjoy it as well. Dr. Viviani also submits a supplement to the petition, under his signature only, and respectively requests that it be considered.

ACTION REQUESTED

Pursuant to section 21 of the Toxic Substances Control Act ("TSCA" or the "Act"), 15 U.S.C. § 2620, and section 553(e) of the Administrative Procedure Act ("APA"), 5 U.S.C. § 553(e), the Center for Biological Diversity and Donn J. Viviani (collectively, "Petitioners") hereby petition the Administrator of the U.S. Environmental Protection Agency ("EPA") to promulgate regulations protecting public health and the environment from the serious harms associated with anthropogenic emissions of carbon dioxide, including ocean acidification. Specifically, Petitioners request that EPA adopt a rule under section 6 of the Act, 15 U.S.C. § 2605, requiring manufacturers and processors to mitigate these emissions.

This petition sets in motion a specific process, placing definite response requirements on EPA. Specifically, TSCA stipulates that the agency "*shall* either grant or deny the petition" within 90 days following its receipt, "promptly commenc[ing] an appropriate [rulemaking] proceeding" if such action is warranted. 15 U.S.C. § 2620(b)(3) (emphasis added). Conversely, should EPA deny this petition, the agency must publish the reasons for denial in the Federal Register. 15 U.S.C. § 2620(b)(3); *see also* 5 U.S.C. § 555(e) ("Prompt notice shall be given of the denial in whole or in part of a written application, petition, or other request of an interested person made in connection with any agency proceeding."). Pursuant to 15 U.S.C. § 2620(b)(4), petitioners may file suit in federal district court to challenge an adverse or untimely determination. *See also* 5 U.S.C. §§ 702, 706.

As described in this petition, anthropogenic emissions of carbon dioxide satisfy the standard for regulation set forth at 15 U.S.C. § 2605. For example, EPA has acknowledged that these emissions have the potential to alter ocean chemistry, thus imperiling important marine ecosystems and presenting an unreasonable risk of injury to the environment. Accordingly, the agency must promptly commence the proposed rulemaking to reduce and mitigate these harms. In the event that EPA concludes that there are insufficient data and experience upon which to determine or predict the effects of carbon dioxide emissions, we alternatively request that the agency adopt a rule under section 4 of the Act, 15 U.S.C. § 2603, requiring manufacturers and processors responsible for the generation of carbon dioxide to undertake testing to determine toxicity, persistence, and other characteristics which affect health and the environment and are necessary to determine if there is an unreasonable risk of injury to health or the environment.

Dated this 30th day of June 2015.

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INTRODUCTION

Ocean acidification — caused by carbon dioxide (“CO_2”) emissions — is a severe threat to the marine environment and the health of people who depend on oceans and coasts. Because of the unreasonable risk that CO_2 poses to the environment and human health, this petition seeks rulemaking under the Toxic Substances Control Act (“TSCA”) to regulate CO_2 from cradle to grave.

About 28% of CO_2 emissions from power generation, cement production, industry, and other sources are absorbed by the ocean. These CO_2 emissions cause seawater to become more acidic and corrosive to sea life. Anthropogenic CO_2 emissions have increased the acidity of the oceans on average by 30%, and by the end of the century scientists predict that the oceans will become 150-170% more acidic.

While the most dangerous consequences of CO_2 on our oceans are still to come, harmful impacts on the environment are already well-documented.

- Billions of oyster larvae have perished in the Pacific Northwest due to ocean acidification;
- 53% of pteropods, plankton that form the base of the marine food web, along the West Coast have severely dissolved shells because of the corrosive nearshore conditions; and
- Calcification rates at coral reef locations in the western tropical Pacific and the Caribbean may have already declined by 15%.

These are just some of the harmful environmental impacts of ocean acidification caused by CO_2 emissions. Anthropogenic CO_2 emissions are contributing to increasingly corrosive conditions for marine animals, and will continue to grow more severe absent actions to promptly reduce CO_2 pollution in the atmosphere.

TSCA was enacted in part to address the threat of ozone depletion caused by chlorofuorocarbon (CFC) emissions. And here again TSCA regulation is needed where airborne emissions are causing damage to our environment — this time threatening ocean ecosystems, fish and shellfish industries, and communities that depend on oceans and coral reefs.

Petitioners specifically request that EPA take the following actions:

1. **Make a determination under TSCA § 6 that CO_2 presents an unreasonable risk of injury to health or the environment; and**
2. **Initiate rulemaking to control CO_2; or**
3. **If EPA finds data inadequate to make a §6 determination then EPA must initiate rulemaking for testing under TSCA § 4.**

This petition presents scientific evidence that establishes that CO_2 presents an unreasonable risk of injury to the environment, and therefore EPA must take action under TSCA section 6.

I. The Toxic Substances Control Act

Congress enacted TSCA, 15 U.S.C. §§ 2601 *et seq.*, "to assure that … innovation and commerce in … chemical substances and mixtures do not present an unreasonable risk of injury to health or the environment."[1] Accordingly, lawmakers required those responsible for the manufacture and processing of these compounds to develop "adequate data" describing their effects, and authorized EPA to devise and implement reasonable controls to prevent the risk of injury to health or the environment.[2]

Section 6 of TSCA mandates that EPA "shall" regulate a chemical substance for which

> there is a reasonable basis to conclude that the manufacture, processing, distribution in commerce, use, or disposal of a chemical substance or mixture, or that any combination of such activities, presents or will present an unreasonable risk of injury to health or the environment.[3]

Permissible regulations include requirements prohibiting or "limiting the amount of such substance … which may be manufactured, processed, or distributed in commerce."[4] EPA can also require processors "to give public notice of such risk [of injury], and . . . to replace or repurchase such substance . . . to adequately protect health or the environment."[5] In assessing risk, EPA must consider:

> (A) the effects of such substance or mixture on health and the magnitude of the exposure of human beings to such substance or mixture,
> (B) the effects of such substance or mixture on the environment and the magnitude of the exposure of the environment to such substance or mixture,
> (C) the benefits of such substance or mixture for various uses and the availability of substitutes for such uses, and
> (D) the reasonably ascertainable economic consequences of the rule, after consideration of the effect on the national economy, small business, technological innovation, the environment, and public health.[6]

Thus, if there is a reasonable basis to conclude that a proposed rule is necessary to protect the environment, then EPA must grant a petition for rulemaking and initiate rulemaking procedures. Factual certainty is not required; instead, the agency may "base its action on scientific theories, consideration of projections from available data, modeling using reasonable assumptions, and extrapolations from limited data."[7] Even if EPA determines that another federal law "could

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[1] 15 U.S.C. § 2601(b)(3) (2012). Within the meaning of TSCA, the term "chemical substance" includes "any organic or inorganic substance of a particular molecular identity." *Id.* § 2602(2).

[2] *Id.* § 2601(b)(1) & (2).

[3] *Id.* § 2605(a) (emphasis added).

[4] *Id.* § 2605(a)(1)(B).

[5] *Id.* § 2605(b)(2)(B).

[6] *Id.* § 2605(c)(1). E.

[7] Lead Fishing Sinkers; Response to Citizens' Petition and Proposed Ban, 59 Fed. Reg. 11,122, 11,138 (Mar. 9, 1994) (*citing* H.R. Rep. No. 1341, 9th Cong., 2d Sess. 32 (1976)).

[sufficiently] eliminate[] or reduce[]" the risk associated with a particular chemical substance, the agency may elect to regulate the substance under TSCA, provided that a "comparison of the estimated costs" and "relative efficiency" reveals that such action promotes the public interest.[8]

In the event that EPA lacks adequate data and experience upon which to determine the health and environmental risks associated with a particular chemical substance, the agency "*shall* by rule require that testing be conducted on such substance."[9] Specifically, Section 4 of the Act authorizes EPA to compel manufacturers and processors to evaluate the safety of substances that "may present an unreasonable risk of injury to health or the environment" or that "[are] or will be produced in substantial quantities" and, thus, "may reasonably be anticipated to enter the environment in substantial quantities" or result in "significant or substantial human exposure."[10] TSCA provides for testing to determine toxicity, persistence, and other characteristics which affect health and the environment and are necessary to determine if there is an unreasonable risk of injury to health or the environment.

Over forty years ago, the Council on Environmental Quality warned of the "high priority need" for a new legal authority capable of ensuring the safe use of toxic chemicals.[11] Despite TSCA's powerful potential, however, EPA has accomplished very little under the Act. This petition presents substantial scientific evidence demonstrating that anthropogenic emissions of CO_2 pose an unreasonable risk to human and environmental health. Indeed, studies show that significant and potentially irreversible harm has already occurred. As the Council recognized decades ago, "[w]e should no longer be limited to repairing [this] damage after it has been done; nor should we continue to allow the entire population or the entire environment to be used as a laboratory." Instead, EPA must take prompt action to reduce and mitigate the anthropogenic production of CO_2.

II. EPA Must Issue a Rule to Regulate or Require Tests for CO_2 Causing Ocean Acidification

CO_2 presents an unreasonable risk of injury to the environment because its exposure to the ocean changes seawater chemistry with harmful impacts on marine life and ecosystems. Substantial evidence supports this conclusion and is discussed in this petition. Accordingly, this petition seeks a rulemaking to regulate CO_2 under TSCA.

This petition requires EPA to make a determination under TSCA section 6 if the injury to the environment and health from CO_2 is unreasonable. Alternately, if the Agency demonstrates that the existing science is insufficient to make a determination under TSCA section 6, EPA must initiate test rules under TSCA section 4 to develop the missing information needed to determine if the TSCA section 6 trigger is met and how best to mitigate the harm.

A. TSCA Authorizes EPA to Act on CO_2

To enable the achievement of TSCA's ambitious objectives, Congress broadly defined EPA's jurisdiction under the Act. As described above, TSCA explicitly directs EPA to initiate

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[8] *Id.*
[9] *Id.* § 2603 (emphasis added).
[10] *Id.*
[11] Council on Envtl. Quality, Toxic Substances at v (April 1971).

rulemaking upon finding that “the manufacture, processing, distribution in commerce, use, or disposal of a chemical substance” threatens public health or the environment.[12] TSCA then authorizes the regulation of “chemical substances” that are “in commerce,” a test met by CO_2. Indeed, CO_2 is already on the TSCA inventory as a “chemical in commerce.”[13] CO_2 necessarily qualifies as a “chemical substance,” a category that includes “any organic or inorganic substance of a particular molecular identity.”[14] Moreover, the anthropogenic emissions at issue are in commerce; federal courts have previously concluded that air emissions[15] and “incidental byproducts of industrial chemical processes” are within the scope of EPA’s authority under the Act.[16] Existing scientific evidence demonstrates that the anthropogenic production of CO_2 has already damaged marine ecosystems and endangered vulnerable portions of the human population. For the reasons described below, EPA must promptly reduce and mitigate these harms.

1. CO_2 Is a Chemical Substance

First, carbon dioxide is a “chemical substance” falling within the scope of the Act. The Act defines “chemical substance” as “any organic or inorganic substance of a particular molecular identity, including any combination of such substances occurring in whole or in part as a result of a chemical reaction or occurring in nature and (ii) any element or uncombined radical.”[17]. CO_2 meets this definition. CO_2 is a chemical substance that occurs both in nature and as a result of a chemical reaction. It consists of a carbon atom bonded to two oxygen atoms:

$$O=C=O$$

It is identified by molecular formula CO_2 and by CAS number 124-38-9.

2. CO_2 Is in Commerce

Second, CO_2 is in commerce, and it is already on the TSCA inventory (CAS 124-38-9) with “chemical in commerce” as the stated reason for regulation.[18] Under TSCA’s statutory text, “commerce” is defined as “trade, traffic, transportation, or other commerce . . . between a place in a State and any place outside of such state, or . . . which affects trade, traffic, transportation, or commerce.”[19] CO_2 is primarily produced as a byproduct from the combustion of fossil fuels; according to the EPA, CO_2 emissions account for 77% of greenhouse gas emissions worldwide.[20]

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[12] *Id.* §§ 2605(a), 2603(a)(1)(A)(i), 2506(a). Although TSCA does not define “disposal,” other federal environmental laws explain that this term encompasses “the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters.” 42 U.S.C. §§ 6903(3), 9601(29).

[13] EPA, Substance Registry at http://1.usa.gov/1IBS1w6 (last accessed June 28, 2015).

[14] 15 U.S.C. § 2602(2). This definition excludes specific compounds already subject to federal control, such as pesticides, tobacco products, nuclear materials and food, drugs and cosmetics. *Id.* § 2602(2)(B).

[15] *Citizens for a Better Env’t v. Thomas*, 704 F. Supp. 149, 152 (E.D. Ill. 1989).

[16] *Envtl. Def. Fund v. Envtl. Prot. Agency*, 636 F.2d 1267, 1271 (D.C. Cir. 1980).

[17] 15 U.S.C. § 2602(2)(A).

[18] EPA, Substance Registry at http://1.usa.gov/1IBS1w6.

[19] 15 U.S.C. § 2602(3).

[20] EPA, Global Greenhouse Gas Emissions Data, http://www.epa.gov/climatechange/ghgemissions/global.html (last updated June 21, 2013; last accessed June 28, 2015).

The most voluminous sources of greenhouse gas emissions are energy suppliers,[21] industry,[22] land use and forestry,[23] agriculture,[24] transportation,[25] commercial and residential buildings,[26] and waste and wastewater.[27] All of these emitters produce CO_2 as a byproduct of their ordinary processes.

TSCA's statutory and regulatory text support the proposition that CO_2 emitted as a byproduct of industrial processes can be regulated under TSCA because CO_2 in this context is manufactured, meaning "produce[d] . . . with the purpose of obtaining an immediate or eventual commercial advantage."[28] All of the industries listed above which emit CO_2 are performed to obtain an immediate or eventual commercial advantage, as all of these industries are commercial and part of a competitive market. Therefore, incidental production of CO_2 is manufactured or produced "for a commercial purpose," and is found "in commerce" pursuant to TSCA regulations.

Accordingly, CO_2 emissions fit the regulatory definition of a chemical substance produced for a commercial purpose. This is bolstered by the broad definition of "commerce" in the TSCA statute; at the very least, CO_2 emissions "affect" trade, traffic, transportation, and commerce.

TSCA's purpose and regulatory text support the regulation of chemical substances that are an incidental byproduct, and indeed EPA has regulated chemical byproducts under TSCA before. For example, PCBs are regulated under TSCA even when they are only incidentally produced as a byproduct of industrial processes.[29] EPA regulates PCB "byproducts" for which there are no separate commercial intents, and TSCA regulates inadvertently vented PCB emissions.[30] Moreover, EPA's authority under TSCA broadly defines what it regulates under "disposal" of PCBs to include intentional and accidental disposal.[31] EPA has also previously prohibited wastes from chemical manufacturing under TSCA.[32]

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[21] Which emit greenhouse gases through "[t]he burning of coal, natural gas, and oil for electricity and heat." *Id.*

[22] Which emit greenhouse gases through "fossil fuels burned on-site at facilities for energy" and "chemical, metallurgical, and mineral transformation processes not associated with energy consumption." *Id.*

[23] Which emit "carbon dioxide . . . from deforestation, land clearing for agriculture, and fires or decay of peat soils." *Id.*

[24] "Greenhouse emissions from agriculture mostly come from the management of agricultural soils, livestock, rice production, and biomass burning." *Id.*

[25] Which emit greenhouse gases through "fossil fuels burned for road, rail, air, and marine transportation." *Id.*

[26] Which emit greenhouse gases from "on-site energy generation and burning fuels or heat in buildings or cooking in homes." *Id.*

[27] Which emit carbon dioxide through the "incineration of some waste products that were made with fossil fuels, such as plastics and synthetic textiles." *Id.*

[28] 40 C.F.R. § 710.3; 40 C.F.R. § 704.3 ("Manufacture for commercial purposes also applies to substances that are produced coincidentally during the manufacture, processing, use, or disposal of another substance or mixture, including both byproducts that are separated from that other substance or mixture and impurities that remain in that substance or mixture. Such byproducts and impurities may, or may not, in themselves have commercial value. They are nonetheless produced for the purpose of obtaining a commercial advantage since they are part of the manufacture of a chemical product for a commercial purpose.").

[29] 44 Fed. Reg. 31525 (May 31, 1979); 40 C.F.R. § 761.

[30] *See, e.g.,* 40 C.F.R. Part 761.

[31] 40 C.F.R. § 761.3.

[32] 45 Fed. Reg. 592 (March 11, 1980);40 C.F.R. § 775 (1980) (prohibiting disposal of 2,3,7,8-tetracholorodibenzo-p-dioxin (TCDD) a manufacturing waste).

Further, CO_2 emissions are in commerce as they are traded, bought, and sold as carbon offsets. CO_2 is also produced for commerical purposes including for uses in fertilizer, beverage carbonation, dry ice, refrigeration, pressurization, fire extinguishment, and packaging.

B. EPA Should Initiate Rulemaking to Control CO_2 under TSCA

Petitioners request that EPA make finding that CO_2 presents or will present an unreasonable risk of injury to the environment or health. TSCA requires that EPA "shall" initiate rulemaking upon finding "a reasonable basis to conclude that the manufacture, processing, distribution in commerce, use or disposal of a chemical substance of mixture … presents or will present an unreasonable risk of injury to health or the environment."[33]

The information and supporting documents provided in this petition indicate that CO_2 is already causing injury to the environment due to ocean acidification. The scientific evidence further supports that the injury to the environment and health will grow more severe as CO_2 pollution continues. EPA cannot deny that CO_2 is harming the environment. Indeed, EPA acknowledges that ocean acidification poses risk:

> Ocean acidification, like Climate change is primarily caused by increasing carbon dioxide (CO_2) concentrations in the atmosphere. As a result of absorbing large quantities of human made CO_2 emissions the ocean chemistry is changing, which is likely to negatively affect important marine ecosystems and species including coral reefs, shellfish, and fisheries.

(Environmental Protection Agency 2010).

EPA must find that such injury is an unreasonable risk.[34] While Congress did not define the phrase "unreasonable risk," EPA has interpreted relevant legislative history to require that the agency:

> balance the benefits derived from risk reduction against the social and economic costs incurred, taking into account such factors as the extent and magnitude of risk posed; the societal consequences of removing or restricting use of products; availability and potential hazards of substitutes; and impacts on industry, employment, and international trade.[35]

No specific factual determination is necessary to establish "unreasonable risk." For example, even under the stricter standard of 15 U.S.C. § 2606, EPA need not present evidence of actual injury before obtaining emergency injunctive relief to control "immanently hazardous chemical substance[s] or mixture[s]."[36] For the reasons discussed below, application of the agency's balancing test supports the additional regulation of CO_2.

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[33] 15 U.S.C. § 2605(a).

[34] *Id.*

[35] EPA, Guidance for Petitioning the Environmental Protection Agency Under Section 21 of the Toxic Substances Control Act, 50 Fed. Reg. 46,825 (Nov. 13, 1985).

[36] *See* H.R. Conf. Rep. No. 94-1679 78 (1976).

According to scientific experts: “Reducing CO_2 emissions is the only way to minimise [sic] long-term, large-scale risks” (IBGP et al. 2013).

1. CO_2 Pollution Presents an Unreasonable Risk of Injury to the Environment

There is clear consensus among leading national and international scientific bodies that anthropogenic CO_2 causes changes in ocean chemistry that harm the marine environment. The Intergovernmental Panel on Climate Change (“IPCC”) determined that human sources of CO_2 have caused a significant decline in surface ocean pH (Rhein et al. 2013), and over 90 national academies of sciences, including the United States’, have signed a statement that ocean acidification will “cause grave harm to important marine ecosystems as CO_2 concentrations reach 450 ppm and above” (Interacademy Panel 2009). The Interacademy Panel concluded that CO_2 has increased ocean acidity with “potentially profound consequences for marine plants and animals” including severe threats to coral reefs, polar ecosystems, and a likely reduction in marine food supplies (*Id.*). The National Research Council also acknowledges that “existing data support a growing consensus in the research community that most documented responses to acidification reflect impairment of physiological capacity or performance” for marine life with likely substantial socioeconomic impacts (National Research Council 2013). The U.S. National Climate Assessment concluded that ocean acidification will alter marine ecosystems in dramatic ways including threatening coral reef habitats and causing reduced growth and survival of shellfish in all regions (Doney et al. 2014).

EPA acknowledges that “ocean acidification presents a suite of environmental changes that would likely negatively affect ocean ecosystems, fisheries, and other marine resources.” 75 Fed. Reg. 13538 (Mar. 22, 2010). EPA previously concluded that greenhouse gases, including CO_2, endanger public health and the environment in part because of ocean acidification.[37]

There is no doubt that CO_2 pollution is changing ocean chemistry and harming the marine environment. Unabated, there will be severe and detrimental impacts on marine ecosystems, the economy, and public health. Accordingly, EPA must find that CO_2 poses an unreasonable risk to the environment and health.

a. CO_2 Causes Irreversible Ocean Acidification

Ocean acidification is a major threat to the marine environment. The oceans have absorbed CO_2 emitted into the atmosphere from power plants, manufacturing, cement production, and land use changes. Between 1750 and 2011, human activities have released 375 gigatons of carbon into the atmosphere, and approximately half of that has been absorbed by the oceans (Rhein et al. 2013). Each day about 22 million metric tons of CO_2 is taken up by the oceans (Feely et al. 2008). This uptake of CO_2 is changing ocean chemistry, causing the oceans to become more acidic. Since the industrial revolution surface ocean pH has declined by 0.11 units on average, corresponding with

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[37] EPA, Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act 80 (Dec. 7, 2009).

a 30% increase in acidity (Orr et al. 2005; Caldeira & Wickett 2005).[38] If emissions continue unabated, ocean acidity will increase up to 170% by the end of the century (IBGP et al. 2013).

