Unforced Errors, Legal Fulcrum & International Climate

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UNFORCED ERRORS, LEGAL FULCRUM & INTERNATIONAL CLIMATE

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“The Earth is where we make our stand.”

Carl Sagan

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I. UNFORCED ERROR IN INTERNATIONAL POLICY

International leaders recently admitted a fundamental unforced error in their calculations shaping critical international law on the Earth’s atmosphere. This error is pushing world climate to the “tipping points” “that will alter regional and global environmental balances” “irreversible within the time span of our current civilization.”

International officials performed basic climate math incorrectly, not accurately inputting a critical key climate operand: Time. Any miscalculation regarding the basic science can operate in favor of the Planet or against it. This miscalculation works against the Planet, and increases tensions among world nations over one of the most contentious and lasting international issues, climate impacts.

The second most pernicious warming chemical was improperly factored and miscalculated by several hundred percent as to its real-time impacts on climate—a Herculean miscalculation of global proportions.

This article highlights this miscalculation, identifies precisely why it occurred with no real-time international correction, and then traces the lasting implications on climate and tension between developed and developing countries going forward in international policy and law. Starting with the chemistry: methane (CH\textsubscript{4}) even before correcting for global officials’ critical failure to consider real impact in real time, is considered by scientists as the second most pernicious warming chemical in the world, after carbon.

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3. See Seth Borenstein, The Great Methane Miscalculation, THE DURANGO HOTEL (Nov. 27, 2013) (An operand is one of the inputs (quantities) for an operation).


5. In real time methane is at approximately eighty-six times more heat trapping than CO\textsubscript{2}. The IPCC Fifth Assessment Report now calculates that a molecule of methane with its calculated lifetime of 12.4 years, exhibits a global warming potential of eighty-six times that of CO\textsubscript{2} (with a value of 1) when calculated over twenty years, or thirty-four times that of CO\textsubscript{2} when calculated over 100 years. Joe Romm, How the EPA and New York Times Are Getting Methane All Wrong, THINKPROGRESS, (Aug 20, 2015, 3:53 PM), https://thinkprogress.org/how-the-epa-and-new-york-times-are-getting-methane-all-wrong-eba397ce9e5f.
dioxide; alone, it causes more than one-quarter of international climate warming, traditionally as shown in Figure 1.6

Figure 1. Contribution of Current Greenhouse Gas Emissions to Global Warming

Nonetheless, the United Nations Framework Convention on Climate Change (UNFCCC) carbon policy, the Kyoto Protocol, and the recent international Paris Agreement, did not correctly calculate or calibrate methane’s critical real impact on climate and international law.7 The short-lived global warming chemicals include methane (CH₄), black carbon (“soot”), and fluorinated gases (F-gases, including hydrofluorocarbons (HFCs)), when correctly accounting for time, together are responsible for about forty percent of current net climate warming forcing change, not only one-third of this amount as traditionally assumed.8 Methane, alone, is responsible for the vast majority of this undervalued forty percent share of climate change.9 The United Nations International Panel on Climate


9. See id. at 10 tbl. 2 (showing methane as having the majority share of warming of chemicals other than CO₂).
Change (IPCC) concludes that to contain warming in the world to less than an increase (over historic levels) of no more than 2°C in temperature, there would need to be a forty to seventy percent reduction of greenhouse gas (GHG) emissions by 2050, including methane, from 2010 levels; to maintain an increase of no more than 1.5°C, a seventy to ninety percent reduction from 2010 levels is necessary.¹⁰

International climate policy focused myopically on one warming chemical: carbon dioxide (CO₂), the most prevalent GHG.¹¹ International organizations committed a palpable miscalculation by not assessing methane in its real-time impact, or factored into international law and policy its actual, accurate increasing damage.¹² Warming molecules released anywhere on the Planet, warm the entire world—not just the immediate space where they are released.¹³ This existing miscalculation of the warming impact of methane was not corrected or remedied as part of the international climate change agreements reached in Paris in December 2015. The international legal regime continued to overlook the real impact of methane and focus principally on carbon dioxide, which has a less intense molecular impact on climate than does methane in real time.¹⁴
This article re-analyzes international science, law, and policy in real time: analyzing the second actor now center-stage, methane, confronted by the next phase of remedial international law and policy. Sector by sector, this article identifies the required policy and law corrections to maintain control over global climate. The dominant role of methane, aside from carbon dioxide, in climate warming is shown in blue in Figure 2. Methane is the dominant causative factor among the short-lived chemicals in Figure 2 pushing the Earth to its climate warming “tipping point.”