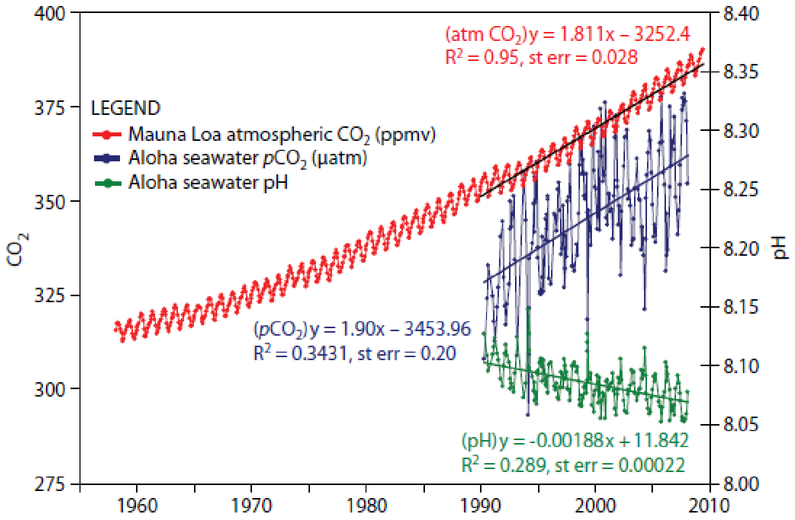

Figure 1. Time series of atmospheric CO 2 at Mauna Loa (ppmv) and surface ocean pH and pCO2 (μatm) at Ocean Station Aloha in the subtropical North Pacific Ocean (see inset map). Note that the increase in oceanic CO 2 over the period of observations is consistent with the atmospheric increase within the statistical limits of the measurements. (Feely et al. 2009).

Anthropogenic ocean acidification exceeds the trend in natural variability significantly, up to 30 times in some regions (Friedrich et al. 2012). The rate of change in ocean acidity is unprecedented in the past 300 million years, a period that includes four mass extinctions (Honisch et al. 2012; Zeebe 2012). The seawater chemistry change is an order of magnitude faster than what occurred 55 million years ago during Paleocene-Eocene Thermal Maximum, which is considered to be the closest analogue to the present, and during that period 96% of marine species went extinct (*Id.*). The current changes in seawater chemistry are irreversible on human timescales (Royal Society 2005).

CO_2's impact on ocean chemistry is fundamentally altering the marine environment with negative impacts on marine species, habitats and ecosystems.

i. What Is Ocean Acidification

When the ocean absorbs CO_2 from the atmosphere it changes ocean chemistry. CO_2 that is absorbed by seawater reacts to form carbonic acid, which dissociates to form bicarbonate and releases hydrogen ions. This reaction reduces the amount of carbonate ions and decreases pH. The oceans store a significant amount of the CO_2 pollution from human activities (Royal Society 2005). While this has provided society with an important service of buffering against climate change impacts, it comes at a cost to the marine environment.

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[38] Because the pH scale is logarithmic a small decrease is a significant change in acidity; for example, a decrease of 0.1 pH is an approximate 30 percent increase in acidity.

Globally, surface water pH has declined 0.11 units on average between 1750 and 1994 (Sabine et al. 2004). Long-term monitoring has documented the impact of increasing atmospheric CO_2 on declining seawater pH in the Pacific and Atlantic Oceans (*see* Figure 2). Results from time-series stations in the North Atlantic and North Pacific show a decrease of about 0.002 pH per year (Rhein et al. 2013).

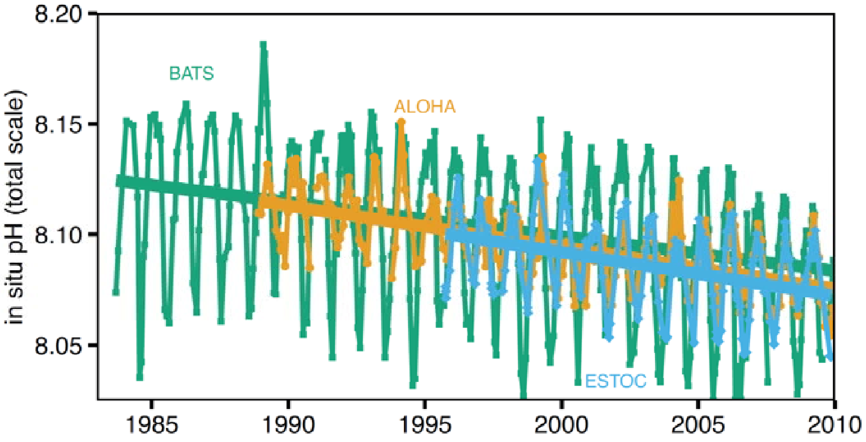

Figure 2. Long-term trends of surface seawater pH at three subtropical ocean time series in the North Atlantic and North Pacific Oceans, including (a) Bermuda Atlantic Time-series Study (BATS, 31°40’N, 64°10’W; green) and Hydrostation S (32°10’, 64°30’W) from 1983 to present (updated from Bates, 2007); (b) Hawaii Ocean Time-series (HOT) at Station ALOHA (A Long-term Oligotrophic Habitat Assessment; 22°45’N, 158°00’W; orange) from 1988 to present (updated from Dore et al., 2009) and (c) European Station for Time series in the Ocean (ESTOC, 29°10’N, 15°30’W; blue) from 1994 to present (updated from González-Dávila et al., 2010). Atmospheric pCO2 (black) from the Mauna Loa Observatory Hawaii is shown in the top panel. Lines show linear fits to the data, whereas Table 3.2 give results for harmonic fits to the data (updated from Orr, 2011).(Rhein et al. 2013)

Ocean acidification not only makes the oceans more acidic, but it also reduces the amount of carbonate ions available for animals to build the shells and skeletons they need to survive. Carbonate is an important constituent of seawater because many organisms form their shells and skeletons by complexing calcium and carbonate. Waters that are supersaturated with aragonite are generally good for shell-building, while undersaturated waters ($<1.0\ \Omega_{ar}$) are corrosive to some marine animals. Corals require supersaturated waters above 3.3 Ω_{ar} (Meissner et al. 2012). Globally, there has been a decrease of about -0.4 Ω_{ar} (Gruber et al. 2012). The aragonite saturation state has declined 16% since the Industrial Revolution due, in large part, to anthropogenic CO_2 (Feely et al. 2012a; Ishii et al. 2011). Modeling of the oceans’ aragonite saturation predicts that by the end of the century up to 75% of ocean volume could be undersaturated with respect to aragonite (Joos et al. 2011).

ii. Observed and Predicted Acidification

CO_2 has already had measurable impacts on seawater chemistry. Some regions, such as those with upwelling systems or high latitudes, are especially vulnerable to ocean acidification.

1. *Pacific Coast*

The West Coast is already experiencing adverse impacts of ocean acidification. As early as 2008, a survey off the coasts of Washington, Oregon, and California revealed that this region is already experiencing corrosive waters not expected until mid-century (See figure 3) (Feely 2008). Researchers found seawater undersaturated with respect to aragonite upwelling onto large portions of the continental shelf, reaching shallow depths of 40 to 120 meters (*Id.*). According to the study, the waters were last at the surface approximately 50 years ago when atmospheric CO_2 concentrations were much lower (Feely et al. 2008). Feely et al. report that in the Pacific Ocean there has been a decrease of the saturation state of surface seawater with respect to aragonite and calcite as well as an upward shoaling of the saturation horizon by about 1-2 meters per year on average, due in large part to anthropogenic CO_2 (R. A. Feely, Sabine, et al. 2012). As a result, marine organisms in surface waters, in the water column, and on the sea floor along the West Coast of the United States are already being exposed to corrosive water during the upwelling season.

Modeling of the California Current System demonstrates that the area is rapidly approaching year-round undersaturation with respect to aragonite and it is departing significantly from natural variability (Hauri et al. 2013). Time series monitoring shows that the aragonite saturation state along the California coast is much lower than would be expected in the North Pacific (Harris, DeGrandpre et al. 2013). Surface Ω_{ar} values ranged between 0.66 and 3.9 compared to an estimated pre-industrial range of 1.0 to 4.7. While some areas, like Puget Sound, already exhibit undersaturated conditions every year (Feely, Klinger, et al. 2012; Reum et al. 2014), scientists predict that most shallow shelf areas along the West Coast will become undersaturated with respect to aragonite within the next 20-30 years (Capone & Hutchins 2013; Gruber et al. 2012).

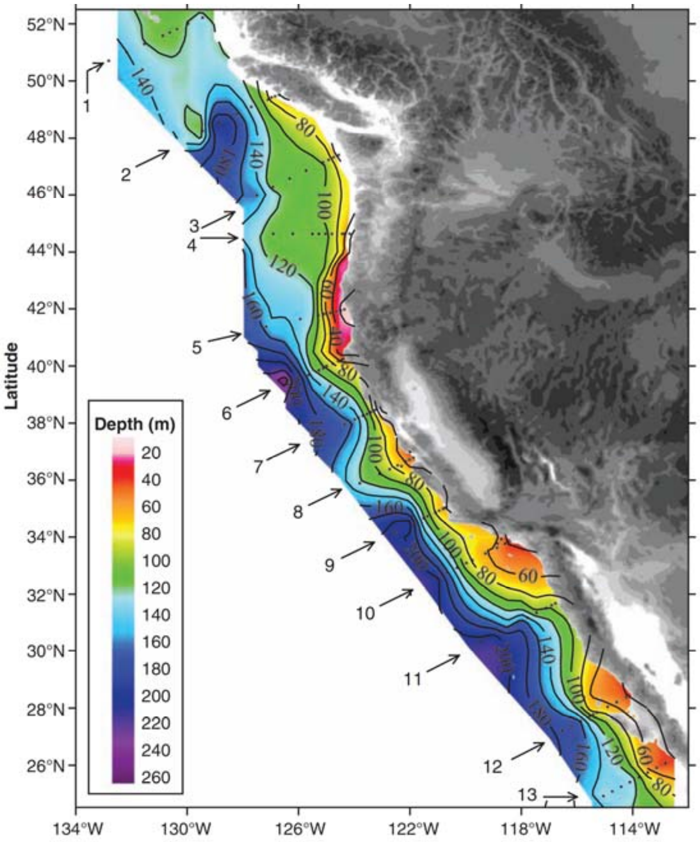

Figure 3. Distribution of the depths of the undersaturated water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada, to San Gregorio Baja California Sur,Mexico. On transect line 5, the corrosive water reaches all the way to the surface in the inshore waters near the coast. The black dots represent station locations (Feely et al. 2008).

2. Alaskan Waters

High latitude waters are the "bellwether" of ocean acidification because these will be the first ocean regions to become persistently undersaturated with respect to aragonite as a result of greenhouse gas pollution (Fabry et al. 2009; Steinacher et al. 2009). High-latitude waters have naturally lower carbonate ion concentrations and saturation states due to a combination of cold temperatures which increase the solubility of CO_2 and ocean mixing patterns (Fabry et al. 2009; Mathis et al. 2011a). As early as 2016, 10% of Arctic surface waters are expected to be undersaturated with respect to aragonite for at least one month per year (Steinacher et al. 2009).

Recent observations of calcium carbonate saturation states in the North Pacific and Bering Sea have found that full water column undersaturation of calcium carbonate due to ocean acidification is already prevalent. Mathis et al. (2011a) reported that extensive areas of bottom waters over the Bering Sea shelf are becoming undersaturated with respect to aragonite for at least several months (July to September), and some areas of bottom water were already observed to be undersaturated with respect to calcite (Fabry et al. 2009, Mathis et al. 2011a).

Scientists predict that polar waters will be corrosive to shellbuilding animals within decades (IBGP et al. 2013). A 2015 study of observations in the Chukchi and Beaufort Seas in the Arctic indicates that within 15 years waters will become so corrosive that it will be difficult for marine animals to build and maintain their shells (Mathis et al. 2015). The highly productive fisheries of Alaska are in some of the most rapidly changing seawater conditions (Mathis et al. 2014).

3. *Sub-tropical Waters*

Subtropical waters have experienced declining saturation states due to ocean acidification. Within decades, scientists believe that ocean acidification will impair coral growth (IBGP et al. 2013). Models show that by the end of the century, most coral reef areas will no longer have aragonite saturation states that are optimal for coral growth. A 10-year study of the Caribbean region found a strong regional decrease in aragonite saturation state between 1996-2006, from 4.05 to 3.9, resulting from CO_2 (Gledhill et al. 2008). Modeling predicts that under various emissions scenarios the coral reefs in the Caribbean will be thermally and chemically stressed between now and 2030 (Meissner et al. 2012). Even under the most optimistic scenario, 98% of reefs will be stressed by 2050 (*Id.*). In the Pacific subtropical ocean near Hawaii, there are nearly 20 years of time-series measurements of significant decreasing seawater pH that match the ocean's uptake of atmospheric CO_2 (Dore et al. 2009)

4. *Atlantic Coast*

Even ocean waters not at high latitude, in upwelling systems, or containing coral reefs ecosystems are, or will soon be, exhibiting signs of ocean acidification. Observations of East Coast waters during all seasons show that while they remain supersaturated with respect to aragonite, by the end of this century, saturation states of aragonite and calcite will decrease by 20–40%, with the lowest Ωar dropping to 1.3 in some seasons (Jiang et al. 2010). A survey of the Atlantic Coast showed that waters in the Northeast and particularly the Gulf of Maine are the most susceptible to ocean acidification (Wang 2013).

iii. CO_2 Kills and Injures Marine Life

High-CO_2 waters seriously harm marine wildlife and the entire ocean ecosystem. When CO_2 concentrations in seawater increase, the availability of carbonate ions decreases, making it more difficult for marine organisms to form, build, and maintain the calcium carbonate shells and skeletons required for their survival. As seawater becomes more corrosive, it can kill fish eggs and inhibit the development of, and essentially dissolve, the shells of small crustaceans, baby shellfish, and other tiny creatures at the base of the food web (Fabry 2008). Ocean acidification also harms and stresses fish, squid, and other animals that do not build shells (*Id.*). Not only does ocean acidification directly threaten various types of marine animals, it also has implications for the broader marine environment and food web.

The harmful effects of ocean acidification have already begun to occur. For example, ocean acidification has caused:

- A massive die-off of oysters in the Pacific Northwest (Barton et al. 2012; R. a. Feely, Sabine, et al. 2012; Washington State Blue Ribbon Panel 2012);

- Declines in abundance and size of the California mussel, blue mussel and goose barnacle in tidepools correlated with a severely declining pH (Wootton et al. 2008);
- Sluggish growth of corals in the Caribbean and Great Barrier Reef (De'ath et al. 2009; De'ath et al. 2012; Gledhill et al. 2008); and
- Shells of plankton to dissolve off the California Coast and thinner and weaker shells of plankton in the Southern Ocean (Bednarsek 2014; Moy et al. 2009).

In a meta-analysis of over 400 experiments examining the impacts of ocean acidification on marine organisms, Kroeker et al. (2013) found the biological effects to be generally large and negative. This analysis was restricted to experiments with pH manipulations of less than 0.5 units, in order to reflect the predicted level of ocean acidification by the end of the century (IPCC 2007). By limiting the analysis to small variations in pH, this study shows that within the foreseeable future ocean acidification will have "profound repercussions for marine organisms" (Kroeker et al. 2010). While the negative effect of ocean acidification was most pronounced for calcification and survival (27% reductions in both responses), the study also revealed significant negative effects on growth and reproduction (11 to 19%, respectively). In addition, abundance was reduced by 15%. The strength of this analysis suggests that the patterns highlighted in this study are a robust representation of the current literature on ocean acidification.

While most of the worst consequences of ocean acidification are predicted for the future, scientists have already observed damage from CO_2 in the oceans. Additionally, the impacts of ocean acidification can affect the entire marine food web by altering habitat, prey availability, and species interactions.

b. High-CO_2 Waters Injure the Growth, Survival, Fitness, and Reproduction of Marine Animals

The primary known harm of CO_2 in the oceans is that it impairs the growth and survival of animals that build shells. Because ocean acidification reduces the availability of carbonate ions that marine animals use to calcify their shells and skeletons, CO_2 reduces the ability of these animals to build their protective structures (Doney et al. 2009). Acidified waters can also damage and dissolve shells.

These negative effects have been observed in the ocean as well as documented in laboratory studies. Corals, coralline algae, plankton, mollusks, and other shellfish exposed to future levels of ocean acidification have all experienced problems (Kleypas & Yates 2009; Kuffner et al. 2007; Barton et al. 2012; Talmage & Gobler 2011; Talmage & Gobler 2009; Orr et al. 2005; Riebesell et al. 2000).

i. Molluscs, Echinoderms, and Crustaceans

High CO_2 waters are lethal to shellfish. Since 2005, waters off the coast of Washington and Oregon have been killing oysters and other molluscs. Shellfish hatcheries in Washington and Oregon reported massive mortalities of oyster larvae (Washington State Blue Ribbon Panel 2012).Wild oysters also failed to reproduce in Willapa Bay, Washington (*Id.*). Scientists have definitively linked oyster production failures to high-CO_2 ocean waters that were used to raise larvae (Barton et al. 2012).

In response to reported shellfish hatchery problems in Oregon, Barton et al. reported the results of their observations from the Whiskey Creek Hatchery on Netarts Bay in the summer of 2009 (Barton et al. 2012). Unlike previous laboratory experiments, this study analyzed calcifying organism responses in the ambient-water CO_2 chemistry of Oregon's coastal waters. Larval production and mid-stage growth (~120 um to ~150 um) of the oyster, *Crassostrea gigas*, were both significantly negatively correlated with the chemistry of waters in which larval oysters were spawned and reared for the first 48 hours of life. Although the impact of the exposure was not immediate, the delayed reaction caused a significant decline in growth for mid-sized oyster larvae and reduced overall production. The findings corroborate other laboratory studies that show that many marine species, especially at the larval stage, are adversely affected by ocean acidification.

Scientific studies have demonstrated that even modest pH declines affect the sensitive and vulnerable early developmental stages of organisms because these life histories have specific environmental needs (Kurihara 2008) (*see* Figure 10, below, showing negative effects from low pH treatments). A number of studies have found a delay in development or less development, degraded shells, decreased rate of metamorphosis, shell thickness, and loss of hinge integrity (Ross et al. 2011a). The resulting reduced larval size can reduce the feeding efficiency of larvae, and smaller larvae are more susceptible to starvation because they encounter comparatively less food (Kurihara & Shirayama 2004). Sub-lethal effects of elevated acidity can severely alter the composition and fitness of larvae, and given the high mortality rates of larvae in the water column and during the transition to benthic settler, small perturbations to larvae potentially may have large alterations to settlement dynamics, post-settlement mortality, recruitment, and ultimately adult populations (Ross et al. 2011).

Watson et al. (2009) exposed one day-old oyster larvae to a range of pH conditions, from 7.6 to 8.1, for 10 days and showed significant decline in the survival and growth of young larvae at lower pH. Waldbusser et al. (2010), in a study on the Chesapeake Bay, showed that even modest changes in pH present conditions that are corrosive to shells and have physiological impacts on adult and larval oysters. Biocalcification declined significantly with a reduction of 0.2 pH units, making juvenile bivalves more susceptible to predation and other mortality factors (*Id.*).

Negative effects have been seen on the metamorphosis, size, and survival of larval hard clams (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), and Eastern oysters (*Crassostrea virginica*) at levels of CO_2 predicted to occur in the 21st century (Talmage & Gobler 2011). At 650 ppm, or an approximate drop of 0.3-0.4 from pre-industrial values, both *M. mercenaria* and *A. irrandians* larvae exhibited dramatic declines (over 50%) in survivorship as well as significantly delayed matamorphosis and significantly smaller size. *C. virginica* also experienced lowered growth and delayed metamorphosis at this level, an indicator that current and future increases in CO_2 populations may deplete or alter the composition of shellfish populations in coastal ecosystems (*Id.*).

The Olympia oyster, *Ostrea lurida*, a foundation species in estuaries along the Pacific coast, exhibits clear decline in larval growth and settlement as levels of CO_2 affect seawater pH. (Hettinger et al. 2012). Oysters in this experiment were raised at three levels of seawater pH, including a control (8.0) and two additional levels (7.9 and 7.8). Larvae reared under pH 7.8 exhibited a 15% decrease in larval shell growth rate, and a 7% decrease in shell area at settlement, compared to larvae reared under control conditions. Impacts were even more pronounced a week after settlement, with juveniles that had been reared as larvae under reduced pH exhibiting a 41% decrease in shell growth rate.