1. Identifies the critical international policy error;
2. Corrects the real-time calculation of methane on climate;

3. Details all of the policy options in each sector of the economy for methane emission control in developing international countries;
4. Assesses the upcoming impact of a new $100 billion/year in annual international climate finance as a re-established fulcrum to remedy the problem; and
5. Contrasts policy responsibility internationally between developed and developing countries.

Section II re-examines the science of methane in real time, analyzes methane both quantitatively in its growing global impact, and qualitatively in its impact in real time, and identifies and outlines necessary corrections in how international law and policy must recalculate the real-time impact of methane on the planet’s environment. Section III analyzes the core sources of methane release from human activity, the prodigious use of fossil fuels around the globe in developing and developed countries, the impacts of recent substitution of natural gas for coal to produce electricity, as well as the substitution of renewable energy sources for fossil fuel use for electricity. Section III compares and contrasts at an international level the developed and developing countries’ options to control GHG emissions of the two chemicals that must be controlled, methane and carbon dioxide.

Section IV examines legal policy options to stop methane escaping from international waste management and handling in landfills, human waste processing, agricultural activities, and from coal extraction. Current international law and policy do not competently or adequately recapture methane waste, nor adequately recycle the captured methane waste to produce renewable energy. Section IV analyzes the policy options, potential results, and legal implications in real time, proposing legal and regulatory alternatives and assessing their efficacy.

Section V enters the international conflict; contrasting the developed countries’ responsibilities compared to the world’s developing countries’ obligations. Energy use is a principal driver of both methane and carbon dioxide emissions causing climate change. In the next five years, there will be a massive

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17. See Overview of Greenhouse Emissions: Carbon Dioxide, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/ghgemissions/overview-greenhouse-gases (last updated Oct. 31, 2018) (showing electric energy production as the most significant contribution); see also STEVEN FERREY,
investment in electrification projects internationally in developing nations.\footnote{18} It is projected that more than seventy-one percent of all future energy use and carbon dioxide emission increases will come from developing countries.\footnote{19} There currently are not programs addressing increasing amounts of methane emissions in developed countries.\footnote{20}

Having identified and excavated this international unforced error, the article constructively navigates a remedial course: Section V analyzes the new $100 billion/year in annual finance starting in 2020 for developing country climate adaption and mitigation (the largest sustained international transfer of wealth in history),\footnote{21} as an international legal fulcrum to correct the unforced error. Section V compares and contrasts international policy responsibilities between developed and developing countries. Analyzing how this international fulcrum could be correctly leveraged, the world could achieve a “win-win” climate outcome.

II. THE INTERNATIONAL SECOND CHEMICAL – METHANE

A. THE CALCULATION UNDERGIRDING INTERNATIONAL CLIMATE LAW

The Paris Agreement of the UNFCCC Conference of the Parties on Climate Change in December 2015, with 186 nations of the 197 nations attending, agreed to hold “the increase in the global average temperature to well below 2°C above pre-
and to “pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.” These promises ignore a different reality: The world is not scheduled to maintain anything close to the pledge of all nations in the 2015 Paris Agreement of a 1.5-2°C temperature increase; instead, the world is already on a path to reach a temperature increase of at least 4°C.

The three predominant GHGs—carbon dioxide, nitrous oxide, and methane (see Figure 1)—occur both naturally and as by-products of human activities. The three more minor GHGs—HFCs, sulfur hexafluoride, and perfluorocarbons (PFCs)—all are synthetic chemicals manufactured and released only by humans. Methane is, by a large margin, the second most damaging GHG after carbon dioxide, as shown in Figure 1. Of key note, according to the conventional UNFCCC policy calculations, methane has twenty to thirty-six times more greenhouse warming capacity (the ability to trap infrared heat) per molecule than does carbon dioxide.

However, this is not correct science and does not create a platform from which to implement correct policy: qualitative and quantitative impacts are critical to perform the correct math. A gram of methane in the atmosphere absorbs seventy times more infrared radiation than a gram of carbon dioxide. Therefore, it is at least seventy times—and by some accounts 100 times—more heat trapping than carbon dioxide. Correspondingly, the UNFCCC has underestimated the role of methane by a factor of

24. WILLIAMS ET AL., supra note 11.
25. STEVEN FERREY, ENVIRONMENTAL LAW: EXAMPLES & EXPLANATIONS 249 (7th ed. 2016) [hereinafter FERREY, ENVIRONMENTAL LAW].
26. Id. at 250.
approximately 300 percent. This is a major policy miscalculation of the basic math that could jeopardize the climate future of the planet.

This legal policy miscalculation occurred because international regulatory institutions have not correctly factored in the constant of real time, which adds a key additional dimension. The United Nation's UNFCCC calculation of chemical impact calculates all chemicals' impacts over 100 years regardless of actual longevity or impact; this arbitrarily and inaccurately dilutes the actual impact in real time and results in assigning methane molecules a heating value of only 28 to 36 times more heat-trapping than carbon dioxide, rather than a value three times greater. The scientific reality is that methane does all of its damage in a more concentrated period of slightly more than a decade, before chemically degrading to non-methane molecules. It is much more intense than acknowledged in its real climate impact in time.

The incorrect calculation ignores the real dimension of time and grossly underestimates the actual impact of methane in real time in the environment. Conventionally, using IPCC estimates for a 100-year time period, a molecule of methane is twenty-eight to thirty-five times more warming, nitrous oxide is 265–298 times more warming, and various HFCs a thousand to tens of thousands of times more warming, than a molecule of carbon dioxide. The conventional extrapolation to a one-hundred-year normalization underestimates the real-time impact of methane on the climate. Over its real-time ten- to twenty-year actual life time, the impact of methane is at least three times greater than as conventionally recalculated and diluted over an incorrect 100-year normalized period. Correctly adjusting for time, recent Harvard University research places the real climate damage of methane at between eighty-six and 105 times that of carbon dioxide.

There are cascading international effects. In addition to warming, methane in the atmosphere also contributes to tropospheric ozone formation—another GHG—and potentially

31. See The White House, supra note 15, at 89.
32. Id.
33. See Romm, supra note 5.
34. McKibben, New Chemistry, supra note 7.
stratospheric ozone depletion.\textsuperscript{35} Methane, when burned, produces only half as much carbon as burning an equivalent heating value of coal; although when it escapes unburned, methane traps heat in the atmosphere much more efficiently than carbon dioxide.\textsuperscript{36} These characteristics make methane an extremely potent GHG, giving it as much as 120 times more heat-trapping power than carbon dioxide.\textsuperscript{37}

\textsuperscript{35} See INST. FOR GOVERNANCE & SUSTAINABLE DEV., PRIMER ON SHORT-LIVED CLIMATE POLLUTANTS, 10–11 (Nov. 2012), http://www.igsd.org/documents/PrimeronShort-LivedClimatePollutants.pdf (noting that methane also contributes to global background levels of ozone in the lower atmosphere (troposphere)).


\textsuperscript{37} U.S. ENVTL. PROT. AGENCY, OFFICE OF AIR AND RADIATION, EPA/400/G-90/007, METHANE EMISSIONS AND OPPORTUNITIES FOR CONTROL 21 (1990) (publishing the findings of two international workshops sponsored by the International Panel on Climate Change which focused on current methane emissions and opportunities to control these emissions).
Making a qualitative adjustment that accurately reflects the additional dimension of time, alone, will not rectify international legal policy. Contrast the quantification of methane comparing the traditional government data showing methane as only sixteen percent of total GHG impact on climate in Figure 3 and the more recent independent, larger calculation reflected conservatively in Figure 1, both of which still do not reflect the even larger methane impact adjusted for real time. Harvard University research data suggest that the natural-gas infrastructure has been bleeding raw, un-combusted methane into the atmosphere in record quantities.\(^{39}\) This Harvard work suggests that world carbon regulators have not correctly estimated success in addressing warming, because there are

\(^{38}\) IPCC, supra note 10, at 5, Fig. SPM.2.