Oysters on the Atlantic coast also experience the ill effects of ocean acidification. Dickinson et al. (2012) found negative effects on juvenile eastern oysters after exposure to water with a 0.2 pH change. Exposure of the oysters to elevated acidity led to a significant increase in mortality, reduction of tissue energy stores and negative soft tissue growth, indicating energy deficiency. Under ocean acidification conditions, thermal tolerance is impaired in oyster larvae, leading to reduced development, size and increased abnormality (Ross et al. 2011; Parker et al. 2010). Similar results have been found in red abalone, with thermal tolerance impaired at pH 7.87 compared to control (pH 8.05) (Zippay and Hoffman 2010).

In studies with edible mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) researchers found a strong decline of calcification under ocean acidification conditions (Gazeau et al. 2007). Based upon these results, researchers concluded that mussel and oyster calcification may decrease by 25% and 10%, respectively, by the end of the century." (*Id.*). Oysters and mussels also exhibit development abnormalities when exposed to acidification (Kurihara 2008). When oyster eggs were reared under pH 7.8, they showed malformations of their shell, and when reared under pH 7.4, more than 70% of the larvae were either completely non-shelled, or only partially shelled, and only 4% of CO_2 treated embryos developed into normal larvae by 48 hours after fertilization, in contrast to about 70% successful development in control embryos.

The shrimp *Palaemon pacificus* displayed variable responses at different developmental stages, pH and length of exposure (Kurihara 2008). Following long term (30 weeks) exposure of adults to pH 7.89 and 7.64, survival and egg production in early developmental stages decreased in both treatments. Findlay et al. (2010) found a slower rate of development of embryos in the common intertidal northern hemisphere barnacle *Semibalanus balanoides* with an estimated 19 days delay in reaching 50% hatching stage at pH 7.7. Other amphipods have exhibited metabolic changes in response to acidification levels greater than what is allowed under the federal criterion (Hauton et al. 2009).

Echinoderms exhibit delayed and asymmetrical development when exposed to acidified conditions. In the absence of adequate adaptation or acclimation, lowered pH levels will have a range of sub-lethal effects on sea urchins, brittlestar and seastar larvae from a range of geographical regions (Ross et al. 2011). Larvae of the ecological keystone brittlestar, *Ophiothrix fragilis*, either were abnormal, had altered skeletal proportions, or asymmetry during skeletogenesis, and there was a delay in development at pH levels of 7.9, or approximately 0.3 units below current surface levels (Gutowska et al. 2009). Other experiments on brittlestar in low pH waters resulted in dramatic results; acidification of 0.2 units induced 100% larval mortality within an eight day period. Control larvae showed 70% survival over the same period. Because the calcite skeleton of the larval brittlestar aids key functions such as feeding and vertical migration, and defense against predators, abnormal development of the skeleton will have drastic consequences for fitness. The developmental abnormalities may be exacerbated by temperature increases predicted for the end of the century; some scientists suggest that this may result in the disappearance of echinoderms from the surface oceans within the next 50-100 years (Ross et al. 2011a).

Reproductive success is compromised by ocean acidification. The fertilization rate of sea urchins decreases with increasing CO_2 concentrations (8.1 to 6.8 pH) (Kurihara 2008). In another sea urchin experiment utilizing six CO_2 concentrations, with a pH between 8.01 (control) and 6.83, cleavage rate, developmental speed, and larval morphology all declined with increased CO_2 concentration (Kurihara & Shirayama 2004). At a 0.2 change from control, effects could be seen on the morphology and development of the larvae, and these effects became more pronounced with greater pH changes (*Id.*) (*see* Figure 4, below). The authors concluded that "all the effects of raised CO_2 concentration observed in this study would have a negative impact on the survival of sea urchin embryos in their early life history." A recent study showed that sea urchin sperm flagellar motility was significantly reduced when seawater pH decreased by .3 units, from 8.0 to 7.7 (Suwa et al. 2010). As discussed above, decreased flagellar motility has severe consequences for fertilization and subsequent population dynamics; if sperm lose their ability to find eggs, the population size will necessarily diminish.

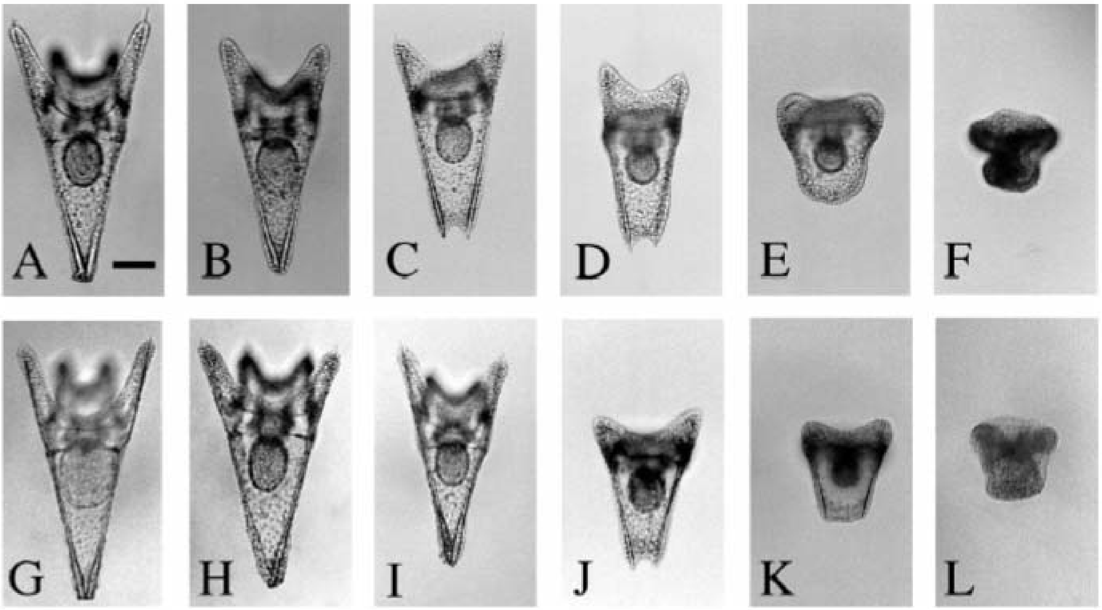

Fig. 6. *Hemicentrotus pulcherrimus.* Morphology of 4-armed pluteus larvae cultured for 3 d in (A–F) CO_2-seawater and (G–L) HCl-seawater. (A & G) control (pH 8.0); (B & H) +500 ppm (pH 7.8); (C & I) +1000 ppm (pH 7.6); (D & J) +2000 ppm (pH 7.4); (E & K) +5000 ppm (pH 7.0); (F & L) +10000 ppm (pH 6.8). Scale bar = 50 µm

Figure 4. Declining development of sea urchin larvae exposed to acidified waters (Kurihara & Shirayama 2004).

Even moderate increases in atmospheric CO_2 and ensuing acidification adversely affect the growth of both gastropods and sea urchins (Shirayama & Thornton 2005). Before the end of this century, atmospheric CO_2 is likely to increase by more than 200 ppm, decreasing the pH of the ocean by approximately 0.3 units from pre-industrial levels. Two species of sea urchin as well as the gastropod *Strombus luhanus* were exposed for six months to waters with this level of elevated CO_2, and all three species exhibited similar consequences. Increased CO_2 negatively affected growth rate, calcification, shell height and body mass, and metabolic activity

(Shirayama & Thornton 2005). The developing embryos of the gastropod and intertidal snail *Littorina obtusata* also demonstrate slower overall development time, altered embryonic movement, and modification of shell shape in hatchlings while exposed to acidified waters (pH 7.6) (Ellis et al. 2009).

Arnold et al. (2009) investigated the effect of ocean acidification on lobsters and found that indirect disruption of calcification and carapace mass may adversely affect the competitive fitness and recruitment success of larval lobsters with serious consequences for population dynamics and marine ecosystem function

Reduced metabolism is expected to impair predator-prey interactions, as well as have consequences for growth, reproduction, and survival. Metabolic suppression has previously been reported to occur in a variety of adult marine invertebrates, including crabs, squid, worms, bivalves, pteropods and amphipods (Albright 2011). Slowed metabolism is generally achieved by halting energy-expensive processes, such as protein synthesis, and therefore may lead to reductions in growth and reproductive potential (*Id.*). The blue mussel *Mytilus edulis* has strong physiological mechanisms by which it is able to protect body tissues against short-term exposure to acidified seawater, but these come at an energetic cost, and will result in reduced growth during long term exposures (Bibby et al. 2008). Consequently, the predicted long-term changes to sea water are likely to have a significant effect on the health and survival of blue mussel populations (*Id.*). Mussel beds are a dominant coastal habitat and provide food and structure for a diverse array of species in an otherwise physically stressful environment; any decline in their population structure will lead to a reduction in appropriate habitat for a myriad of other species.

In summary, acidified waters impact the development, growth, and reproductive success of a suite of echinoderms, crustaceans, and molluscs. A growing body of information is becoming available on the effecting of declining pH on these organisms and their ecosystems. The results of these studies are clear; as pH falls even 0.2 units from pre-industrial values, these organisms will struggle to survive in their increasingly acidic environment.

ii. Corals

Coral reef ecosystems, which are estimated to harbor one-third of marine species and which support the livelihoods of a half billion people, are particularly threatened by ocean acidification. Some corals are already experiencing reduced calcification (De'ath et al. 2009; Cooper et al. 2008; Bates et al. 2010; Gledhill et al. 2008). Due to the ocean acidification and warming, reefs are projected to experience "rapid and terminal" declines worldwide at atmospheric CO_2 concentrations of 450 ppm (Veron et al. 2009; Bijma et al. 2013). Prominent coral scientists have called for reducing atmospheric CO_2 to less than 350 ppm to protect coral reefs from collapse (Veron et al. 2009, Frieler et al. 2012). Coral reefs cannot exist below 7.8 pH units (Fabricius et al. 2011), and the threshold for coral growth is 3.3 Ω_{ar} (Meissner et al. 2012).

Ricke et al. (2013) analyzed aragonite saturation state (Ω_{ar}) surrounding reefs in CMIP5 simulations under several representative concentration pathway (RCP) scenarios (Ricke et al. 2013). The study found that in preindustrial times, 99.9% of reefs adjacent to open ocean in the CMIP5 ensemble were located in regions with $\Omega a > 3.5$. Accordingly, the study used $\Omega a = 3.5$ as an upper bound viability threshold for corals, while also examining thresholds of $\Omega a = 3.25$ and 3. Under a business-as-usual scenario (RCP 8.5), every coral reef considered was projected to be surrounded by water with $\Omega_{ar} < 3$ by the end of the 21st century and the reefs' long-term fate was independent of their specific saturation threshold. Under scenarios with significant CO_2 emissions abatement, the Ω_{ar} threshold for reefs was critical to projecting their fate. The study concluded that the "results indicate that to maintain a majority of reefs surrounded by waters with $\Omega_{ar} > 3:5$ to the end of the century, very aggressive reductions in emissions are required."

Corals are among the ecosystems most threatened by ocean acidification. To date, most scientific investigations into the effects of ocean acidification on coral reefs have been related to the reefs' unique ability to produce voluminous amounts of calcium carbonate (Kleypas & Yates 2009). The persistence of carbonate structures on coral reefs is essential in providing habitats for a large number of species and maintaining the extraordinary biodiversity associated with these ecosystems. As a consequence of ocean acidification, the ability of marine calcifiers to produce calcium carbonate will decrease, resulting in a transition from a condition of net accretion to one of net erosion, with drastic consequences for the role and function of these ecosystems (Kleypas & Yates 2009).

Coral reefs are predicted to drastically lower their calcification rates in the near future, and historical records show that calcification rates have already fallen relative to pre-industrial values. According to scientists, the main reef building organisms will calcify up to 50% less relative to pre-industrial rates by the middle of this century (*Id.*). A drop of approximately 60% coral reef calcification is projected for the end of the century, when pH is predicted to fall 0.5 units below pre-industrial values (Caldeira & Archer 2007). Many studies suggest calcification rates could be reduced between 20-60% at 560ppm, or 7.9 pH, and that a reduction of this magnitude would fundamentally alter reef structure and function (Convention on Biological Diversity 2009). According to the model of Silverman et al. (2009), developed from field observations from more than 9,000 reef locations, all coral reefs are expected to reduce calcification by more than 80% relative to their pre-industrial rate at 560 ppm (0.3 pH change), and at this point "all coral reefs will cease to grow and start to dissolve." The Interacademy Panel on International Issues concurs; "at current emission rates models suggest that all coral reefs and polar ecosystems will be severely affected by 2050 or potentially even earlier."

In a meta-analysis on coral calcification responses to ocean acidification, the coral calcification declined by a mean of 15% per unit decrease in aragonite saturation state ($2 < \Omega < 4$) (Chan and Connolly 2013). On current emission trends, calcification will decline 22% on average for corals by the end of the century (*Id.*). This falls to the lower range of responses that have been predicted by ocean acidification researchers and described above, which the authors believe reflects variation in the calcification responses of different corals.

Calcification rates at coral reef locations in the western tropical Pacific and the Caribbean may have already declined by 15%, (Caldeira & Archer 2007), and data from the Great Barrier Reef indicates a 14% decline in calcification rates between 1990 and 2005 (De'ath et al. 2009). Other studies in the Great Barrier reef indicate a decline of approximately 21%, and analysis of coral growth records confirm that this decline is unprecedented in recent centuries (Cooper et al. 2008). A model based on field samples shows that calcification of coral reefs in French

Polynesia declined 15% between the pre-industrial period and 1992, and that rates will decline 40% by 2050, when CO_2 levels reach 560 ppm (pH 7.9) (Anthony et al. 2011). Near Bermuda, historical records show that coral skeletal density has decreased 33%, and coral calcification rates have declined by 52% as a result of changes in seawater carbonate chemistry (Bates et al. 2010). These observed changes have occurred even before a 0.2 unit decline in ocean pH; as atmospheric CO_2 continues to rise and lower pH values, calcification rates will maintain their precipitous decline.

Ocean acidification acts in concert with ocean warming and coral bleaching in furthering coral reef decline (Anlauf et al. 2011) (observing a 3% reduction in acidification with a 0.2 decline in pH, and a 30% decline when acidification is coupled with 1° C warming). While natural variability in the annual cycle and interannual variability may account for some of the observed change in coral growth rates, scientists are "virtually certain" that anthropogenic trends already exceed natural variability (Friedrich et al. 2012). Studies projecting the combined impacts of ocean acidification and ocean warming on corals predict that coral erosion will exceed calcification rates at atmospheric CO_2 concentrations of 450 to 500 ppm, (Hoegh-Guldberg et al. 2007), and all coral reefs will begin dissolve at CO_2 concentrations of 560 ppm (Silverman et al. 2009). These figures correspond to a 0.2 and 0.3 unit drop in pH, respectively, as compared to pre-industrial values. Van Hooidonk et al. (2014) presented updated global projections for threats to coral reefs from ocean warming and ocean acidification based on ensembles of IPCC AR5 climate models using the Representative Concentration Pathways (RCPs). For all tropical reef locations, the study projected absolute and percentage changes in aragonite saturation state (Ω_{ar}) for the period between 2006 and the onset of annual severe bleaching.

In the Caribbean, a recent study concluded that "coral reef communities are likely to be essentially gone from substantial parts of the Southeast Caribbean by the year 2035" (Buddemeier et al. 2011). The Great Barrier Reef has lost 50% of its coral cover since 1985 as a result of the combined effects of ocean acidification, global warming, coral bleaching, coral predation by starfish, and cyclone damage (De'ath et al. 2012). In short, due to the synergistic impacts of ocean acidification, mass bleaching, and local impacts, coral reefs are projected to experience "rapid and terminal" declines worldwide at atmospheric CO_2 concentrations 450 ppm, or pH 8.0, a level that is expected before mid-century (Veron et al. 2009).

Many experimental studies show declining calcification rates and other ill effects when corals are exposed to acidified waters. Decreases in calcification rates across a suite of benthic species and calcifying systems range from 3 to 60% for a doubling in pCO_2, which corresponds to a 0.3 reduction in pH (Abbasi & Abbasi 2011). The average response of corals is a 30% decline in calcification in response to a doubling in pCO_2 (*Id.*). In a study of an assemblage of corals exposed to conditions designed to mimic the change that may be experienced in the next 50-100 years (pH decline of 0.22 to 0.28 units), calcification rates declined between 44% and 80%.

The coral *Acropora palmata* (listed as threatened under the Endangered Species Act), once the dominant reef building coral in the Caribbean, experiences impaired fertilization, settlement, and growth with increasing pCO_2 (Albright et al. 2010). The cumulative impact of ocean acidification on fertilization and settlement success is an estimated 52% and 73% reduction in the number of larval settlers on the reef under pCO_2 conditions projected for the middle and end of this century, respectively (0.2 and 0.5 decline in pH) (*Id.*). After only 8 days of high CO_2 conditions (pH 7.75), *Acropora* experiences a statistically significant (18%) reduction in calcification rate (Murubini et al. 2003). Furthermore, there 22 coral species listed as threatened under the Endangered Species Act primarily because of threats from ocean warming, acidification and disease. The rule proposing listing for the corals found that ocean acidification was one of the highest priority threats for corals:

> Ocean acidification has the potential to cause substantial reduction in coral calcification and reef cementation. Further, ocean acidification adversely affects adult growth rates and fecundity, fertilization, pelagic planula settlement, polyp development, and juvenile growth.

77 Fed. Reg. at 73230 (Dec. 7, 2012). In other words, ocean acidification is driving the extinction of corals and the destruction of coral reef ecosystems.

Experimental studies evaluating the effects of ocean acidification on early life history stages of corals generally conclude that primary polyp growth is hindered by increasing acidity (Albright et al. 2010, Cohen & Holcomb 2009). Renegar and Riegl (2005) showed a significant decrease in the growth rate of *Acropora cervicornis* larvae at pH levels 0.3-0.5 units below control. Larvae of the common Atlantic golf ball coral, *Favia fragum*, shows significant delays in both the initiation of calcification and subsequent growth of the primary corallite in acidic waters (8.17 – 7.54 pH) (Cohen & Holcomb 2009). Visible changes in the skeletal development were observed in all non-control treatments, and in the most acidic waters skeletal development was 75% less than the control.

Acidification also affects cold water corals. Cold water corals have a worldwide but patchy distribution, and are often found in areas with highly productive fisheries (De Mol et al. 2002; Kenyon et al. 2003). Overall, more than two-thirds of all known coral species are cold water corals (Roberts & Hirshfield 2012; Cairns 2007). Recent exploration and research that has begun to search for, map, and observe cold water corals has found that these organisms are fragile, long-lived, slow-growing, very sensitive to physical or environmental disturbance and adapted for a specific environmental niche (McDonough & Puglise 2003). Alaskan waters are already showing widespread evidence of ocean acidification as a result of greenhouse gas emissions (Mathis et al. 2011a). By 2100, 70% of cold-water corals will be exposed to corrosive waters (Convention on Biological Diversity 2009). Conditions in waters typically inhabited by cold-water corals are even less favorable for calcification than those experienced by warm water corals; this may cause cold-water corals to be affected earlier and more strongly by CO_2-related ocean acidification than their warm water counterparts (Abbasi & Abbasi 2011).

The vulnerable early developmental and reproductive stages of cold water corals may be especially strongly impacted (Kurihara 2008; Dupont & Thorndyke 2009; Kroeker et al. 2010). In an experiment on the cold-water coral *Lophelia pertusa*, lowering the pH by 0.3 units relative to the ambient level resulted in calcification being reduced by 56% (Maier et al. 2009). Lower pH reduced calcification more in fast growing, young polyps (59% reduction) than in older polyps (40% reduction). Thus, corals' larvae and young corals are significantly more susceptible to ocean acidification than adults, and will likely show a higher degree of reduced calcification and growth with reduced pH, making young and larval corals less likely to survive to maturity as the ocean continues to absorb anthropogenic CO_2 and as climate change progresses.

In addition to reduced calcification rates, the strength of cementation may also be reduced in waters with a lower pH, promoting higher rates of physical and bio-erosion (Manzello et al. 2008). Once coral reefs experience lowered calcification and poor cementation, erosion and reef flattening can result, which severely reduced the structural heterogeneity of reefs and lowers its potential to support biodiversity. An important new study of reef bioerosion determined that the combined effects of lower calcification with increased bioerosion can significantly degrade coral reefs (Wissshak et al. 2012). In the study, a common bioeroding sponge in the Great Barrier Reef was observed on massive Porites. The sponge was more effective at bioerosion of the corals at high CO_2, ranging from 17% increase from present day levels to 61% increase at the highest CO_2 treatment. The researchers describe the important role of balancing the antagonistic processes of calcification and bioerosion in a reef for a healthy coral ecosystem, and predict detrimental consequences under ocean acidification as calcification declines and bioerosion increases.