\(^{39}\) McKibben, New Chemistry, supra note 7.
actual increases in methane emissions where officials have publicly stated that they have been decreasing.40

B. THE SOURCE, THE SOLUTION

Bacteria that adapt to relatively oxygen-free environments produce methane, including in garbage landfills, bogs, marshes, rice paddies, arctic permafrost, and the intestinal tracts of animals.41 Methane remains a potent climate pollutant, up to approximately eighty six times more powerful than carbon dioxide over a twenty-year timeframe. It exerts an even higher impact on climate when normalized over a decade, and is thirty-four times more powerful when officials normalize the data over 100 years, as they conventionally have.42

Data indicate that methane levels in the atmosphere have increased by almost 100 percent since 1800.43 Euan G. Nisbet notes that “[r]oughly one-fifth of the increase in radiative forcing by human-linked GHGs since 1750 is due to methane”;44 and additionally that “the past three decades have seen prolonged periods of increasing atmospheric methane.”45 Although the growth rate slowed in the 1990s and particularly from 1999 to 2006, the methane burden on the atmosphere has increased since.46

The 2013 international IPCC report noted that the radiative forcing of methane measured from 1750–2011 was 0.48 W/m2 [±0.05], which was more than a quarter of carbon dioxide radiative forcing.47 But recent reports present new radiative forcing calculations, making the radiative forcing number twenty-five percent higher (increasing from .48 W/m2 to .61

40. Id.
41. Schneider, supra note 27, at 100–101.
43. See Schneider, supra note 27, at 101.
45. Id.
46. Id. at 494.
W/m²). In addition, the global methane emissions rate of increase continues to grow at a rapid rate. From 2014 to 2015, global methane increased substantially faster (11.5 ppb/yr) than it had from 2007 to 2013 (5.7 ± 1.2 ppb⁻¹). The Institute for Governance and Sustainable Development (IGSD) report forecasts that methane emissions are expected to grow twenty-five percent over 2005 levels by 2030, which is due to increased production from coal mining, growth in agricultural, municipal waste emissions, and oil and gas production, which could have a large impact on emissions estimates. The US Energy Information Administration (EIA) projects consumption of natural gas (methane) worldwide to increase from 120 trillion cubic feet (Tcf) in 2012, to 203 Tcf in 2040; a roughly sixty-nine percent increase.

In terms of policy concern, this is a larger increase of methane concentrations in the atmosphere than occurred for carbon dioxide, on which chemical international climate policy has been focused. This increase in methane accumulation in the environment is mainly attributed to population growth and human-related activities, accounting for about two thirds of total methane emissions. The primary sources of anthropogenic methane emissions are oil and gas systems, rice cultivation, landfills, wastewater treatment, emissions from coal mines, and agriculture, including enteric fermentation, and manure management.

International law and policy can and should exert greater leverage to recapture more of this damaging release of GHG chemicals. Although methane presents numerous problems when released directly into the Earth’s atmosphere, it offers...

48. See M. Etminan et al., Radiative Forcing of Carbon Dioxide, Methane, and Nitrous Oxide: A Significant Revision of the Methane Radiative Forcing, 43 GEOPHYSICAL RES. LETTERS 24, 12,614 (2016).
50. See INST. FOR GOVERNANCE & SUSTAINABLE DEV., supra note 35, at 11.
51. See INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 37.
52. Nisbet, supra note 44, at 493.
significant benefits when captured and utilized as an energy source, with methane being a constituent of natural gas. When compared with other fossil fuels, natural gas combustion emits significantly lower emissions of carbon dioxide, sulfur dioxide (SO₂), oxides of nitrogen (NOₓ), and particulates. When directly substituted for electricity generated by other fossil fuels, significant reductions of carbon dioxide are achieved in the burning of natural gas.