Bioerosion may result in a loss of change in fish assemblages, lower densities of commercially important species, and lower rates of larval fish recruitment (Feary et al. 2007). Weaker reef calcification and cementation also increases the potential for reef damage as storm frequency and intensity increases with continued global warning, leading to further reef degradation (*Id.*). In a study looking at the impacts of storm damage and ocean acidification, researchers concluded that table coral populations are vulnerable to collapse (Madin et al. 2012). In the Indo-Pacific, table corals provide an important role in the reef ecosystem by creating reef structure and sheltering other reef species. They are also particularly vulnerable to ocean acidification, thermal stress, bleaching, disease and stress from storm waves. The table corals will become more vulnerable to storm waves as ocean acidification reduces calcification and increases bioerosion, therefore weakening their cementation and structure. Madin et al. (2012) found that a coral colony was four times more likely to be dislodged by a storm wave by the end of the century ocean acidification levels. Because of this vulnerability, the results showed that table corals are prone to large and rapid declines in coral cover.

Numerous biological responses independent of calcification are also negatively impacted by ocean acidification. Corals in acidifying waters are likely to be in a nutritionally or energetically stressed state and thus less likely to initiate reproduction, or successfully reproduce, due to negative impacts of ocean acidification on all stages of the reproductive cycle (Maier et al. 2009; McCulloch et al. 2012). Sperm flagellar motility also declines in response to decreasing pH. If sperm lose their ability to find eggs in the vast extent of the sea, the life of marine organisms is potentially limited. Sperm flagellar motility, which is indispensable for fertilization, is regulated by an elevation of intracellular sperm pH (Morita et al. 2010). While 69% of *Acropora* sperm were motile at pH 8.0, 46% were motile at pH 7.8, and fewer than 20% at pH 7.7 (*Id.*). Additionally, the physiological costs associated with reproduction are more likely to result in the demise of the organism due to the compounding stressors from ocean acidification and climate change (Wood et al. 2008, Cohen & Holcomb 2009). Significant reductions in metabolism have been observed for coral larvae following exposure to waters with a 0.2 decline in pH, levels projected to occur by the middle of this century (Albright & Langdon 2011).

Albright et al. (2010) concluded that with increased CO_2 concentrations to those projected to occur in this century (560 atm to 800 atm, or a 0.3 to 0.5 decline in pH from pre-industrial values), the fertilization success of the tropical reef-building coral *Acropora palmata* decreased by 12-13%, settlement success reduced 45-69%, and linear extension was significantly reduced. The compounding effect of these impacts translated to 52-73% reduction in the number of larval settlers on the reef. Albright et al. (2010) predicted that the net impact on recruitment would actually be greater than that given that the depressed post-settlement growth is likely to result in elevated rates of post-settlement mortality. This corroborates other studies showing negative impacts on early-stage tropical corals.

Albright and Langdon (2011) tested the effects of ocean acidification on sexual recruitment of tropical corals. Larval metabolism was depressed by 27% at acidification levels expected by mid-century (0.3 pH reduction) and 63% at end-of-century acidification levels (0.4-0.5 pH reduction). Settlement was also reduced 42-45% and 55-60% at the mid and end-of-century levels respectively, relative to controls (Albright & Langdon 2011). Another study of larvae of tropical corals showed that short-term or long term exposure of larvae to ocean acidification decreased their metamorphosis (Suwa et al. 2010). This means that even when larval survivorship is unchanged, the success of recruiting new corals could be inhibited by ocean acidification (*Id.*).

Additionally, under conditions of acidification planktonic larvae lose their preference for settlement on the optimal crustose coralline algae communities (Doropoulos et al. 2012). Crustose coralline algae in turn, will experience a lower recruitment rate as marine waters become more acidic. Crustose coralline algae, a red calcifying algae, is of key importance in coral reef ecosystems, stabilizing reef structures and providing an important food source for benthic organisms (Convention on Biological Diversity 2009). Crustose coralline algae form a major calcifying component of the marine benthos from polar to tropical regions and are considered to influence the settlement of coral recruits. With a mean pH change of 0.26 between control and treatment, Kuffner et al. (2007) found that crustose coralline algae growth rates declined by 40%, and recruitment rate and percentage cover decreased by 78% and 92%, respectively.

In sum, reproduction is critical to maintaining a healthy coral reef population, and the long-term impacts of ocean acidification on reproduction, especially on larval settlement and growth, may significantly reduce the corals' ability to recover or maintain a population in the face of human caused disturbances and anthropogenic CO_2 emissions. This would result in a lack of reproductive capacity, genetic bottlenecks, and population collapse (Dupont et al. 2010; Ross et al. 2011).

As the world's oceans become more acidic and less saturated with carbonate minerals, corals are expected to build weaker skeletons and experience slower growth rates, which will make it more difficult for corals to retain competitive advantage over other marine organisms (Guinotte et al. 2006). As coral skeletons weaken, they will become increasingly at risk of storm damage and bioerosion, which will reduce the structural complexity of the reef system, reducing habitat quality and diversity alongside the loss of coastal protection functions (Hoegh-Guldberg et al. 2007). At greater than 550 ppm, coral reef ecosystems will be reduced to "crumbling frameworks." (*Id.*). Extensive studies have demonstrated that small changes in ocean chemistry will cause a suite of negative impacts, from reduced calcification rates to lowered reproductive success.

iii. Plankton

Plankton, which comprise the basis of the marine food web, are among the calcifying organisms adversely affected by ocean acidification. Changes to calcifying zooplankton, such as pteropods and foraminfera, have the potential to affect the ecological and tropic dynamics which govern the exchange of energy and cycling of nutrients throughout the marine food web (Gattuso & Hansson 2011). For example, the shelled pteropod, *Limacina helicina*, an Arctic pelagic mollusc, is a food source for higher predators such as fishes, whales and birds that are particularly important in high latitude areas. *L. helicina* makes up about 60 percent of the pink salmon diet (Comeau et al. 2012). A decline of pteropod population would likely cause dramatic changes to various pelagic ecosystems, and impact the commercially important salmon fishery; a 10% decrease in pteropods can lead to a 20% reduction in pink salmon body weight (Aydin 2005).

Pteropods form integral components of food webs, and are considered an overall indicator of ecosystem health (Orr et al. 2005). Studies have shown that pteropods exposed to a pH value predicted for the end of this century exhibited a 28% decrease in calcification (Comeau et al. 2009). Experiments on *L. helicina* showed that changes from 8.05 pH to 7.89 pH (Δ -0.16 units) cased shell dissolution and cracks appeared at 7.76pH, and linear extension of the shell decreased as a function of declining pH (Comeau et al. 2012). Samples show dissolution already happening in areas that have low aragonite saturation states. A sampling study off the coasts of California, Oregon, and Washington showed average to severe dissolution of *L. helicina* for 53% of onshore individuals and 24% of offshore individuals (Bednarsek 2014). A sampling study in 2008 of the Southern Ocean found severe dissolution of *L. helicina* in Ω_{ara} 1.0 (Bednarsek 2012). Another study found shell weights of one form of Antarctic species declined 35% from 1997-2006 (Roberts unpublished).

Ample studies corroborate that high CO_2 waters dissolve the shells of *L. helicina* and reduce calcification rates. Comeau et al. (2010) noted decreased calcification for *L. helicina* with decrease in aragonite saturation. Lishka (2012) looked at overwintering *L. helicina* and L. retroversa in the Arctic and noted that they do not calcify in the winter, and they are subject to dissolution under high CO_2 conditions. Bednarsek (2012) looked at *L. helicina* and *Clio pyramidata* from the Southern Ocean under different aragonite saturation states and recorded dissolution stages.

Modeling by Comeau et al. (2012) shows that by the end of the century *Limacina helicina* will not be able to calcify over much of the Arctic because of aragonite undersaturation—prediction may be conservative because it did not account for shell dissolution. Commentary suggests that as waters warm these pteropods will be trapped in acidified conditions and will "disappear entirely by the end of the century." Modeling suggests that waters in the California Current will be undersaturated year-round by 2050 (Gruber 2012). Modeling of the Arctic suggests that by mid-century the Bering Sea will be persistently undersaturated with respect to aragonite (Mathis 2011). An analysis of survey measurements in 2005-2006 and 1991-1992 demonstrated a shoaling of the aragonite saturation state in waters off Alaska (Feely et al. 2012). In the North Pacific the aragonite saturation state shoaled to depths less than 200 m between 40˚N and 50˚N (*Id.*). On average, the calcite saturation horizon in the Pacific shoaled about 1 m/yr from 1991 to 2006 (*Id.*).

Other species of plankton are also harmed by CO_2. Another pteropod, *Clio pyramidata,* kept in aragonite undersaturated waters began to dissolve within two days (Orr et al. 2005). Some coccolithophorids are also susceptible to ocean acidification. Studies showed that CO_2 related changes to seawater caused reduced calcification, resulting in malformed and incomplete shells. Calcification of cocolithophorids declined 15-44%, and their shells were malformed as pH changed up to about 0.3 units (Riebesell et al. 2000). Coccolithophorids are globally distributed and bloom in massive areas affecting the optical properties of the ocean, reflecting light from the earth, and play a major role in the ocean carbon cycle. Elevated CO_2 concentrations also reduce the shell mass of foraminifera (Kleypas et al. 2006). Modern shell weights of foraminifera in the Southern Ocean are 30–35% lower than those from preindustrial sediments, which is consistent with reduced calcification induced by ocean acidification (Moy et al. 2009).

iv. Cephlopods and Fish

The negative physiological effects of ocean acidification are not confined to invertebrates. For example, the gametes, embryos, and larvae of vertebrates such as fish are vulnerable to changes in ocean chemistry and have shown impairments in their homing and predator/prey detection capabilities.

Changes in the ocean's CO_2 concentration result in accumulation of CO_2 in the tissues and fluids of fish and other marine animals, called hypercapnia, and increased acidity in the body fluids, called acidosis. These impacts can cause a variety of problems for marine animals, including difficulties with acid-base regulation, calcification, growth, respiration, energy turnover, predation response, and mode of metabolism (Pörtner et al. 2005; Pörtner et al. 2004). Studies have shown adverse impacts in squid and fish, among other animals (Rosa & Seibel 2008; Ishimatsu et al. 2004; Pörtner et al. 2004). For example, when exposed to acidification, orange clownfish suffer a type of brain malfunction that interferes with their homing abilities and makes them 5-9 times more likely to swim toward a predator (Munday et al. 2009; Simpson et al. 2011; Ferrari et al. 2011).

Laboratory experiments have shown that ocean acidification at levels expected to occur within this century impairs larval orange clownfish and damselfish sensory abilities and behavior, making it more difficult for them to locate suitable settlement sites on reef habitat and avoid predators. Specifically, ocean acidification disrupts smell, hearing, and behavior of larval orange clownfish, (Munday et al. 2009; Nilsson et al. 2012), making larval clownfish attracted to odors from predators and unfavorable habitat (Munday et al. 2010; Dickson et al. 2010). Olfactory cues that prompted avoidance or neutral behavior in controls (pH 8.15) stimulated strong preference behavior in larvae raised at pH 7.8, in addition to significant reduction in response to usually positive preferences. Ocean acidification also impairs the hearing capacity of larval clownfish, which is predicted to have negative effects on settlement success and survival (Simpson et al. 2011).

Similarly, research on six damselfish species found that ocean acidification impairs larval damselfish smell, vision, learning, behavior, and brain function, leading to higher risk of mortality. For example, in acidified waters, larval damselfish (1) become attracted to predator odors and display much riskier behaviors, making them more prone to predation; two species suffered a five-fold to nine-fold increase in predation rate at CO_2 levels of 700 to 850 ppm, or 0.3 pH units below control (Munday et al. 2009; Ferrari et al. 2011); (2) cannot discriminate between habitat olfactory cues, making it more difficult to locate appropriate settlement habitat (Devine et al. 2011); (3) settle on the reef during dangerous times—the full moon rather than new moon—when they are more vulnerable to predation (Devine et al. 2011); (4) fail to visually recognize or evade important predator species; (5) cannot learn to respond appropriately to a common predator by watching other fish react or by smelling injured fish, unlike fish under normal conditions (*Id.*); and (6) suffer disruption of an important neurotransmitter which is thought to result in the sensory and behavioral impairment observed in acidified conditions (Nilsson et al. 2012).

An animal's ability to transport oxygen is reduced by pH changes (Pörtner 2005). Water breathing animals have a limited capacity to compensate for changes in the acidity (Haugan 2006). For example, fish that take up oxygen and respire CO_2 through their gills are vulnerable because decreased pH can affect the respiratory gas exchange (Royal Society 2005). Changes in metabolic rate are caused by the changes in pH, carbonates, and CO_2 in marine animals (Haugan 2006).

Squid, for example, show a very high sensitivity to pH because of their energy intensive manner of swimming (Royal Society 2005). Because of their energy demand, even under a moderate 0.15 pH change squid have reduced capacity to carry oxygen and higher CO_2 pressures are likely to be lethal (Pörtner 2004). Even species more tolerant to pH changes experience decreased metabolism from increased CO_2 in the water (Pörtner 2004). For example, as much as 50% mortality was observed in copepods after only six days of exposure to waters with a pH level 0.2 units below the control (Pörtner 2005). Reducing pH by 0.3 pH cased a 31% decline in metabolic rate and a 45% decrease in activity level for the jumbo squid, an important predator in the Easter Pacific (Rosa & Seibel 2008).

In fish, pH also affects circulation. Fishexposed to high concentrations of CO_2 in seawater experience cardiac failure and increased mortality (Ishimatsu 2004). At lower concentrations sublethal effects can be expected that can seriously compromise the fitness of fish. Juvenile and larval stages of fish were found to be even more vulnerable (Ishimatsu 2004).

In sum, ocean acidification can have many adverse effects on marine animals that can reduce their fitness and survival (Royal Society 2005). Many marine animals have low thresholds for long-term CO_2 exposure (Pörtner 2005).

c. Other Environmental Impacts of Ocean Acidification

i. Increased Toxicity of Harmful Algal Blooms and Sediments

Ocean acidification may already be increasing the toxicity of harmful algal blooms known as "red tides." These toxic red tides poison shellfish, marine mammals, fish, and even cause paralytic shellfish poisoning in people. High CO_2 levels in seawater magnify the toxins of harmful algae. (Fu et al. 2012; Avery O Tatters et al. 2013; Tatters et al. 2012; Avery O. Tatters et al. 2013). Studies of the genus *Pseudo-nitzscia* show that the toxicity of diatoms which produce a neurotoxin increases significantly under ocean acidification conditions. A -0.5pH change caused toxin production in the diatoms to increase 4.2-fold and a -0.3pH unit change increased the toxicity 2.5-fold (Tatters et al. 2012). Many studies on the effects of ocean acidification and algal blooms have been conducted at CO_2 levels that are already occurring in California, and the increase in the toxicity of harmful algal blooms in Southern California (and resulting mass mortalities of fish and marine mammals) may be due, in part, to acidified waters (*Id.*) However, these studies suggest that the damage will become much worse.

Additionally, research shows that under conditions of ocean acidification sediments become more toxic (Roberts, Birchenough et al. 2013). Ocean acidification makes sediment-bound metals more available and thus more toxic for aquatic life (*Id.*) For example, ocean acidification increases the toxicity of copper (Campbell & Mangan 2014).

ii. Noise Pollution Increases in Low pH Waters

Ocean acidification can also decrease the sound absorption of seawater, causing sounds to travel further with potential impacts on marine mammals and other marine life sensitive to the sounds of vessel traffic, seismic surveys, and other noise pollution (Hester et al. 2008). Sound travels 10-15 percent further with a change of 0.1 pH, and it is predicted to increase about 40 percent by mid-century (Hester et al. 2008). Additionally, a decline of 0.3 pH units causes a 40 percent decrease in the sound absorption of surface seawater and sound may travel 70 percent farther, further affecting sensitive marine mammals (Brewer et al. 2009).

d. Ocean Acidification's Ecosystem Impacts

While the full implications of elevated CO_2 on marine ecosystems are not well-documented, there is high confidence that there will be negative ecosystem consequences from ocean acidification. The exact changes are difficult to predict, but some of the anticipated impacts include loss of diversity, loss of abundance of calcifying species, shifting prey and predator interactions, and loss of suitable habitat.

New mesocosm studies have sought to understand some of the potential ecosystem impacts of CO_2. Studies of biodiversity near underwater volcanic vents demonstrate reduced richness in high-CO_2 waters. For example, coral species diversity declined by about 39% between low and high-CO_2 sites, with the reefs shifting from complex communities to a coral reef dominated by massive Porites. Most importantly, the researchers found that coral reef development ceases at 7.7 pH, and they concluded that a pH decline below 7.8 would be "catastrophic for coral reefs" (Fabricius et al. 2011). Scientists also observed that in high-CO_2 waters the loss of complex coral reef habitat resulted in a loss of diversity of reef-associated species such as crustaceans and crinoids (Fabricius et al. 2014). Looking at the macroinvertebrates, the density declined 48% between control and high-CO_2 areas and taxa diversity declined by 77% (*Id.*).

Loss of species diversity associated with ocean acidification can also result from changes in competitive interactions. A study of a rocky reef near volcanic vents documented that macro algae outcompeted calcareous species in low-pH waters (Kroeker et al. 2012). The researchers explained that under the high-CO_2 conditions the calcifying species grew more slowly while the seaweed took hold and that grazing of seaweed was depressed (*Id.*). In another study, while the areas near volcanic vents lacked scleractinian corals and had low abundance of sea urchins and coralline algae, invasive algal species benefited from the acidified conditions (Hall-Spencer et al. 2008).

Research on the diversity the intertidal community in the Pacific Northwest documented a shift from a ecosystem dominated by calcifying animals to one with non-calcifying organisms as pH declined. Researchers documented declines in abundance and size of the California mussel, blue mussel, and goose barnacle in tidepools on the Olympic Coast in Washington (Wootton et al. 2008). They found that in years with low pH waters the calcifying animals were replaced by non-calcifying organisms (*Id.*).

The synergistic impacts of ocean acidification and warming are also potentially severe. Ocean acidification may induce a negative climate feedback that may increase temperature rise. Mesocosm studies found that ocean acidification may amplify global warming through decreasing biogenic production of the marine sulfur component dimethylsulphide which can impact cloud albedo (Six 2013). Ocean acidification therefore may also contribute to climate change impacts on the environment.

2. Risk Reduction Costs and Benefits

EPA must make a determination whether the risk of ocean acidification is unreasonable and this constitutes a balancing of costs and benefits. While it is EPA's burden to conduct this analysis, petitioners present some limited data on (1) the socio-economic costs of CO_2 pollution in light of ocean acidification, (2) the feasibility of controls on CO_2 pollution, and (3) the social cost of carbon including the costs of delaying action to reduce and mitigate CO_2 pollution.

a. Socioeconomic Costs of Ocean Acidification

The release of CO_2 into the environment is already having social and economic impact, and these impacts are predicted to become even more concerning. Primary economic concerns are from the loss of fisheries and coral reefs. Ocean acidification also poses food security and nutrition risks.

U.N. Convention on Biological Diversity estimated costs on the predicted damage of ocean acidification and predicts that the oceans will lose more than $1 trillion in value annually from ocean acidification (Convention on Biological Diversity 2014). CO_2 related ocean warming and acidification will threaten marine food resources by disrupting marine communities, promoting harmful algal blooms and the spread of some diseases, and increasing contaminants in fish and shellfish (Tirado et al. 2010).

The United Nations Environment Programme reported that ocean acidification's impact on marine organisms is a threat to food security (UNEP 2010). The report documents that ocean acidification is measurable and increasing, which poses a threat to fisheries resources and the billions of people that have a marine-based diet (United Nations Environment Programme 2010). Seafood has been shown to prevent hundreds of thousands of premature deaths, as well as significantly reduce infant morbidity; a decline of seafood availability will decrease these benefits. Some populations, including subsistence fishing populations and poor communities, depend on seafood and mortality and morbidity can result from the loss of these food sources (Mozaffarian 2006). For example, 95% of Alaskan households do some sort of subsistence fishing, and 17% of the state's population, 120,000 people, depend on subsistence fishing (Mathis et al. 2014). Many subsistence fishers also have cultural ties threatened by ocean acidification. Accordingly, CO_2 can result in social and environmental justice concerns that must also be assessed and weighed (Convention on Biological Diversity 2014).

Not only will ocean acidification affect global food webs and ecosystems, it will have a direct effect on the global economy. The U.S. economy is very dependent on the health of the ocean. In 2009, the ocean economy contributed over $223 billion annually to the U.S. gross domestic product and provided more than 2.6 million jobs (NOAA, http://oceanservice.noaa.gov/facts/oceaneconomy.html). Cooley and Doney (2009) estimate that if just a 10-25% decrease in United States mollusk harvests from 2007 were to occur today, $75-187 million in direct revenue would be lost each year henceforth, with a net loss of $1.7-10 billion through mid-century, when pH levels are approximately 0.3 units below pre-industrial values. In Washington State alone, the seafood industry generates $1.7 billion for gross state product and employs 42,000 people (Washington State Blue Ribbon Panel 2012). Already, shellfish hatchery failures in Washington have caused an economic stir and caused some hatcheries to relocate. Alaska's commercial fishing industry is valued at over $4 billion a year, and supports 90,000 jobs—recreational fishing and fishing tourism add even more value. Meanwhile, Alaska is ranked among the most vulnerable areas to acidification.

Tropical coral reefs provide ecosystem services, such as habitat and nursery functions for commercial and recreational fisheries and coastal protection. As reefs decline in acidified waters, there will be an ecological shift to a new ecosystem state dominated by less commercially valuable species. In 2009, Brander et al. estimated the annual economic damage of ocean acidification-induced coral reef loss to escalate rapidly over time, reaching $870 billion by 2100 (Brander et al. 2009a). In 2014, Brander et al. increased the anticipated loss of ecosystem services from corals to be $1000 billion (UNEP 2014). Shoreline protection offered by coral reefs and the services it provides by preventing loss of life, property damage and erosion are also reduced by CO_2 emissions.

Lane et al. (2014) modeled three major U.S. locations for shallow water reefs -- South Florida, Puerto Rico, and Hawaii – to project future reef cover and the economic values generated by coral reefs for a greenhouse gas emissions mitigation scenario that represents international implementation of policies to reduce global emissions (resulting in a CO_2 concentration of 427 ppm in 2100), compared to a business as usual greenhouse gas emissions scenario resulting in a CO_2 concentration of 785 ppm in 2100. The study estimated that reducing emissions would result in an "avoided loss" in Hawaii of approximately $10.6 billion in recreational use values compared to business as usual. Reducing emissions was projected to provide fewer economic benefits in Puerto Rico and South Florida, where sea-surface temperatures are already close to bleaching thresholds and coral cover is projected to drop well below 5% cover under both scenarios by 2050, and below 1% cover under both scenarios by 2100 (Lane et al. 2014).

As discussed previously, the toxicity of harmful algal blooms increases under conditions of ocean acidification. These toxins not only poison marine mammals, but also cause paralytic shellfish poisoning in people. Scientists hypothesize that some of the increases red tides off the coast of Southern California may be related to ocean acidification, though this has yet to be confirmed. In turn, harmful algal blooms cost the United States approximately $82 million each year from impacts to fisheries, public health, management, and lost recreational opportunities (Hoagland and Scatasta 2006).

A recent study estimated that the damage our oceans will face from emissions-related problems will amount to $428 billion a year by 2050 and nearly $2 trillion per year by the century's end (Noone et al. 2012).

> Acidification impacts processes so fundamental to the overall structure and function of marine ecosystems that any significant changes could have far-reaching consequences for the oceans of the future and the millions of people that depend on its food and other resources for their livelihoods.

(Doney et al. 2009). There is also a significant cost to delaying action. According to a recent report by the Council of Economic Advisers, delaying the implementation of policies to mitigate climate change could significantly increase economic damages, in addition to worsening environmental harm.[39]

While there are still large unknowns on the biological consequences of ocean acidification, the science we have is clear: from shellfish to corals, and from pteropods to fish, our marine resources are threatened by the acidification of our ocean waters.

b. Risk Reduction Methods

There are several ways to reduce risk from CO_2. EPA should use a suite of tools to reduce emissions, sequester CO_2, mitigate harms, and promote alternatives. Under TSCA EPA has authority to:[40]

- prohibit or limit the amount of production or distribution of a substance in commerce;
- prohibit or limit the production or distribution of a substance for a particular use;
- limit the volume or concentration of the chemical produced;
- prohibit or regulate the manner or method of commercial use;
- require warning labels and/or instructions on containers or products;
- require notification of the risk of injury to distributors and, to the extent possible, consumers;

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[39] Executive Office of the President of the United States, The Cost of Delaying Action to Stem Climate Change at 1 (July 2014).

[40] 15 U.S.C. § 260.

- require record-keeping by producers;
- specify disposal methods; and
- require replacement or repurchase of products already distributed.

EPA also may impose any of these requirements in combination or for a specific geographical region. [41] Specifically, the agency must impose controls sufficient "to protect adequately against such risk using the least burdensome requirement."[42]

There is evidence that many industries could employ existing technology to achieve meaningful emissions reductions affordably. EPA's own data demonstrate that lower pollution rates are readily achievable for many industrial sources of CO_2. For example, the agency has identified dozens of "control measures and energy efficiency options that are currently available for pulp and paper mill processes," ranging from technological upgrades to improved equipment maintenance.[43] Similarly, EPA has compiled more than a decade of reports on "cost-effective" control strategies and other approaches available to reduce cement plant CO_2 emissions, "includ[ing], for example, energy efficiency measures, reductions in cement clinker content, and raw materials substitution."[44]

Although cost-effective strategies to reduce CO_2 emissions are available, existing controls have not reduced CO_2 emissions sufficiently to protect against environmental harm. For example, most natural gas power plants have *never* exceeded the agency's recently proposed emissions limit, thus indicating that existing and newly constructed facilities could easily satisfy a more stringent standard.[45] Because energy-related CO_2 pollution accounts for more than eighty percent of U.S. greenhouse gas production, readily achievable reductions in this sector would significantly benefit the environment.[46] Similarly, the pulp and paper industry ranks among the largest consumers of energy,[47] and emitted nearly 58 million metric tons of CO_2 equivalent gases in 2004.[48] Moreover, market incentives and regulatory controls are effective in increasing the rate of innovation for technologies that can reduce CO_2 emissions.

If a chemical presenting an unreasonable risk to health and the environment has already been distributed, EPA may prescribe procedures by which relevant manufacturers and purchasers must replace or repurchase that chemical.[49] In the present situation, we urge the agency to exercise its

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[41] *Id.*
[42] 15 U.S.C. § 2605(a).
[43] *See* EPA, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Pulp and Paper Industry at 11 (2010).
[44] EPA, National Emission Standards for Hazardous Air Pollutants From the Portland Cement Manufacturing Industry and Standards of Performance for Portland Cement Plants, 75 Fed. Reg. 54,970, 54,997 (Sep. 9, 2010).
[45] Ctr. for Biological Diversity, Comments on Standards of Performance for Greenhouse Gas Emissions from New Stationary Sources: Electric Utility Generating Units (Proposed Rule) Docket No. EPA-HQ-OAR-2013-0495 at 13-14 (May 9, 2014).
[46] U.S. Dept. of State, U.S. Climate Action Report at 16 (2010).
[47] *See* U.S. Energy Information Administration, First Use of Energy for All Purposes (Fuel and Nonfuel), 2010 (Mar. 2013), http://www.eia.gov/consumption/manufacturing/data/2010/#r1.
[48] EPA, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Pulp and Paper Industry at 7 (2010).
[49] 15 U.S.C. § 2605(a)(7)(C).

authority to remediate existing harm by requiring that responsible parties mitigate past CO_2 emissions.

There are numerous approaches to mitigating and sequestering CO_2 emissions that EPA must evaluate. Effective land use and agricultural practices can significantly reduce carbon emissions and sequester CO_2. Federal programs aimed at consumers can reduce CO_2 emissions. For example, EPA's Energy Star program has prevented 1.8 billion tons of greenhouse gas emissions by providing information that helps customers select energy efficient devices. Sequestration of CO_2 in products, infrastructure, and waste management are among numerous methods that could be cost-effective to mitigate CO_2 pollution.

c. Social Costs of Carbon

In any analysis of the cost and benefits of reducing CO_2 pollution, the costs of failing to address the problem of global warming should be included. Most efforts to quantify the social costs of carbon underestimate the real-world costs of CO_2 pollution. Nevertheless, EPA may not ignore these costs.

Global emissions must be less than 1000 Gt of CO_2 between 2000 and 2050 to avoid dangerous climate change, which scientists have recommended that this means maintaining temperature change below 2° C.[50] This means keeping atmospheric CO_2 to 450 ppm, a threshold below which experts also use for ocean acidification (Veron et al. 2009; Silverman et al. 2009; Interacademy Panel 2009; McNeil & Matear 2008; Sea et al. 2007). For example, coral scientists predict that at 450 ppm, reef-building will be severely diminished or will cease altogether (Veron et al. 2009). But the global community has already used a substantial portion of this CO_2 budget, emitting 305 Gt of CO_2 between 2000 and 2008 alone.[51] As a result, the years between now and 2020 have been dubbed the "critical decade."[52] Because carbon emissions must peak soon and decline thereafter, the sooner emissions peak, the less severe the subsequent annual reductions will need to be;[53] correspondingly, if emissions are not sufficiently curbed in this decade, avoiding catastrophic damages will require much more drastic, disruptive and costly measures and may no longer be possible at all. Nonetheless, if action is taken immediately, it is both technologically and economically feasible to reduce emissions by 2020 and lay the groundwork for future emissions reductions.[54]

Every year that the world delays its efforts to reach sustainable levels of greenhouse gas emissions represents a lost opportunity of tremendous economic significance. McKinsey & Company estimated in 2009 that for every year of delay, 1.8 Gt of potential CO_2 abatement is foregone.[55] This delay, and the accompanying Gts of lost CO_2 abatement, has a price tag, as the

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[50] Australia Department of Climate Change and Energy Efficiency, The Critical Decade: Climate Science, Risks and Responses at 53 (May 2011), *available at* http://www.scribd.com/doc/56043375/The-Critical-Decade-Climate-Change-Commision-Report.

[51] *Id.*

[52] *Id.*

[53] UNEP, The Emissions Gap Report at 14 (Nov. 2010), *available at* http://www.unep.org/publications/ebooks/emissionsgapreport/; for a discussion of economic implications of these facts, *see infra.*

[54] *Id.* at 23.

[55] McKinsey & Company, Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve at 16 (2009), *available at* www.worldwildlife.org/climate/WWWFBinaryitem11334.pdf.

damage caused by CO_2 emissions accelerate while the cumulative amount of greenhouse gases in the atmosphere rises, both because of the increasingly dire damages wrought by rising temperatures and other greenhouse gas effects, *and* because of the delay factor itself. If governments delay mitigation in the present, the emissions reduction curve in future years necessarily becomes much steeper, requiring much more drastic and costly emission reduction mechanisms with tremendous economy-wide disruptions, just to "catch up" with the lost opportunities from prior years to reach a sustainable emissions trajectory—or risk undergoing unsustainable climatic extremes.

Economists have sought to quantify the costs of waiting to embark upon an emissions reduction path. In 2007, researchers used the DICE model[56] to estimate the cost of delaying mitigation for a given period of time and then switching to an optimal abatement trajectory. According to their findings, the global cost of ten years of delay, relative to starting on an optimal trajectory in the present, ranges from hundreds of billions to several trillion dollars.[57] For instance, this study estimates that it would cost somewhere between $200 and $400 billion dollars to delay action for ten years and then embark upon a mitigation strategy that would result in stabilization at 3 °C (a level now universally understood to far exceed the dangerous). The cost of delaying mitigation soars into the trillions of dollars as the delay continues, until it ultimately becomes impossible to achieve a certain level of temperature stabilization. According to this study, more than thirty years' delay of changing the current course would make it impossible – no matter what the expense – to stabilize temperature rises at 2° C above pre-industrial levels.

EPA and other federal agencies have been using the social cost of carbon to estimate the climate benefits of rulemakings since it was first developed by a dozen agencies (including USDA, CEQ and EPA) and published by the Interagency Working Group in 2010.[58] The social cost of carbon, usually expressed as a dollar-per-ton figure, provides an estimate of the economic damages associated with an increase in CO_2 emissions, conventionally one metric ton, in a given year. The dollar figure can also represent the value of damages avoided for emission reductions achieved by federal rulemakings. The social cost of carbon is designed to provide a comprehensive estimate of climate change damages, including, but not limited to, changes in net agricultural productivity, human health, and property damages from increased flood risk. However, given current modeling and data limitations, even EPA has conceded that that the social cost of carbon protocol is likely a conservative estimate because it does not yet account for all important damages.[59] Nevertheless, the protocol is designed for use in regulatory processes like this one. In 2013 the Federal Interagency Working Group increased its estimates of the social cost of carbon, using the same 3% annual discount rate, by 50%.[60] The 2013 estimates are 50% higher for emissions in 2010, with greater percentage increases in subsequent years. Yet, even these social

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[56] DICE stands for the Dynamic Integrated Climate and Economy model developed by William Nordhaus in 1990.

[57] Keller, K. et al., The Regrets of Procrastination in Climate Policy, Environmental Research Letters (2007), *available at* iopscience.iop.org/1748-9326/2/2/024004/.

[58] EPA, The Social Cost of Carbon, http://www.epa.gov/climatechange/EPAactivities/economics/scc.html (last accessed June 28, 2015).

[59] *Id.*

[60] Interagency Working Group on Social Cost of Carbon, United States Government, Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (Nov. 2013) at 3, available at http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-updatesocial-cost-of-carbon-for-regulator-impact-analysis.pdf.

cost of carbon figures significantly underestimate the true social cost of carbon, possibly by several orders of magnitude.

Economists have noted that the social cost of carbon is far greater than the $21 per ton of CO_2 assumed by interagency protocol in 2010 and greater than the 2013 revision.[61] There are several inadequacies that make the values too conservative. Foremost, the models fail to evaluate ocean acidification—to the contrary the models consider the ocean a sink for CO_2. The FUND model used in the Working Group's analysis wholly excludes consideration of climate-induced catastrophic events. But the Working Group weighs the values generated by each of the three models equally, even though the FUND model's values is significantly lower[62] than the others, and consequently pulls down the final value of the social cost of carbon. The potential for catastrophic climate events, and the increasing likelihood that tipping points will be reached even sooner than anticipated, are increasingly serious risks, however, and, despite the associated uncertainties, must be fully represented in any evaluation of the social cost of carbon. Instead, the Working Group employed a risk-neutral approach, clearly inappropriate in light of the vast majority of scientific studies. Also, the models used fail to account fully or even partially for certain highly complex aspects of climate change, including the possibility of interrelations between different sectors and accelerating damage feedback loops, non-CO_2 emissions,[63] and social and political instability. Moreover, the valuation techniques and discount rates used to reach these values are inherently problematic and fail to represent the full value of all losses from climate change, in significant part because some cannot be reduced to monetary terms.

Other evaluations of the social cost of carbon attempt to account for these omitted factors. The Stern Review, in particular, reaches a SCC of $85/ton of CO_2 (in 2000 dollars).[64] For comparison purposes with a Working Group value of $21 in 2005 dollars, this amount is equivalent to

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[61] F. Ackerman & E. Stanton, Climate Risks and Carbon Prices: Revising the Social Cost of Carbon (2010) (the social cost of carbon could be over $800 per ton of CO2 equivalent; F. Ackerman & E. Stanton, Climate Risks and Carbon Prices: Revising the Social Cost of Carbon, in Economics, vol. 6 (Apr. 4, 2012) (reaching similar conclusions), available online at http://www.economics-ejournal.org/economics/journalarticles/2012-10 (last visited June 27, 2014); P. Epstein et al., Full cost accounting for the life cycle of coal, Ann. N.Y. Acad. Sci. (2011) (estimating the social cost of coal at between $10 and $100 per ton of CO2 equivalent); L. Johnson & C. Hope, The social cost of carbon in U.S. regulatory impact analyses: an introduction and critique, J. Envtl. Stud. & Sci. (Sept. 9, 2012) (finding a social cost of a ton of CO2 emissions to be 2.6 to over 12 times larger than the Interagency Working Group's central estimate of $21 per ton of CO2) available online athttp://link.springer.com/article/10.1007%2Fs13412-012-0087-7 (last visited June 27, 2014) E. Stanton et al., Comments on the 2013 Technical Update of the Social Cost of Carbon, January 27, 2014.

[62] Interagency Working Group on the Social Cost of Carbon, Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, at 16-A-11, Fig. 16-A-4.2, *available at* http://www.rff.org/Publications/WPC/Pages/Estimating-the-Social-Cost-of-Carbon-for-Regulatory-Impact-Analysis.aspx.

[63] For instance, the estimated social cost of methane and SF_6, are, respectively, $105/tonne and $200,000/tonne. *See* Intergovernmental Panel on Climate Change, Climate Change 2007 Synthesis Report 822, *available at* http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html. For a critical analysis of the Working Group's assumptions, *see also* Ackerman, F. and Stanton, E. A., The Social Cost of Carbon A Report for the Economics for Equity and the Environment Network (April 1, 2010), *available at* http://www.e3network.org/papers/SocialCostOfCarbon_SEI_20100401.pdf.

[64] Nicholas Stern, Stern Review on the Economics of Climate Change Part III: The Economics of Stabilisation at 287 (2006), *available at* http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

$96.25/ton in 2005. The Stern Review uses the PAGE model, which explicitly models for the risk of catastrophic climate change.[65] In contrast with the Working Group, the Stern Review uses a mean temperature increase of 3.9 °C for its baseline scenario (consistent with the Third IPCC Report) and a 4.3 °C increase for its higher climate scenario. The resulting higher value of the social cost of carbon is thus very likely to be a closer approximation of the real cost of CO_2.

Meanwhile, the costs of reducing CO_2 emissions are well worth taking prompt action. The "central estimates of the annual costs of achieving stabilisation between 500 and 550ppm CO_2 are around 1% of global GDP, if we start to take strong action now. [...] It would already be very difficult and costly to aim to stabilise at 450ppm CO_2e. If we delay, the opportunity to stabilise at 500-550ppm CO_2e may slip away.'"(Stern 2006). Likewise, the benefits of addressing CO_2 for ocean acidification also have the ancillary effect of slowing global warming and preventing costs associated with climate change.

The recently proposed rule to reducing power plant CO_2 emissions calculates both costs and benefits—notably the benefits far exceed the costs. The recently proposed rules for reducing power plant carbon emissions, calculates both costs and benefits for a more modest reduction. EPA projects that the annual compliance cost will be $4.3 to $5.5 billion (in 2011 dollars, depending on discount rate) in 2020 and $5.5 billion (for a 5% discount rate) in 2030.[66] The total combined climate benefits and health co-benefits are estimated to be $15.6 to $88 billion in 2020 and $32.3 to $151 billion in 2030 (depending on discount rate and the options chosen).[67] The insurance industry also is well aware of the potential costs of failing to address CO2 emissions and its associated effects, including: "[h]urricanes and other flooding events … [h]ealth issues associated with heat waves… more airborne allergens, rising temperatures, greater humidity, more wildfires, and more dust and particulate pollution may considerably exacerbate upper respiratory disease (rhinitis, conjunctivitis, sinusitis, asthma) and cardiovascular disease."[68] A European insurance company estimates losses from extreme climate change events of 37% within a decade, over $1 trillion under bad circumstances.[69] The increasing frequency and severity of storms in the U.S. has caused damages to increase 60-fold from 1950s to the 1990s.[70]

Petitioners ask that action to mitigate ocean acidification under TSCA be initiated, either through TSCA section 6 (e.g., requiring "repurchasing" relief using sequestration, emission reductions, etc.), or through section 4 in order to determine the need for action under section 6 and the most effective mitigation strategies. In any case, petitioners suggest that costs be apportioned among

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[65] According to the Working Group itself, DICE "offers the best insight into the SCC if the world were to experience catastrophic climate change." *See* Working Group, *supra* note 62, at 16-A-35.

[66] EPA, Regulatory Impact Analysis Technical Document EPA-452/R-14-002 (June 2014).

[67] *Id.*

[68] National Association of Insurance Commissioners, The Potential Impact of Climate Change on Insurance Regulation at 10 (2008).

[69] See e.g. Allianz, Climate Change and the Financial Sector: An Action Plan; Evan Mills, Responding to Climate Change: The Insurance Industry Perspective.

[70] Mills, E. Insurance in a Climate of Change, Science 308: 1040 (2005).

CO_2 emission contributors according to the cumulative CO_2 emission inventory information EPA has collected.[71]

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In summary, the weight of the scientific information on ocean acidification is sufficient to make a determination that CO_2 poses an unreasonable risk, to the extent that EPA declines to find the data adequate, then EPA must develop a test rule under TSCA section 4 as described below.

C. Alternatively, EPA Must Require Testing to Develop Adequate Data

EPA must make a determination as to whether adequate data exist to evaluate the environmental and health effects of CO_2. There is well-established scientific information on the risk of CO_2 on the environment, but if EPA determines that the data are insufficient then it must develop a testing rule.

In enacting TSCA, Congress declared that "adequate data should be developed with respect to the effect of chemical substances and mixtures on health and the environment and that the development of such data should be the responsibility of those who manufacture and those who process such chemical substances and mixtures."[72] Accordingly, section 4 directs EPA to require additional testing upon determining that "the manufacture, distribution in commerce, processing, use, or disposal of chemical substance or mixture … may present an unreasonable risk of injury to health or the environment," or if the chemical is produced in substantial quantities and there is a potential for a substantial quality to be released into the environment.[73]

1. CO_2 May Present an Unreasonable Risk

As described in depth in this petition, CO_2 may present an unreasonable risk to the environment. EPA interprets this to mean that there is a "substantial (i.e., more than theoretical) probability" of unreasonable risk to the environment or health.[74] The information in this petition meets the threshold for a testing rule and establishes a substantial probability that CO_2 poses an unreasonable risk to the environment, but EPA need not even make such a determination because CO_2 is produced in such large volumes that it clearly meets the criterion of exposure of substantial quantities being released into the environment.