Existing technologies and strategies globally could reduce short-lived climate chemical pollutants emissions and reduce the expected rate of global warming by half. The California Environmental Protection Agency has said that “[u]sing cost-effective and available technologies and strategies, worldwide anthropogenic sources of [short-lived climate chemical pollutant] emissions could be significantly controlled by 2030,” resulting in global benefits. Doing so requires a multi-media international strategy successfully implemented to recycle and utilize organic waste for:

- Soil amendments/compost,
- Electrical generation and grid interconnection,
- Transportation fuel, and
- Pipeline-injected renewable natural gas.

54. U.S. Steel Corp. v. Hoge, 468 A.2d 1380, 1386 (1983) (Flaherty, J., dissenting) (noting that natural gas shares many characteristics with coal-bed gas, often called methane, but it is generally found in strata deeper than coal veins).
55. Environmental Impacts of Natural Gas, UNION OF CONCERNED SCIENTISTS, https://www.ucsusa.org/clean-energy/coal-and-other-fossil-fuels/environmental-impacts-of-natural-gas#.WkZSFlQ-eLI (noting that global warming emissions from natural gas are much lower than those of oil and coal: “[c]leaner burning than other fossil fuels, the combustion of natural gas produces negligible amounts of sulfur, mercury, and particulates. Burning natural gas does produce nitrogen oxides (NOx), which are precursors to smog, but at lower levels than gasoline and diesel used for motor vehicles.”).
56. U.S. ENVTL. PROT. AGENCY, supra note 37, at 37.
57. PROPOSED SHORT-LIVED CLIMATE POLLUTANT REDUCTION STRATEGY, supra note 8, at 1 (“[This would] keep average warming below the dangerous 2° C. . . . threshold at least through 2050 . . . [c]utting global SLCP emissions immediately will slow climate feedback mechanisms in the Arctic.”).
58. Id. at 2.
59. Id. at 2–3.
Doing so would also:
• Cut methane emissions from dairy operations by more than forty percent,\(^{60}\)
• Eliminate disposal of organic materials in landfills,\(^{61}\) and
• Significantly reduce fugitive methane emissions from oil and gas systems.\(^{62}\)

Opportunities for controlling anthropogenic methane emissions include the installation of methane recovery systems at landfills, improvements in leak detection and containment at natural gas transportation systems, fire management programs for biomass burning, and recovery of coal-bed methane from coal mining operations. It is estimated that if one-third of the technically feasible fugitive methane release reductions could be achieved within the next ten years, then atmospheric methane concentrations could be stabilized.\(^{63}\) Therefore, if laws and regulations are correctly implemented internationally to reflect the correct role of methane emissions, a global remedy would be possible. However, coal production worldwide is expected to increase significantly over the next few decades, with a resulting increase (rather than decrease) of methane emissions in some countries estimated to be twenty-five percent.\(^{64}\)

Next, we assess the role of fossil fuel and methane risk to the climate.

III. FOSSIL FUEL SUPPLY, USE, AND METHANE

In 2012, eighty-seven percent of primary energy use in the world is from fossil fuels.\(^{65}\) The release of methane is associated with extraction, transportation, and use of these fossil fuels, which collectively warms the atmosphere at key stages of the process of extracting and utilizing fossil fuels. Among the fossil

\(^{60}\) Id. at 66.
\(^{61}\) Id. at 71–72.
\(^{62}\) Id. at 76–80.
\(^{63}\) See U.S. ENVT. PROT. AGENCY, supra note 37, at 28.
\(^{64}\) Id. at 38.
fuels, the coal-mining sector accounts for approximately ten percent of methane emissions.66

A. ELECTRIC POWER CONFRONTS METHANE

The electric power sector internationally is a critical energy sector in every country, both in terms of function and its GHG emissions to the atmosphere.67 Electricity was recently designated as the second-most important invention since the wheel.68 Nothing is more indispensable than electricity in the modern economy.69 The Congressional Research Service concluded that “in 2010, fossil fuels accounted for seventy eight percent of U.S. primary energy production,”70 which is a smaller share than it comprises among total world economics.71 The oil-and-gas industry is the largest emitter of methane, and is responsible for twenty-nine percent of the U.S.’s overall methane emissions.72