2. Substantial Quantities of CO_2 Are Released into the Environment

It is undeniable that substantial qualities of CO_2 are released into the environment. EPA established a threshold value of one million pounds for a release of a chemical to be substantial. *TSCA Section 4(a)(1)(B) Final Statement of Policy; Criteria for Evaluating Substantial*

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[71] This could be structured similar to the sponsorship format used in TSCA's High Production Volume (HPV) Program.

[72] 15 U.S.C. § 2601(b)(1).

[73] 15 U.S.C. § 2603 (a)(1)(A), (B)(i).

[74] *Chemical Mfrs. Ass'n v. EPA*, 859 F.2d 977, 988 (D.C. Cir. 1988).

Production, Substantial Release, and Substantial or Significant Human Exposure, 58 Fed. Reg. 28736, 28746 (May 14, 1993). According to the IPCC:

> From 1750 to 2011, CO_2 emissions from fossil fuel combustion and cement production have released 375 [345 to 405] GtC to the atmosphere, while deforestation and other land use change are estimated to have released 180 [100 to 260] GtC. This results in cumulative anthropogenic emissions of 555 [470 to 640] GtC.

(IPCC 2013, Summary for Policymakers).

In 2012, a total of 9.7 gigatonnes of CO_2 were released into the atmosphere from fossil fuel combustion and cement production (Global Carbon Project 2013). These emissions are expected to increase to 9.9 gigatonnes in 2013 (*Id.*). The United States contributed 14% of CO_2 emissions to the atmosphere (*Id.*). Models estimate that between 2003 and 2012, the oceans absorbed 27% of CO_2 from the atmosphere (*Id.*). Over the next millennium, the oceans will absorb 90% of anthropogenic CO_2 (Kleypas et al. 2006).

Therefore, the threshold of substantial release is exceeded by more than a million times over.

3. Recommendations for Testing

EPA should consider a test rule to fill the information gaps needed to make a determination of whether CO_2 presents an unreasonable risk of injury to the environment. Some recommendations for consideration include:

- Testing CO_2 reduction strategies. For example, research and development for emissions reduction strategies that include alternative practices, conservation, alternative fuels. Testing CO_2 sequestration and capture approaches, and assessing attainable CO_2 emissions reductions for industries with significant CO_2 emissions.
- Conducting a vulnerability assessment for marine and coastal species and ecosystems. Determining atmospheric CO_2 levels necessary to conserve marine ecosystems from dangerous ocean acidification. Emissions scenarios are important for informing policy approaches to acidification.
- Forecasting species' responses to ocean acidification using modeling tools to predict range shifts, demographic and population trends, and physiological responses across taxonomic groups using a range of climate models, emissions scenarios, and management timelines (25, 50, 100 years). Identify wildlife species and ecosystems imperiled by ocean acidification by evaluating range shift models and population viability models run under future ocean acidification levels. Recommend conservation actions, including protected status, for species that are most at risk. Protect species across their range since populations are likely to have different adaptations to local oceanic conditions.
- Determining the economic values of ecosystems that are at risk from ocean acidification and the costs of reducing CO_2 emissions to preserve those ecosystems.

Additionally, EPA can use guidance on research needs based on existing research plans. There are a number of sources recommending research and data needs (National Research Council 2013; Washington State Blue Ribbon Panel 2012; National Research Council 2010).

According to TSCA, developing the data is "the responsibility of those who manufacture and those who process such chemical substances and mixtures."[75] For example, responsibility could be apportioned based on the historical carbon emissions from the EPA Greenhouse Gas Emission Inventory together with current emissions. Typically for test rules with multiple responsible parties consortiums are set up to comply.[76] Here, for example, utilities, cement and lime manufacturers, waste incinerators, and other large producers of CO_2 should be responsible for developing unbiased, independent data.

While this may seem like a complicated undertaking, EPA has successfully completed more complex test rules. For example, from 1998 through the present, the agency used three sets of regulatory test rules under TSCA to collect chemical data for almost 3,000 high production volume (HPV) chemicals, including over 10,000 individual studies with data from domestic and foreign producers.[77]

EPA must develop test rules under TSCA section 4 for research and data development focused on information essential for making a definitive TSCA section 6 finding. These would include risk, benefit and cost information.

D. Inadequacy of Existing CO_2 Reduction Strategies

Petitioners are aware that the Agency has recently planned and initiated several emission reduction actions aimed at slowing the rate at which carbon emissions are increasing. However, these actions by themselves, while laudable, will not stabilize atmospheric CO_2 at a level which will prevent widespread harm from ocean acidification.

1. Global Greenhouse Gas Emissions Are Increasing Substantially

The atmospheric concentration of CO_2 reached 400 parts per million (ppm) for the first time in human history in May, 2013, compared to the pre-industrial concentration of ~280 ppm (Scripps Institution of Oceanography 2013). The current CO_2 concentration has not been exceeded during the past 800,000 years and likely not during the past 15 to 20 million years (Denman et al. 2007; Tripati et al. 2009). Atmospheric CO_2 emissions have risen particularly rapidly since the 2000s (Raupach et al. 2007; Friedlingstein et al. 2010). The global fossil fuel CO_2 emissions growth rate was 1.0% per year in the 1990s compared with 3.1% per year since 2000, and this growth rate has largely tracked or exceeded the most fossil-fuel-intensive emissions scenarios projected by the IPCC (A1FI and RCP 8.5) since 2000 (Raupach et al. 2007, Peters et al. 2012). The CO_2 emissions growth rate fell slightly in 2009 due largely to the global financial and economic

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[75] 15 U.S.C. § 2601

[76] 15 U.S.C. § 2602 (b)(3)(A)

[77] EPA, High Production Volume (HPV) Challenge; http://www.epa.gov/chemrtk/index.htm (last accessed June 28, 2015).

crisis; however, the decrease was less than half of what was expected and was short-lived (Fiedlingstein et al. 2010). In 2014 and 2015, global CO_2 concentrations exceeded 400ppm.[78]

2. U.S. Measures to Reduce Greenhouse Gas Emissions Are Insufficient

EPA has taken some initial steps toward curbing greenhouse pollution under the Act. In 2009, the agency issued a formal finding that greenhouse pollution endangers public health and welfare and moved to limit emissions from passenger cars and trucks. The EPA also acknowledged that major new or modified "stationary" sources of greenhouse pollution, like power plants and factories, must obtain permits and control their emissions before beginning construction. However, it narrowed the scope of this requirement considerably under its so-called "tailoring rule," which initially limits the permitting program to only a few hundred very large sources of greenhouse gases, letting a huge number of smaller — but still significant — sources off the hook.

While existing domestic laws including the Clean Air Act, Energy Policy and Conservation Act, Clean Water Act, Endangered Species Act and others provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the United States, these agencies are either failing to implement or only partially implementing these laws for greenhouse gases. The landmark 2014 pact with China to reduce greenhouse gas emissions is significant, but there is little to ensure it is enforced and implemented. According to the plan, United States will reduce CO_2 emissions 26 to 28% below 2005 levels by 2025.

Proposed power plant rules also fail to do enough to cut CO_2 pollution. Using the Clean Air Act, the president aims to reduce existing power plant emissions 30 percent below 2005 levels (or about 7.7 percent below 1990 levels, the base year for the international climate treaty) by 2030. But international scientists warned years ago that developed countries like the United States must reduce their emissions 25 percent to 40 percent below 1990 levels by 2020 to avoid tipping the scales further toward a climate catastrophe. Likewise, the recently announced plans to limit power plant emissions (Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units) focuses on emission reduction. Power plants are responsible for about a third of our carbon emissions, and the rule is designed to reduce those emissions by almost a third by 2030. This would result in a 10% decrease in 15 years. Stabilizing atmospheric concentration to prevent further acidification of the oceans would require about an 80% decrease in all emissions. Clearly this is a good first step, but by itself inadequate to address acidification.

EPA has issued a rulemaking regulating greenhouse gas emissions from automobiles that will reduce greenhouse emissions emitted per vehicle mile traveled by passenger vehicles in the future. But because the improvements are modest and more vehicles are projected to drive more miles in the future, the rule will not reduce emissions from this sector overall but will only slow the rate of increase.[79] Meanwhile, even the government concedes that "these reductions in emissions are not sufficient by themselves to reduce total HD vehicle emissions below their 2005

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[78] NOAA, Trends in Atmospheric Carbon Dioxide, http://www.esrl.noaa.gov/gmd/ccgg/trends/

[79] EPA, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 Fed. Reg. 25324 (May 7, 2010).

levels by 2020."[80] This means that the vehicle rule is far from achieving emissions goals agreed to by the U.S. in the Copenhagen Accord, which aim to keep global warming below 2˚C.

The EPA has also to date issued only a single proposed rule under the new source pollution standard program for stationary sources of pollution, for electric generating units (power plants). While there is enormous potential to reduce emissions through this program overall and through the power plants rule in particular, the EPA has instead proposed a weak and flawed rule that it admits will not reduce emissions from these sources between now and 2020 compared to what would be expected without the rule.[81] Indeed, in the rulemaking the EPA conceded that new power plant rule on greenhouse gas emissions "will not have direct impact on U.S. emissions of greenhouse gases under expected economic conditions."[82]

While full implementation of our flagship environmental laws, particularly the Clean Air Act, would provide an effective and comprehensive greenhouse gas reduction strategy, due to their non-implementation, existing domestic regulatory mechanisms must be considered inadequate to protect marine species from climate change and ocean acidification.

3. International Measures to Reduce Greenhouse Gas Emissions Are Inadequate

International initiatives are also currently inadequate to effectively address climate change. The United Nations Framework Convention on Climate Change, negotiated in 1992 at Rio de Janeiro, Brazil, provides the forum for the international negotiations. In the Framework Convention, signed and ratified by the United States, the world agreed to take the actions necessary to avoid dangerous climate change. Parties to the Convention also agreed as a matter of fairness that the world's rich, developed countries, having caused the vast majority of emissions responsible for the problem, would take the lead in solving it. It was not until the 1997 meeting in Kyoto, Japan, that the first concrete, legally binding agreement for reducing emissions was signed: the Kyoto Protocol. The Protocol requires the world's richest countries to reduce emissions an average of 5 percent below 1990 levels by 2012, while developing nations also take steps to reduce emissions without being subject to binding emissions targets as they continue to raise their standard of living. The United States has been a major barrier to progress in the international negotiations. After the Clinton administration extracted many concessions from the rest of the world in exchange for the United States signing on in Kyoto, the Senate rejected the equity principles behind the Convention, saying the United States should not agree to reduce its own emissions unless all other countries — regardless of their responsibility or ability — were similarly bound. Citing the same excuses, President George W. Bush repudiated the Kyoto Protocol entirely. Thus the United States is the only industrialized country in the world that has yet to ratify the Kyoto Protocol. The United States negotiating team under both the George W. Bush and the Obama administrations has pursued two primary objectives in the international talks: to refuse any legally binding emissions reduction commitments until all other

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[80] NHTSA, Medium- and Heavy-Duty Fuel Efficiency Improvement Program – Final Environmental Impact Statement (June 2011).

[81] EPA, Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units, 77 Fed. Reg. 22392, 22430-33 (April 13, 2012).

[82] *Id.* at 22401.

countries— but particularly China and India — do so, and to push back the date for a new agreement. Not surprisingly, the United States had failed to meet its (never ratified) Kyoto pledge to reduce emissions to 7.2% below 1990 levels by 2012; to the contrary, U.S. emissions have increased by 10.5% since 1990 (EPA 2012).

Moreover, the Kyoto Protocol's first commitment period only sets targets for action through 2012, and there is still no binding international agreement governing greenhouse gas emissions in the years beyond 2012. While the 2009 U.N. Climate Change Conference in Copenhagen called on countries to hold the increase in global temperature below 2°C (an inadequate target for avoiding dangerous climate change), the non-binding "Copenhagen Accord" that emerged from the conference, and the subsequent "Cancún Accords" of 2010 and "Durban Platform" of 2011 failed to enact binding regulations that limit emissions to reach this goal.[83] Even if countries were to meet their Copenhagen and Cancún pledges, analyses have found that collective national pledges to cut greenhouse gas emissions are inadequate to achieve the 2°C target, and instead suggest emission scenarios leading to 2.5°C to 5°C warming (Rogelj et al. 2010; UNEP 2011; UNEP 2010). As of July 2013, many governments were not implementing the policies needed to meet their inadequate 2020 emission reduction pledges, making it more difficult to keep global temperature rise to 2°C and likely leading to a temperature rise of at least 3.5°C (USGCRP 2013). As noted in the NMFS Management Report, the U.S. has yet to issue regulations to limit greenhouse gas emissions in accordance with its pledge under the Copenhagen Accord (NMFS 2012).

CONCLUSION

In conclusion, this petition requires EPA to make a determination whether CO_2 poses an unreasonable risk to the environment therefore requiring regulation under section 6 of TSCA. In an extensive review of the literature on the impact of ocean acidification on marine fauna and ecosystem processes, the authors found that while additional research is called for, sufficient information exists to state with certainty that deleterious impacts on some marine species are unavoidable, and that substantial alteration of marine ecosystems is likely over the next century. (Fabry et al. 2008). If, nonetheless, EPA determines that the information is insufficient to make such a finding it must develop testing rules pursuant to TSCA section 4.

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[83] The non-legally binding Copenhagen Accord of 2009 and Cancún Accords of 2010 recognize the objective of limiting warming to 2°C above pre-industrial temperatures, but do not enact binding regulations to achieve this goal (http://cancun.unfccc.int/cancun-agreements/main-objectives-of-the-agreements/#c33; unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf). According to the Durban Platform, developed and developing nations agreed to a process to develop a "new protocol, another legal instrument, or agreed outcome with legal force that will be applicable to all Parties to the UN climate convention"; this legal instrument must be developed as of 2015 and will not take effect until 2020 (unfccc.int/resource/docs/2011/cop17/eng/l10.pdf).

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June 30, 2015

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Re: Supplement to the Petition for Rulemaking Pursuant to section 21 of the Toxic Substances Control Act, 15 U.S.C. 2620, Concerning the Regulation of Carbon Dioxide

Dear Administrator McCarthy,

On June 30, 2015, the Environmental Protection Agency (EPA) received a petition to regulate carbon dioxide (CO_2) from cradle to grave under section 6 of the Toxic Substances Control Act (TSCA) or in the alternative to develop a testing rule for CO_2. The petition provides information concerning the devastating risk to the marine environment and wildlife, and risk to human health from ocean acidification. Accordingly, EPA must make a determination as to whether CO_2 presents or may present an unreasonable risk of injury to the environment or human health due to the severe environmental consequences of ocean acidification. As a cosigner of that petition, I submit this supplement to the petition under my signature.

US EPA section 21 guidance states: "The key findings relating to unreasonable risk must be made both when a new regulation is proposed, and when an existing regulation is amended or repealed. Petitioners should provide data to support these finds." This supplement provides additional information supporting the unreasonable risk find. I respectfully request that EPA consider the data and information provided in this supplement to the petition in making its determination on our petition.

Petitioners demonstrated that the acidification of the open ocean has a single cause but multiple effects. That the decreasing ocean pH is being inexorably driven by the increase in the atmospheric concentration of carbon dioxide from anthropogenic emissions and is the incontrovertible result of the second law of thermodynamics. That this physical and chemical dynamic has been observed, monitored, documented, and is straightforward to predict into the future. [1] That it has many harmful effects on the ecology of the ocean, some of the harmful effects are well established, others lack conclusive information or are more speculative. Many of these are significant

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[1] Caldeira and Wickett, Nature 425, 2003 and Journal of Geophysical Research 110, 2005; Orr et al. 2005 Nature 437; Raven et al. 2005 ,The Royal Society.

effects, and some could be catastrophic. That these harmful effects are exacerbated in near shore areas by NOx and SOx emissions, runoff, temperature rise and other effects.[2]

Climate Impacts

According to scientific experts: "Reducing CO_2 emissions is the only way to minimise [sic] long-term, large-scale risks" (IBGP et al. 2013). So any abatement will by necessity also abate Climate change disamenities.

Under TSCA the reasonableness of the risk depends on whether the costs of the ecological and health disamenities outweigh the benefits from mitigation, minus the costs of mitigation. To the extent possible the costs and benefits must be quantified to make this determination. According to USEPA Benefit Assessment Guidelines action to mitigate ocean acidification would be classified as a "significant regulatory action" ...the ... " economic analysis of regulatory or policy options should present all identifiable costs and benefits that are incremental to the regulation or policy under consideration. These should include directly intended effects and associated costs, as well as ancillary (or co-) benefits and costs."

In EPA regulations, ancillary benefits can be much larger than direct benefits. (For example, Agency regulations to control NOx emissions are premised on the enormous ancillary particulate matter and ozone reduction benefits that result indirectly from the NOx reduction and control). This is also the case for ocean acidification (Although ocean acidification mitigation has enormous human health and environmental benefits in it's own right). Mitigation options for ocean acidification have by necessity the ancillary effect of slowing global temperature rise and preventing the disamenities associated with a global rise in temperature. Therefore this supplement presents both ocean acidification and climate information relevant to the reasonable risk finding.

Mitigation Under TSCA Includes Sequestration of Legacy Carbon

While current emissions may be the immediate cause of the increase in ocean acidification, past emissions are the proximate cause. The oceans have absorbed from about a third of the 500 plus billion tons of past or legacy carbon emissions, lessening Climate impact. However, these emissions have eroded, i.e., "used up" the buffering capacity of the oceans. This buffering capacity is what keeps ocean pH in a narrow, bio-friendly range. As the buffering capacity lessens, smaller and smaller amounts of CO_2 will result in larger and larger decreases in pH. The absorption by the ocean of legacy emissions over the past decades have caused the rapid current decrease in pH and have made the projected future decrease in pH to carbonate unsaturation levels possible, and have caused it to accelerate. Since legacy emissions are the proximate cause of both the current level and the acceleration in the decrease in pH, these emissions must be part of the design and funding of any remedy, or an undue burden is placed on the current emitters to remedy the damage caused by past emitters.   The courts have held, e.g., in CERCLA cases that requirements stemming from past actions (which were legal at the time) isn't retroactive, but rather a reimbursement obligation.[3]

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[2] Duarte et al. Coastal and Estuarine Research Federation 2013

[3] UNITED STATES v. MONSANTO COMPANY, 858 F.2d 160 (4th Cir. 1988)

Again, the oceans absorb about a third of the anthropogenic emissions. This means that for decades rent seekers have extracted the benefits of fossil energy without paying for the environmental damages of the carbon emission, including the loss of the buffering capacity of the ocean and the attendant damages from ocean acidification. This is a classic “tragedy of the commons” situation. EPA has a long standing tradition and policy of making the polluter pay for environmental injury. Petitioner asks that both legacy and current emissions be included in determining the remedies and who must comply, based on the contributory proportion to the harm from ocean acidification, using, for example, the Emission Inventory. (The Agency has the authority to ignore small emitters when transactional costs of including them are too large)

CO_2 Poses an Unreasonable Risk to Human Health

Petitioner asks the Agency to consider not only the well documented health effects from climate change[4] discussed in the petition but also the direct health impact from ocean acidification. Some of these are very significant and can be quantified.

The body of the petition cites increased mortality and morbidity from loss of fisheries and declines in marine based diets. These human health effects are in addition to the increased toxicity of algal blooms mentioned in the body of the petition, which can cause paralytic shellfish poisoning in humans. The loss of fisheries from ocean acidification, and the resultant scarcity of seafood also has significant human health impacts. For example, in a Harvard School of Public Health comprehensive analysis of fish and health, combining the evidence for major health effects of omega-3 fatty acids, while accounting for the health risks of mercury, and health risks of PCBs and dioxins in both adults and infants/ young children: results show that the benefits of eating a modest amount of fish per week--about 3 ounces of farmed salmon or 6 ounces of mackerel--reduced the risk of death from coronary heart disease (CHD) by 36%. By combining results of randomized clinical trials, the investigators also demonstrated that intake of fish or fish oil reduces total mortality--deaths from any causes--by 17%. [5]

USEPA consumption surveys find that about 10% of the US population consumes at least enough fish to garner the benefit.[6] Depending on price elasticity of demand this could translate into up to half a million premature deaths/year from loss of fisheries and the resultant scarcity of seafood.[7] In addition, increase in seafood prices will result in a loss of consumer surplus. Petitioner asks that the Agency develop a deterministic or a probabilistic assessment to quantify mortality and morbidity from the decreased availability and consumption of seafood that would result from ocean acidification fishery damage, as mentioned in the body of the petition (e.g., effects on salmon from plankton impacts). This will help the risk assessment to capture this significant human health impact as required in EPA’s Benefit Assessment Guidelines.