Hydropower is a major source of power in many developing countries; even dams produce methane.73 From two-thirds to

66. WHITE HOUSE, CLIMATE ACTION PLAN: STRATEGY TO REDUCE EMISSIONS, at 5 (2014).
67. See generally INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 9 (citing statistics of current, past and future predictions of fossil consumption by region and worldwide).
68. James Fallows, The 50 Greatest Breakthroughs Since the Wheel, THE ATLANTIC (Nov. 2013), https://www.theatlantic.com/magazine/archive/2013/11/innovations-list/309536/ (Electricity finished behind only the movable type printing press; electricity is essential to operate seven other ‘top 50’ inventions of all time: The Internet, computers, air-conditioning, radio, television, the telephone, and semiconductors).
69. See generally FERREY, ENVIRONMENTAL LAW, supra note 25, at 580–82.
71. Gonzalez & Lucky, supra note 65 (noting eighty seven percent of worldwide primary energy consumption is from coal, natural gas and oil).
73. Hydroelectric Dams Emit a Billion Tonnes of Greenhouse Gases a Year, Study Finds, GUARDIAN (Nov. 14, 2016), https://www.theguardian.com/global-development/2016/nov/14/hydroelectric-dams-emit-billion-tonnes-greenhouse-
three-quarters of a dam’s total GHG emissions are in the form of methane — organic matter behind a dam decays and releases GHGs — with the remainder of dam-related emissions being carbon dioxide. Because methane is a relatively potent GHG, one Brazilian hydroelectric project created GHG emissions equal to those otherwise emitted from the city of Sao Paulo, Brazil.

Natural gas combustion produces carbon dioxide emissions at about a twenty-five percent lower amount per equivalent unit of energy produced than oil, and only approximately half as much as coal combustion; and gas produces less than four of the six criteria air pollutants regulated by many countries’ laws. More gas available at lower prices today and going forward will mean a rise of fifty percent in global demand for natural gas as an energy source between 2010 and 2035, according to the International Energy Agency (“IEA”). This could raise atmospheric concentrations of carbon dioxide to 650 parts per million, causing world temperature to rise dramatically, which would undercut climate change work being implemented across the globe.

Since the first use of electricity in the 1870s, coal has been used as the primary fuel for electricity production in the world and in the U.S. There has been a recent change where coal use has decreased dramatically in the last five years in the U.S. and also in China. The decreasing share of coal-fired power

gas-methane-study-climate-change ("We estimate that dams emit around 25% more methane by unit of surface than previously estimated.").
75. Id.
76. See generally FERREY, ENVIRONMENTAL LAW, supra note 25, at 594–96 (discussing the advantages of natural gas emissions versus coal emissions).
78. See New Chemistry, supra note 7 (describing how methane releases from natural gas resource development will substantially contribute to climate change even though natural gas burns cleaner than coal or oil).
80. See Rakteen Katakey, World Coal Production Had Its Biggest Drop on Record, BLOOMBERG MARKETS (June 13, 2017), https://www.bloomberg.com/news/articles/2017-06-13/coal-era-starts-to-wane-as-world-shifts-to-cleaner-energy ("[In 2016], China, the world’s biggest energy consumer, burned the least coal in six years and use dropped in the U.S. to a level last seen in the 1970s.").
generation in the U.S. from almost sixty percent in the mid-1980s, to 27.4 percent in 2018, counterbalanced by an increasing share of power generation from natural gas to 35.1 percent in 2018,\textsuperscript{81} is shown through 2016 in Figure 4.

Coal use worldwide is expected to increase significantly, at a rate of 0.6 percent per year from 2012 to 2040.\textsuperscript{82} With hydro-fracking, the U.S. now suddenly has liberated the largest recoverable reserves of oil and gas resources.\textsuperscript{83} Energy markets are now international. As long as developing countries continue to increase coal use,\textsuperscript{84} the U.S. could be the supplier of increasing world coal markets even if U.S. coal use continues its fast-declining path, as U.S. proven coal reserves are the largest in the world.\textsuperscript{85}

\textsuperscript{82} INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 3.20.
\textsuperscript{84} INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 64.
1. Effect of Renewable Power Deployment on Warming in the 21st Century

U.S. coal demand will fall to a thirty-year low, caused by relatively weak economic growth, a shift to renewable energies, and improved energy efficiency, which also will trim European demand for coal. With natural gas prices decreasing in the last decade, unrelated to this, the cost of key renewable power generation technologies has decreased even more rapidly. A big change is ushered in through the technological and cost declines of wind and solar photovoltaic (“PV”) technologies.


distributed generation.\(^9\) Photovoltaic solar panels have plunged dramatically by approximately sixty percent.\(^9\) Prices for PV panels have declined from \(\sim \$1.90/watt\) in 2009 to between \(\$0.35\) - \(\$0.70/watt\) around the world.\(^9\) To convert photovoltaic direct current to alternating current distributed by the grid, inverter prices declined by more than sixty percent from 2005 to 2013.\(^9\)

Consequently, the solar photovoltaic market increased at more than forty percent average each year, estimated almost triple PV capacity over the next five years.\(^9\) Internationally, solar photovoltaic modules have decreased in cost by eighty percent since 2009, and continue to decline.\(^9\) Internationally, wind turbine prices have decreased by approximately half over the same most recent eight years, yielding to wholesale electric power from onshore wind projects at an international price equivalent to \(\$0.06/kWh\) in 2017.\(^9\) Figure 5 illustrates the approximately one-third decrease in solar energy costs in the U.S. over the most recent decade, and the related increase in solar generation capacity.\(^9\)


\(^90\). Shaina Mishkin, Are Home Solar Panels Worth the Cost? Here’s When They Make Sense – And When They Don’t, TIME (Apr. 10, 2018), http://time.com/money/5229935/when-to-install-home-solar-panels/.

\(^91\). WILSON RICKERSON ET AL., RESIDENTIAL PROSUMERS - DRIVERS AND POLICY OPTIONS (RE-PROSUMERS) 9, 70 (2014).

\(^92\). RICKERSON ET AL., supra note 91, at 9 (changing from \(\$0.60\) - \(\$1.00+/watt\) in 2005 to less than \(\$0.20/watt\) in 2013); see NAVIGANT CONSULTING INC., A REVIEW OF PV INVERTER TECHNOLOGY COST AND PERFORMANCE PROJECTIONS (2006).


\(^95\). Id.

\(^96\). UNITED STATES MID-CENTURY STRATEGY FOR DEEP DECARBONIZATION, supra note 15, at 17 Figure E9.
Wind power is now the cheapest electricity source in Germany and the U.K., even without government subsidies, and is expected to be cheaper than coal and gas before 2025.\footnote{97} Clean energy investment was $329 billion in 2015, with an estimate that investment in wind, solar and other clean technologies is projected to reach about $7 trillion by 2040.\footnote{99} New solar capacity in developing nations surged fifty-five percent to 34 GW in 2017.\footnote{100} China accounted for twenty-seven GW, almost eighty percent of the total, followed by India with 4.2 GW, with installed capacity at least doubled in some countries including Brazil, Chile, Mexico, and Pakistan.\footnote{101}

\footnote{97} Id.
\footnote{99} Andrea Vittorio, Climate Deal Requires Trillions More in Investment, 47 BLOOMBERG BNA ENVT REPORTER 308, 308 (2016).
\footnote{100} Chisaki Watanabe, Solar Jumps in Developing Nations with Cheap Panels, Innovation, BLOOMBERG BNA DAILY ENVT REPORT, at 19 (Nov. 28, 2017).
\footnote{101} Id.
The projection of the DOE, going forward, is that there will be a significant increase in natural gas usage and various non-hydro renewable power resources, with a corresponding significant decrease in coal use, in the next twenty-five years, as shown in Figure 6. Substitution of renewable wind and solar power, both intermittent and relatively unpredictable sources of power, in place of conventional fossil-fired generation, has implications both for electric power grid reliability and for an increase of emissions from ramping back-up power supply. New, intermittent wind and solar renewable resources deployed internationally cannot supply reliable around-the-clock base-load power.