There are also indirect effects and economic consequences, which after consideration of the effect on the national economy, small business, technological innovation, the environment, and

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[4] National Climate Assessment, U.S. Global Change Research Program, 2014

[5] JAMA. 2006;296(15):1885-1899;]

[6] Estimated Per Capita Fish Consumption in the United States, USEPA August 2002

[7] Am J Public Health. 2010 February; 100(2): 216–222

public health as required under TSCA, are reasonably ascertainable.[8] These include other effects on Fisheries. It is probable that wild catch seafood loss, at least in part, will be replaced by aquaculture (currently about half of the world's seafood is farmed[9]). Farmed fish are fed fishmeal, soy and grain. It has been well established that fisheries have and will be increasingly negatively affected by ocean acidification. This will cause scarcities of fishmeal, both driving up the price of farmed fish (and negatively affecting consumption) and causing more reliance on grain and soy.

The substitution of grain and soy for fishmeal, and the additional amounts of grain and soy needed for the increased farmed fish to replace the decreasing availability of wild catch may itself result in increased cost and, in some cases substitution may not be not possible due to grain and soy yield limitations. A recent Nature Communication article [10] shows robust evidence of yield plateaus due to biophysical limitations for rice, wheat and maize, which together account for ~85% of global cereal production and contribute a majority of human calories eaten directly as staple foods, or indirectly through consumption of livestock fed with grain. Seafood accounts for about 15% of the global dietary protein from animal sources. Both farmed seafood and livestock will be stressed by the plateauing grain yields.

Aside from increasing demand, grain costs will also increase due to greater input requirements[11] as marginal lands are brought into production to keep up with the increased demand. This demand and cost increase will be exacerbated by population growth, currently changing global increases in dietary animal protein, and increased labor costs from the fine tuning of many different facets of management in the production system required to increase or maintain yields.

Another factor to be considered is the dietary exposure effect of using increased soy and grain for aquaculture. The Food Quality Protection Act (FQPA) requires EPA to assess the cumulative risks of pesticides that share a common mechanism when developing tolerances. EPA has issued guidance relative to assessing that risk.[12] [13] Pesticides with common mechanisms (organophosphates (OPs), N-methy carbamates, triazines, chloroacetanides, pyrethrins/pyrethroids) all have grain and soy tolerances. This will change cumulative exposure, and under FQPA requirements EPA must reassess tolerances if these exposure pathways become larger contributors. Additionally, the metabolic pathways for the degradation products will have to be determined if they are different for aquatic species.

Petitioner requests EPA address this through its FIFRA information gathering authority and tolerance reassessment program, or explain why it's not necessary to do so. Petitioner asks that the additional exposure and risk be shared with the public if tolerances are maintained at current levels, and that these risks to human health be included in the benefits assessment. If tolerances are

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[8] TSCA section 6(c) 4

[9] State of the World Fisheries and Aquaculture, FAO, 2010

[10] Nature Communications 4, Article number: 2918 doi:10.1038

[11] CGIAR Research Priorities for Marginal Lands. FAO 1997

[12] General Principles For Performing Aggregate Exposure And Risk Assessments USEPA, 2001

[13] Guidance on Cumulative Risk Assessment of Pesticide Chemicals That Have a Common Mechanism of Toxicity. Office of Pesticide Programs, USEPA 2002

lowered, petitioner asks that any costs to growers or loss of consumer surplus be also included in the assessment.

As FQPA requires local effects be considered, USEPA should consider whether farm location relative to runoff of these pesticides need be considered in the assessment, perhaps using the monitoring protocols and mathematical models that OPP typically relies on to generate exposure estimates for water quality assessments. As more of the US population become locovores[14], local fish farming and local crops may expose special populations to increased cumulative risk.

Executive Order 12898 requires that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations". EPA's Framework for Human Health Risk Assessment to Inform Decision Making[15] recommends including social considerations and environmental justice in informing decisions on risk. In addition, under either NEPA's (National Environmental Policy Act) guidance or TSCA's "functional equivalence"[16] the analyses should consider the effects on a community by addressing the full range of consequences of a proposed action as well as other environmental stresses which may be affecting the community, including diets, or differential patterns of consumption of natural resources, which may suggest increased exposures to environmental pathways presenting potential health risk. To comply with these goals petitioner asks that EPA consider the Environmental Justice implications of whether the increased cost of seafood high in omega-3's will result in a more unhealthy ratio of omega-3 to omega-6 oils in certain low income communities. This ratio has been shown to be an important driver in mortality and morbidity studies.

Petitioner asks that the Agency consider the net effect on diet from ocean acidification and include the expected morbidity and mortality from all the changes in diet described above.

Market Failure

Petitioner endorses the President's Counsel of Economic Advisors' statement that "The emission of greenhouse gases such as carbon dioxide (CO_2) harms others in a way that is not reflected in the price of carbon-based, energy, i.e., CO_2 emissions create a negative externality. Because the price of carbon-based, energy does not reflect the full cost or economic damages, of CO_2 emissions, market forces result in a level of CO_2 emissions that is too high. Because of this market failure, public policies are needed to reduce CO_2 emissions and thereby limit the damage to economies and the natural world from further climate change."[17] One of these "harms" is Ocean Acidification. The petition and the options presented herein provide vehicles for implementing the public policy called for by the Counsel necessary to rectify the market failure.

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[14] R.E. Galt Counting and Mapping Community Supported Agriculture, ACME: An International E-Journal for Critical Geographies, 2011, 10 (2), 131 - 162

[15] Framework for Human Health Risk Assessment to Inform Decision Making, April 5, 2014, U.S. Environmental Protection Agency

[16] 489 F.2d 1247 (D.C. Cir. 1973).

[17] The Cost of Delaying Action to Stem Climate Change, CEA, July 2014.

Emission Reduction *and* Sequestration

Given the magnitude of the ocean acidification problem, the mitigation prescription to address this market failure must also be large. Nature maintains carbon dioxide atmospheric concentrations within a narrow band, by balancing emissions with sequestration. Nature efficiently removes atmospheric carbon by transforming it into biomass and minerals, or “storing” it in the oceans (the source of the ocean acidification problem). Unlike the natural cycle which is in dynamic equilibrium, the anthropogenic carbon cycle is not in equilibrium and is unbalanced. Man takes Gigatons of fossil carbon and puts it in the air, but takes very little back. In excess of a third of this increase in atmospheric carbon ends up in the ocean and lowers the ocean pH. The economics of the anthropogenic carbon cycle don’t take in account the externalities of ocean acidification (or climate change) so the economic carbon cycle is skewed towards emissions and away from sequestration. While the amount of the imbalance is relatively small when compared to the annual amount of carbon nature moves into and out of the atmosphere, it is consistently biased in one direction and over the years has almost doubled the baseline atmospheric carbon.

While the Administration has not directly attempted to regulate ocean acidification it has attempted to reduce carbon emissions because of Climate considerations. The Administration’s recent Climate Initiative and in fact, almost all of USEPA’s climate and carbon initiatives to date, are and have focused on reducing emissions. Almost none of the efforts focus on sequestering carbon. Petitioner stresses that the carbon cycle can’t presently be balanced by reducing emissions only, since, in the foreseeable future, there will continue to be a large net bias towards carbon emissions over carbon removal stemming from increasing energy demand, as well as wealth and population effects and the fossil fuel requirements of the extant energy infrastructure. (Petitioner observes that if you can’t turn a sink faucet off, then you must open the drain to avoid an overflow…our energy infrastructure is a “faucet” and sequestration can be the “drain”)

This is a market failure, because the environmental cost of emissions is not included in the price of energy, and therefore the environmental benefit of sequestration is not valued. Petitioner recommends that the Agency include options in the cost analysis that can significantly affect this bias, i.e., options which sequester carbon as well as options which reduce emissions. In any case, in order to determine if a risk is unreasonable under TSCA, the Agency must determine the efficacy, efficiency and supply function of all significant mitigation remedies.

Remedies

Determining whether a risk is unreasonable under TSCA is a function of government. However, as the Agency’s Petition Guidance points out, petitioners have an obligation to present as much information as possible, e.g, to identify relevant aspects of the unreasonable risk determination and demonstrate that these aspects are knowable. Petitioner believes the Agency is both knowledgeable and active concerning carbon emission reduction, but less well versed and less active in sequestration. It’s beyond the petitioner’s responsibility and ability to provide an exhaustive, quantitative list of sequestration options. Rather examples are provided herein to demonstrate that sequestration opportunities to offset both legacy carbon and current emissions exist. The list is limited and not meant to be definitive of sequestration opportunities.

TSCA requires that the Agency consider "the reasonably ascertainable economic consequences of the rule, after consideration of the effect on the national economy, small business, *technological innovation*, the environment, and public health" (emphasis added). [18] Some of the sequestration opportunities mentioned below are currently being employed, others are in small demonstration or pilot stages and may require additional technological innovation to become economically competitive. (Irrespective of their current status all rely on the same chemical, physical or biological mechanisms / processes that nature uses effectively to sequester large volumes of carbon.)

There is considerable literature on the ability of both Market Pull policies or Technology Push policies to increase the rate of innovation.[19]. While not all of these sequestration technologies/methods are available at the current time to provide significant mitigation, they could be in the near future given the proper market. In any case, the Agency has a successful history of setting regulatory "reach" targets (e.g., CAFE standards).

If information on the efficacy of sequestration technologies is inadequate to determine if the risk is unreasonable, Petitioner asks that the Agency use TSCA Section 4 to remedy the inadequacy. The Agency has in the past required TSCA test rules for many chemicals already released and in the environment in high volumes (such as dyes, plasticizers, flame retardants) to determine if treatment/mitigation methods (for example aerobic digestion) are sufficient to reduce the risk to human health and the environment to a reasonable level. Petitioner asks the Agency to assess the information available on the efficiency and cost of sequestration technology and methods to treat/mitigate released CO_2 to determine the adequacy of data for the purpose of a robust unreasonable risk determination. Petition asks that the Agency by rule require that testing be conducted to address any inadequacy.

Petitioner suggests costs for testing (and for remedies under sections 6 or 9, vide infra) be apportioned among CO_2 emission contributors according to the cumulative CO_2 emission inventory information the Agency has collected. This could be structured similar to the sponsorship format used in TSCA's High Production Volume (HPV) Program (a more complex format than for a single chemical, i.e., $CO_{2\,,}$ it covered thousands of chemicals and thousands of tests from both foreign and domestic sources). [20]

Since any carbon emissions that result from sequestration actions must be subtracted to calculate net carbon sequestration, the Agency should in particular examine options that rely (completely or substantially) on alternative energy, such as biosequestration relying on solar power. Nature removes an order of magnitude more carbon out of the atmosphere every year using natural processes. By increasing the process area, volume, or efficiency of these naturally occurring processes gigatons of carbon can be sequestered. For example, grass pastures can build soil carbon slowly through microbial processes. Legume-based pastures that fix N and drive higher biomass

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[18] TSCA section 6a (4)

[19] "Impact of Renewable Energy Policy and Use on Innovation"A Literature Review, Felix Groba and Barbara Breitschopf 2013, Deutsches Institut für Wirtschaftsforschung

[20] EPA, High Production Volume (HPV) Challenge; http://www.epa.gov/chemrtk/index.htm

production of associated grasses, drive a more rapid carbon accretion.[21] Marginal lands can be managed to trap a ton of carbon per hectare a year to equilibrium with proper management. Enhanced soil carbon is beneficial not only from it's increased productivity but also because it enables greater infiltration and retention of rainfall and this compensates for expected increases in temperature and more uncertain rainfall. In the oceans, microalgae can be fertilized sequestering carbon and then removed- harvested for products. For example the nutritional value of micro algae[22], and it's potential as a biodiesel source[23] have been extensively researched. Including ancillary benefits like these with the net sequestration benefit will provide a more complete analysis.

Recently, the World Bank investigated the capacity of different agricultural land use management practices to sequester carbon. Biomass, and especially it's soils, sequester carbon out of the atmosphere and this role as a carbon sink and as a carbon store can be strategically optimized through proven farming techniques and methods that simultaneously reduce emissions. These technical elements of climate-smart agriculture are well understood, and in addition to their technical feasibility, they can be highly productive and profitable. In the Report they estimate a enormous capacity of agriculture to sequester carbon and in turn provide marketable carbon offsets. Looking at different scenarios, that are based on different levels of international integration and ecological concern, the employment of land use and management techniques in Asia, Africa and Latin America could sequester between 12 and 18 Gt of carbon, with net positive welfare benefits, of between 1.4 and 1.6 trillion dollars by 2030. [24]

More aggressively, it has been proposed that lignin rich crops, which sequester carbon refractorially, might be used directly as a soil amendment to enrich and provide carbon to desertified or otherwise depleted lands, enabling the growth of more lignin crops to produce additional fertile soils, geometrically magnifying the sequestration.[25] Climate change may worsen desertification because of temporal changes in radiation, wind, temperature, rainfall and other parameters driven by the increased energy in the atmosphere[26]. Another economically beneficial use for tree, litter and other forestry and agricultural high lignin sources (>15%) would be for erosion control necessitated by the expected increase in rainfall in many areas from the rising temperatures.[27]

Sustainable biocharring has both an energy and a sequestration component. biocharring can be used to produce fuels and the char itself can be used to increase soil fertility and NPP, enabling sequestering more carbon. Researchers estimate that up to 12% of anthropogenic emissions can be offset by biochar. [28]

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[21] Dalal, RC, Strong, WM, Weston, EJ, Cooper, JE, Lehane, KJ, King, AJ, Chicken, CJ (1995). Australian Journal of Experimental Agriculture, **35**

[22] FAO Fisheries Technical Paper 361

[23] NREL/TP-580-24190

[24] Carbon Sequestration in Agricultural Soils, The World Bank, REPORT NO. 67395-GLB, 2012

[25] pp 150-168, Viviani, Bioenergy and Biobased Products, DOE National Bioenergy Center Strategic Partnerships Workshop April 11-12, 2001 Colorado

[26] World Meterological Oraganization, Climate_Change Desertification, 2007.

[27] Trees, Crops, and Soil Fertility: Concepts and Research Methods edited by G. Schroth, Fergus L. Sinclair

[28] Nature Communications 1: 56 doi:10.1038/ncomms1053

Reforestation and reducing deforestation can also play enormous roles and most importantly, they provide a relatively straightforward remedy that can be paid for directly by those found responsible under TSCA for the legacy carbon in the oceans. Reforestation to combat desertification is underway in Mongolia by the Mongolian government and South Korean[29]

Additionally, “blue” or coastal carbon can also play a very significant role. NOAA is encouraging the conservation of these coastal sinks and points out that current studies suggest that mangroves and coastal wetlands annually sequester carbon at a rate two to four times greater than mature tropical forests and store three to five times more carbon per equivalent area than tropical forests.[30] Most coastal blue carbon is stored in the soil, not in above-ground plant materials (biomass), as is the case with tropical forests.

The Agency should also examine options which produce (and net) carbonates from carbon dioxide[31], especially those producing salable products, such as carbon mineralization processes making carbonate building materials from carbon dioxide, e.g., green bricks and green cement, and can net energy. Building materials comprise an enormous market, as there are about 30 billion tons of concrete produced and used each year alone. Concrete accounts for about 7% of global carbon emissions. Sequestering CO_2 into green cement provides multiple opportunities and benefits: potential increases in concrete’s strength, reductions in emissions, carbon sequestration, and provides significant opportunities for offset purchase.

The use of timber in high rises (to 40 stories or some cases more) to replace some of the concrete and steel can also reduce the carbon footprint of construction drastically (as both concrete and steel are carbon intensive) and can sequester atmospheric carbon at the same time. A cubic meter of wood substituted for other construction material can result in savings of 0.75 to 1 ton of CO_2.[32] This can reduce the carbon footprint of buildings by two thirds.

Practice and performance based economic incentives could be used to encourage sequestration in the building and forestry/agricultural sectors. Banked credits could be sold to offset any added cost from the differing practices/products. In the US, government construction accounts for about a quarter of new projects. These projects could account for significant sequestration if additional green construction were required to be incorporated in design. In government directed economies it could be higher.

3D printers, which can and do use biological materials (containing carbon harvested from the atmosphere) as substrates can produce myriad consumer products. This is particularly helpful because increased consumer expenditures and economic growth is almost always associated with increased energy/resource use and drive carbon emissions. In this case consumer purchases can

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[29] Min-Kyung Kang et al, Jour. Korean For. Soc. Vol. 99 No. 5, pp 655-663 (2010)

[30] http://www.habitat.noaa.gov/coastalbluecarbon.html

[31] Annu Rev Chem Biomol Eng. 2013;4:103-17. doi: 10.1146/annurev-chembioeng-062011-080951. Epub 2013 Feb 28.

[32] International Institute for Environment and Development, Using Wood Products to Mitigate Climate Change, 2004

actually reduce net atmospheric carbon. Other research demonstrates direct storage of CO2 into nonbiological compounds which can also be accessed to make consumer products[33]

These sort of options help bring the economic carbon cycle more into balance, providing value by removing carbon from the atmosphere. CO_2 not only becomes an essentially limitless resource, which can be both reduced or oxidized to produce products and/or energy, it also couples sequestration with population and economic growth.

The Agency, through TSCA section 9's access to other Federal programs, could use economic incentives to foster growth of some these options by the general population. For example, DOE and EPA's Energy Star program has prevented 1.8 billion tons of GHG emissions, by providing information that helps consumers select energy efficient devices. A similar program could be established that provides information about the net amount of atmospheric carbon sequestered in products.

Providing information to consumers concerned about ocean acidification (and climate change) enables them take direct action to mitigate these problems, and also provides a marketing incentive to companies to develop and sell these products. There is already a trend in the US for development of biocarbon products substituting for petroleum or mineral based products. Examples range from large volume products, such as home foam insulation based on soy, to smaller niche products, such as wetsuits made using biorubber rather than petroleum based neoprene (Patagonia).

As mentioned above, Nature cycles atmospheric carbon primarily by storing it in the ocean, reducing it into biological materials and oxidizing it into minerals. This latter process also provides sequestration opportunities. The IPCC [34]estimates that magnesium and calcium silicate deposits are sufficient to fix all the CO_2 that could be produced from the production of all fossil fuels resources. There have been demonstration and pilot projects that have sequestered carbon at a costs ranging from $50 to $300/ ton.[35] Some of these processes also have the advantages of yielding salable product. For example olivine has been used as an amendment to replenishing beach sand, and the weathering of the sand from the ocean waves has the potential to raise the pH of the waters.[36]

There are high volume industrial waste materials, such as 'red mud' from aluminum production[37] as well as steel and blast furnace slag, fly ash and waste concrete that can sequester atmospheric carbon, and in some cases produce salable products[38]

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[33] CO_2 Coordination by Inorganic Polyoxoanion in Water, Guanggang Gao et al, JACS communications, 2008

[34] IPCC Special Report Carbon Dioxide Capture and Storage, 2005

[35] Chem. Soc. Rev., 2014, 43, 8049

[36] International Journal of Greenhouse Gas Control 4 (2010) 855–856

[37] Peterson et al. Science of The Total Environment Volume 338, Issue 3, 15 February 2005

[38] Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard USEPA, February 2014

IntraAgency Coordination

Petitioner is aware that the Agency has operated cross-Agency programs, i.e., initiatives that all media program and other offices are required to participate in. Examples include, P2 Pollution Prevention, the IntraAgency Integration Program and the Priority Pollutant Program, all of which required coordination to achieve an environmental goal(s). Almost every Agency action, initiative, grant, etc. has carbon implications. Petitioner asserts that Ocean Acidification is, at the very least, on a par with the problem these programs were designed to address. If this is not already being done, the petitioner asks the Agency to require that all significant actions take carbon benefits explicitly into account.

The Economic Costs of CO_2 and Discount Rate

The discount rate is critical in the unreasonable risk determination, as benefit estimates depend heavily on the discount rate applied. There is debate as to applicability of current methodologies to derive these rates when applied to distant events and transgenerational effects. As Cowen and Parfit pointed out "Why should costs and benefits receive less weight, simply because they are further in the future? When the future comes, these benefits and costs will be no less real. Imagine finding out that you, having just reached your twenty-first birthday, must soon die of cancer because one evening Cleopatra wanted an extra helping of dessert".[39]. Or putting it in terms of dollars instead of baklava: Frank Partnoy, (University of San Diego) observed "A human life is often estimated to be worth around $10 million. But if you apply a three percent discount rate to this, that means that a human life five hundred years from now is only worth $3.81 today."

Further, the basis for a discount rate is the opportunity cost of taking action today to avoid future effects, i.e., the discount used must reflect the profitability of the best alternative investment opportunity. However, global warming, and even ocean acidification will have such enormous effects on agriculture, real estate, water availability, fisheries, etc, that investments in many sectors could well have limited or even negative discount rates without mitigation action. People may well be poorer in the future because of ocean acidification and climate change and have less rather than more resources to mitigate and adapt[40].

To use an ocean acidification example, an investment in ocean property in Florida could well have a negative return (if not for the owner, than for federal government which guarantees flood insurance) when the coral reefs erode and flatten (as discussed in the body of the petition) and fail to provide adequate buffer for storm surges, as could investments in commercial fisheries. Climate change effects on investment returns would be even larger. For example, the IPCC predicts a 2% net decrease in agricultural production per decade from global warming. Petitioner asks the Agency to take into account how ocean acidification and climate change will affect return on capital investment when setting a discount rate in their assessment of benefits as recommended in USEPA's Guidelines for Preparing Economic Analysis. OMB Guidance on regulatory analysis states " In some instances, if there is reason to expect that the regulation will cause resources to be reallocated away from private investment in the corporate sector, then the oppor-

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[39] Tyler Cowen and Derek Parfit, Against the Social Discount Rate, in Peter Laslett and James S. Fishkin, eds, Justice Between Age Groups and Generations 144, 145 (Yale 1992).

[40] Johnson et al, Journal of Environmental Studies and Sciences September 2012, Volume 2, Issue 3, pp 205-221

tunity cost may lie outside the range of 3 to 7 percent. "[41] The same logic must apply when it is not the regulation but the effect itself that provides an economic distortion in the absence of regulation.

Petitioner asks the Agency to consider and explain the choice of using either a Willingness to Pay (WTP), or a Willingness to Accept (WTA) in the economic valuation of benefits. This seems germane relative to the loss of oceanic buffering capacity due to past absorption by the 600 billion tons of carbon emissions from the burning of fossil fuels. Like many other effects of Ocean Acidification this loss of capacity is not presently included in the calculation of the SCC. If the Agency decides to use a Contingent Valuation Method to value the lost buffering capacity, then WTA may be appropriate as this capacity is a public good.[42]

Low Probability Catastrophic Impact Effects

Current climate cost and benefit estimates do not take into account many low probability effects with catastrophic impacts. For example, there is research to estimate probability densities for positive feedback and/or climactic tipping points, such as unstable methane deposit releases from permafrost[43], the collapse of the marine food web, impacts to cloud albedo[44], or alterations in ocean circulation[45]. These may be low probability events, but have enormous consequences. Many of these can have catastrophic Earth System effects and once they occur are essentially irreversible. Because of this, current cost and benefit estimates must be considered conservative.[46]

This is one of the reasons why the President's Council of Economic Advisors recommended treating Climate Change prevention action as an insurance investment. Current regulations, proposed regulations, and planned regulations, do not address these severe Earth System potential impacts and do not, measurably decrease their likelihood of occurrence. Petitioner agrees with the President's Council that Climate Change be treated as an insurance investment, and asks that the potential cost of these low probability, very high impact effects, be valued to inform the TSCA section 6 unreasonable risk decision. In lieu of a better Agency alternative, Petitioner suggests the Agency estimate the cost of an insurance premium using occurrence and impact probability of these tipping points/catastrophic events as basis, much like insurance premiums in

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[41] OMB Circular A-4

[42] Kahneman et al, Journal of Environmental Economics and Management, 22 57-70, 1992

[43] Schaefer, K., T. Zhang, L. Bruhwiler, and A. P. Barrett (2011), Amount and timing of permafrost carbon release in response to climate warming, Tellus Series B: Chem. Phys. Met., DOI: 10.1111/j.1600-0889.2011.00527.x.; oven teal, Analysis of Permafrost Thermal Dynamics and Response to Climate Change in the CMIP5 Earth System Models, JOURNAL OF CLIMATE
2013

[44] Six K.D., Kloster S., Ilyina T., Archer S.D., Zhang.K, Maier-Reimer,E., Global warming amplified by reduced sulphur fluxes as a result of ocean acidification. Nature Climate Change, doi:10.1038/nclimate1981, 2013.

[45] Rahmstorf, S., Box, J., Feulner, G., Mann, M., Robinson, A., Rutherford, S., Schaffernicht, E. (2015): Evidence for an exceptional 20th-Century slowdown in Atlantic Ocean overturning. Nature Climate Change (online) [DOI: 10.1038/nclimate2554]

[46] Weitzman, Martin L. 2009. Review of Economics and Statistics 91(1): 1-19.

the nuclear energy industry against catastrophic incidents are calculated and apply that as a surrogate for the cost of not reducing carbon emissions to mitigate ocean acidification and accompanying climate benefit.

Other Insurance Considerations

Petitioner asks that the Agency consider as a cost any direct insurance impact from Climate change: “Climate change can also adversely impact the prevalence of vector-borne diseases, food poisoning, water quality, aeroallergens, and the health of natural systems that can cause economic losses for humans, sometimes insured” “Changing weather patterns and rising ocean temperatures as a result of climate change will also likely continue to put financial stress on the National Flood Insurance Program (NFIP). Currently, the NFIP has a $19 billion deficit, and this deficit may increase each year because of $900 million in subsidies to properties that are not paying actuarially based rates. In addition, the cost to the NFIP of servicing its debt consumes much of its revenue. ... millions of Americans depend upon the NFIP for flood coverage ...“

According to Dr Evan Mills (US Department of Energy’s Lawrence Berkeley National Laboratory) “there is growing acknowledgement among insurers that the impact of climate change on future insured losses is likely to be profound. The chairman of Lloyd’s of London has said that climate change is the number- one issue for that massive insurance group. And Europe’s largest insurer, Allianz, stated that climate change stands to increase insured losses from extreme events in an average year by 37 per cent within just a decade. Losses in a bad year could top US$1 trillion. Insurers increasingly recognise that it is the lack of action to combat climate change that is the true threat to their industry and the broader economy; engaging with the problem and mounting solutions represents not only a duty to shareholders but also a boon for economic growth.

The insurance sector thus finds itself on the front lines of climate change. The response of many, particularly in the United States, has been to focus on financial means for limiting their exposure to high-risk areas along the coastlines and areas prone to wildfires. Allstate, for instance, has said that climate change has prompted it to cancel or not renew policies in many Gulf Coast states, with recent hurricanes wiping out all of the profits it had garnered in 75 years of selling homeowners insurance. [47]The company has cut the number of homeowners’ policies in Florida from 1.2 million to 400,000 with an ultimate target of no more than 100,000. The company has curtailed activity in nearly a dozen other States.”

EPA Can Use TSCA to Complement Existing Federal Laws

Petitioner asks that, as required under TSCA, the Agency determine if relief is more efficient under any other Federal statute and if so, to use that authority as is required under TSCA § 9. Choosing a regulatory strategy and determining what actions are required to mitigate unreasonable risks is, again, inherently a governmental function. However, the cost and the efficiency of the mitigation options that are considered during regulatory development and assessment drive the determination of whether a risk is “unreasonable” and the array of alternatives considered need to be robust.

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[47] Conley 2007 in "Insurance in a Climate of Change: Availability & Affordability." Berkeley Lab, U.S. Department of Energy.

Because of the magnitude of Ocean Acidification risk, Petitioner believes good government demands the Agency consider a complete array of options using all authorities and tools available to efficiently address the problem. Petitioner will show that in addition to requiring relief under TSCA § 6, the Agency can use the TSCA § 9 authority to require action under either, or both, the Clean Air Act (CAA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authorities. Relief under these statutes should also be considered in determining the cost, benefit and the most efficient remedies to mitigate the harm and risk from Ocean Acidification.

Petitioner is aware that the Agency has recently planned and initiated several emission reduction actions aimed at slowing the rate at which carbon emissions are increasing. These actions by themselves while laudable, will not stabilize atmospheric CO_2 at a level that prevents widespread harm from ocean acidification. Consider that even with a successful implementation of the Agency's planned emission reduction regulations, atmospheric concentration will pass 450 ppm around 2030, a tipping point likely to induce aragonite undersaturation in surface waters. Petitioner believes that a combination of aggressive emission reduction and sequestration is necessary to mitigate the unreasonable risk and harm caused by ocean acidification. Both CERCLA and the CAA can provide relief.

Petitioner asks that the Agency consider whether that CERCLA and/or CAA authorities present efficient opportunities for remediating ocean acidification.

1) **Remedies under the Clean Air Act (CAA)**

There are several remedies under the CAA either directly accessible or accessible under TSCA section 9. Title 42 § 7415 of the Clean Air Act addresses endangerment of public health or welfare in foreign countries from pollution emitted in United States, and directs "the Administrator, upon receipt of reports, surveys or studies from any duly constituted international agency"...to have... " reason to believe that any air pollutant or pollutants emitted in the United States cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare in a foreign country ...the Administrator shall give formal notification thereof to the Governor of the State in which such emissions originate. The notice of the Administrator shall be deemed to be a finding under section 7410 (a)(2)(H)(ii) of this title "

There have been many reports addressing the endangerment of public health or welfare from ocean acidification that have been published by duly constituted international agencies and of which the Agency is well aware and in some cases participated in. These include: the Royal Society[48]; The European Union's European Project on Ocean Acidification (EPOCA) published over a hundred scientific papers detailing the effects; the UN's Climate Change and Ocean Acidfication Synegies and opportunities within the UNFCCC, Harrould-Kolieb and Herr; and Australia's GBRMPA published Climate Change and the Great Barrier Reef: A Vulnerability Assessment in association with 85 scientific and management experts; as well as numerous IPCC Reports, in which the Agency and other Departments of the Federal Government actively participate.

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[48] Royal Society (Ocean acidification due to increasing atmospheric carbon dioxide, 30 June 2005

The Columbia Journal of Law[49] describes the applicability of Section 115 to CO_2 regulation for ocean acidification mitigation, including the legislative history and how SIPs under section 7410 are mandated. The Agency's current Proposed Rule for Electric Utilities using section 7411, can serve as a template. The flexibility for State SIPs in the Rule includes by reference, their current State programs as applicable to compliance with the Rule. Some of these cited include provisions for, and allow "offsets" or carbon sequestration to be counted in reaching program goals, using for example, Cap and Trade. State by State assessment of legacy carbon could be calculated by the Agency from the Emission Inventory and these could be included in State Implementation Plans.

§ 7415 includes the requirement that a reciprocity finding that the affected foreign country gives the U.S. "essentially the same rights with respect to the prevention or control of air pollution occurring in that country as is given that country". This requirement directly addresses the often raised argument against US EPA action that posits: since Ocean Acidification has a global cause, only international action can address it successfully. Implementation of State plans would presuppose a concurrent implementation internationally. The Montreal Protocol (which found it's genesis in a TSCA action) could serve as a template for coordinating international plans for ocean acidification mitigation. The European Union's REACH (Registration, Evaluation, Authorization and Restrictions of Chemicals) regulation serves as an example of how a large attractive market (like the EU or the US) can induce foreign companies and government directed economies who wish to have continued access to the markets, to comply with environmental regulation.

Recently the US and China, which account for almost 40% of global carbon emissions, jointly announced new targets to cut emissions. Germany, Finland and other industrialized counties are also drastically cutting emissions. The foundation for a reciprocity agreement with the nations that account for most of the legacy and current emissions is already in place.

Alternatively, the CAA emission trading mechanism, which offers an often used, efficient market approach might also be accessed directly through TSCA section 9 to mitigate ocean acidification.

Under TSCA section 6: (1) A requirement ...." (B) limiting the amount of such substance or mixture which may be manufactured, processed, or distributed in commerce." ...clearly gives the Agency authority to limit current emissions, and Section 6's: "Any manufacturer or processor subject to a requirement to replace or repurchase a chemical substance or mixture may elect either to replace or repurchase the substance or mixture and shall take either such action in the manner prescribed by the Administrator." gives authority for trading options. While 'repurchase' is sequestration, "replace" is trading.

Since EPA has treated air pollutants like CO_2 as fungible in order to efficiently regulate when the "net" pollution is key, replacing carbon emitting facilities with new facilities that rely on renewable sources will reduce the net carbon in the atmosphere and thereby reduce the amount in the oceans. This would be one way for facilities to "pay down" their legacy carbon debt. The

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[49] Cap-and-Trade Under The Clean Air Act?: Rethinking Section 115 , H Chang, April 2010

Agency could consider a current carbon emitting facility's development of green (e.g. solar or wind) energy capacity to *replace* (not augment) fossil energy as a legacy offset. (Assuming this is not double counting, i.e., being used to bring the facility into compliance for current emissions under another requirement). The new energy production from the no- or low- emitting source would "replace" the carbon that would be emitted from the existing energy production source, leading to a net reduction in carbon emissions. This type of offset also has the advantage of helping to build the market base for green energy and eventually lower costs for additional facilities, accelerating the needed energy infrastructure change. This is an approach the German State is pursuing through subsidies.

2) Remedies under CERCLA Under the 42 U.S. Code § 9604 Response authorities

Whenever (A) any hazardous substance is released or there is a substantial threat of such a release into the environment, or (B) there is a release or substantial threat of release into the environment of any pollutant or contaminant which may present an imminent and substantial danger to the public health or welfare, the President is authorized to act (under 42 U.S. Code § 9621), consistent with the national contingency plan, to remove or arrange for the removal of, and provide for remedial action relating to such hazardous substance, pollutant, or contaminant at any time (including its removal from any contaminated natural resource).

CO_2 can meet the CERCLA definition of "hazardous substance in in either of two ways: 1) under 9602 "The Administrator shall promulgate and revise as may be appropriate, regulations designating as hazardous substances... such elements, compounds, mixtures, solutions, and substances which, when released into the environment may present substantial danger to the public health or welfare or the environment, or, 2) by definition: "any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to section 7 of the Toxic Substances Control Act".

If the Administrator takes action under TSCA §7 based on the imminent hazard to coral reefs and marine life, as explained in the petition, CERCLA becomes applicable[50]. While some risks to marine organisms from ocean acidification may be uncertain, many are not. Also, the risk to the coral reefs which provide protection to life and property along America's coastlines as well as significant recreational and nutritional benefits is both manifest and well documented and the risk is "imminent" within the definition of TSCA. (Alternatively, these same dangers might be used by the Administrator to directly designate CO_2 as a hazardous substance)

The imminence stems not from the point in time when the threat will be completely manifest but rather from the point in time when action must be begun to effectively mitigate or avoid the threatened effect(s). That time is now, primarily because of the enormous inertia in the carbon economic cycle. The infrastructure of energy use relies on fossil fuel combustion. There are no alternatives of sufficient capacity in the near term. To avoid reaching the point, mid to late century (given the current trajectory) where the oceans are undersaturated in carbonate and shells and coral begin dissolving wholesale, either a robust sequestration program must be developed,

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[50] CERCLA section 101(14)

and/or significant energy alternatives must be made available. These are both long term programs that require decades, and must begin now.

Scientists are well **aware of the enormous risk posed by ocean acidification.** A recent study in Science found that the largest extinction event on earth was caused by ocean acidification[51]. **Dr. Jane Lubchenco, The head of the National Oceanic and Atmospheric Administration from 2008 -2013 has called ocean acidification global warming's "equally evil twin."** Unfortunately, unlike the risk from Climate Change, the magnitude of the risk to the oceans from acidification is not well known or understood by the general public. A TSCA § 7 Notice informing the public of the serious risks to coral reefs, provides the information needed to decide if changes in personal energy use, and consumption is warranted. (TSCA § 7 grants EPA authority to "require warning labels and/or instructions on containers or products". USEPA could encourage consumer choice by labeling products with large embedded carbon volume).

Changes in energy use and consumption can begin to retard the ongoing increase in atmospheric CO_2 and to lessen the effect of acidification on coral reefs. Changes in consumer choice toward less carbon intensive products could build markets for those products, making them less expensive and spurring innovation. Information on the risks can help localities plan as well. Notification of risks is one of the TSCA § 7 remedies. A TSCA § 7 Notice explaining the risks would help inform decisions concerning where to live in order to be secure in life and property, given the inevitable loss of protection to some coastal areas from extreme weather events (coincidently expected to increase with climate change) which will occur with the loss of reefs.

It also seems reasonable that, to the extent the US is harmed, it can use CERCLA to fund remedies from transboundary actors, as was the case in the Trail Smelter Arbitration.[52] Wherein the downstream Confederated Tribes of the Colville Reservation, and the State of Washington, in the US sued a Canadian smelter for dumping into the Columbia River upstream in Canada under CERCLA. This is a successful resolution of an international dispute that provided an important principle of international customary law concerning state responsibility and transboundary pollution. (Again, a TSCA § 7 action for CO_2 effect on coral reefs would define CO_2 as hazardous under CERCLA.)

Another important theory of international law is the polluter-pays principle. This theory stands for the proposition that nations should focus on internalizing environmental costs for purposes of public interest by making the polluter bear the cost of pollution. By mandating that the responsible party bear these costs, the polluter-pays principle achieves the effect of encouraging individual responsibility for environmental harm. The countries attending the Rio Convention, including the US and Canada, reaffirmed this principle in Article 16 of the 1992 Rio Declaration"[53] CERCLA's strict, joint and several liability, holds polluters responsible for damage.

The oceans have essentially been a "dump site" for CO_2 emissions, so CERCLA is a natural vehicle for seeking remedy. CERCLA has been applied to other water bodies, e.g., the upper 40 or

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[51] Clarkson et al. Science 10 April 2015: Vol. 348 no. 6231 pp. 229-232

[52] United States District Court for the Eastern District of Washington, April 4, 2012

[53] Greenfield: CERCLA'S applicability abroad, Emory International Law Review;Fall2005, Vol. 19 Issue 3, p1697

so miles of the Hudson are a NPL site for pcb contamination. CERCLA is an excellent tool for seeking remedy from multiple, diverse parties, i.e., “CERCLA casts a wide net in bringing in responsible parties. Through the broad definition of hazardous substance (§101(14) - liability is extended to anything that presents an "imminent and substantial danger"), the loose interpretation of "release" (there is no time constraint on this) and the wide scope of liability (each party involved may be responsible for the entire clean up) the statute seeks to fund the clean up of these sites. Although there have been challenges to the apparently retroactive nature of this (because people are being held liable for actions that predate the statute), and as noted above, the courts have held that as the waste is continuing to cause problems, and the statute is not a punishment but rather a reimbursement obligation, the statute is not retroactive, and thus not unconstitutional. And again, small contributors can be and are routinely ignored if transaction costs are high.

Summary

Ocean acidification and its effects are complex and the state of knowledge is uneven. Depending on what USEPA knows and believes about the effects of ocean acidification there are a number of decisions that the Agency must make and actions associated with those decisions. In the introduction and in the body of the petition, petitioners ask USEPA to take several actions under TSCA § 4 and 6, and in this supplement petitioner asks the Agency to take additional appropriate actions under other federal statutes through TSCA § 9 and other TSCA authority, in order to mitigate the human health and environmental risk from ocean acidification caused by CO2 emissions.

The following describes the different paths the Agency can take in responding and what the petitioner believes the public deserves in each case. While mentioned below is the possibility of taking action under TSCA § 7, petitioner understands that § 21 cannot be used to for § 7 action, however, petitioner believes that the threat to coral reefs presented in the petition and as discussed herein make a compelling case for § 7 action.

1) EPA could decide that the current state of knowledge concerning ocean acidification is sufficient to decide that the risk(s) of ocean acidification are not unreasonable. This requires evidence that the demonstrated loss of the coral reefs, decrease in shell fish harvests, loss of competitiveness of pteropods and other organisms that secrete calcium carbonate and other ecological and health effects are known to the Agency, as are the ancillary climate benefits that occur with atmospheric carbon controls, are either outweighed by the cost of mitigation, which is also known to the Agency, or are not significant effects. In this case, petitioner asks that the Agency publish and share this information with the public.

2) EPA could decide that all or some of the information necessary to make the unreasonable risk finding is either not sufficient or not available, but this lack of data does not meet the criteria for action under TSCA § 2(b)(1) and/or TSCA § 4 . Petitioner expects in this case, an explanation of why the triggers are not met by the information presented in the petition. Since much of the risk cited in this petition come from EPA, NOAA, and other government sources, petitioner asks if USEPA has information that supersedes or discounts these conclusions, and if so to publish and share this information with the public.

3) EPA could decide that all or some of the information necessary to make the unreasonable risk finding is either not sufficient or not available, and take action under TSCA § 4. Petitioner expects in this case that the Agency will explain what information is sufficient and what is not, and develop test rules to gather information sufficient to make an unreasonable risk finding in a timely fashion.

4) EPA could decide that some of the risks from ocean acidification are unreasonable and take action under TSCA §'s 6, 9 and other statutes, but that some information is lacking for other risks and write a TSCA § 4 rule to develop the missing information. Petitioner expects in this case that the Agency will explain what information is sufficient and what is not, develop test rules to gather information sufficient to make an unreasonable risk finding for the risks that are uncertain, and take action for the risks that are unreasonable.

5) The Agency, in combination with any of the above options, could publish a TSCA § 7 Notice informing the public of the serious risks to coral reefs associated with ocean acidification, it's causes, and what must be done to mitigate it. As explained above this information is needed by the public to judge the severity of the risk, adequacy of governments response to protect human health and the environment, and what precautions, if any, are necessary to take.

6) EPA could grant the petition and propose rules to mitigate ocean acidification using TSCA, CERCLA, CAA and/or other Agency and Federal authorities as appropriate. Petitioner endorses this action.

Sincerely,

/s/ Donn J. Viviani

Donn J. Viviani PhD.

Donn J. Viviani is a retired U.S. Environmental Protection Agency scientist. He was the Director of the Climate Policy Assessment Division in the Office of Policy, Economics and Innovation. He also served as Chairman of the Great Lakes Water Quality Board's Toxic Substances Committee, and as a member of the Science Coordinating Committee for the International Joint Commission for the Great Lakes. Dr. Viviani greatly enjoys the ocean and cosigns the petition and submits this supplement, in part, so his grandchildren will be able to enjoy it as well.