102 See United States Mid-Century Strategy for Deep Decarbonization, supra note 96.
104 See Steven Ferrey, Law of Independent Power § 2:11 (45th ed. 2018) (noting inability of intermittent sources to serve as base-load resource). Wind and solar are not reliable as peak power, because they are not reliably available on call.
Without cost-effective power storage, which does not currently exist at a reasonable cost, “spinning” non-quick-start reserve fossil-fuel-fired units will need to be maintained at partial-power output to be ready to operate on immediate notice when wind power dies or clouds pass between the sun and solar collectors.\textsuperscript{105} Evidence from the most advanced state subsidizing the storage of electric power, California, with its Self-Generation Incentive Program has demonstrated that energy storage increased statewide GHG emissions in 2016 and 2017. This occurs when consumers charge storage when fossil-fuel-fired projects are at the margin of the wholesale power queue as the next to be will be used at the margin for additional consumption to charge storage batteries.\textsuperscript{106}

Excessive generation by intermittent renewable energy has already become an issue in several countries at the forefront of the adoption of renewable energy: “Germany rapidly built up wind and solar resources but did not adequately plan for the problems posed by their intermittency.”\textsuperscript{107} As a result, to ensure its grid stability, Germany was forced to construct additional coal-fired base-load generation after its commitment to retire its nuclear facilities following the Fukushima disaster in Japan, between 2011 and 2015 opening 10.7 GW of new coal-fired power stations.\textsuperscript{108} Half of Tamil Nadu’s large amount of 8,000 MW of installed wind capacity is curtailed and nonoperational, in part, because distributors can’t afford to transmit the wind power given existing transmission tariffs and artificially low power pricing.\textsuperscript{109} During February to April 2014, the California

\textsuperscript{105} See RANDY T. SIMMONS ET AL., THE TRUE COST OF ENERGY: WIND POWER 32 (2015); see infra Figure 8; see also J. Nicolas Puga, The Importance of Combined Cycle Generating Plants in Integrating Large Levels of Wind Power Generation, ELECTRICITY J., Aug.–Sept. 2010, at 33 (“[T]o facilitate the integration of large penetration of wind, SPP will have to make sure that generation sources connected to its system are flexible enough to accommodate the intermittent nature of wind generation”).


\textsuperscript{108} Id. (“[B]etween 2011 and 2015 Germany will open 10.7 GW of new coal-fired power stations.”).

\textsuperscript{109} Rajesh Kumar Singh & Anindya Upadhyay, India’s Dilemma: Cheap Power or Energy?, ENERGY & CLIMATE REP. (BNA), July 2015, at 15–1.
Integrated System Operator was forced to curtail wind and solar generation four times for a total of six hours to balance supply and demand on the system, which curtailments raised power system costs.\textsuperscript{110} A significant number of wind turbines in China, comprising more than fifteen percent of the country’s wind capacity, were not able to operate because of the grid’s inability to absorb and transmit the power, even as China adds more wind turbines.\textsuperscript{111}

As one redeploys existing fossil-fuel facilities to fill growing gaps created by intermittent power, there is an efficiency and environmental price which few studies have recognized or factored in.\textsuperscript{112} Natural gas combined cycle turbine facilities, which can be modified to increase their start-up times by up to fifty percent to accommodate pressure and temperature transients of their steam turbines and readiness of their heat recovery steam generators, still may not be flexible enough to be able to follow and instantaneously respond to the ongoing intermittency caused by use of greater renewable power in the grid.\textsuperscript{113} Other power generation technologies must cycle up and down to fill the gap created by intermittent renewable energy technologies when the evening starts and electric demands peak.\textsuperscript{114}

Natural gas-fired combined cycle power generation units will experience higher heat rates, less efficient operation,

\begin{itemize}
  \item 110. See David Howarth & Bill Monsen, \textit{Renewables Face Daytime Curtailments in California}, NORTON ROSE FULBRIGHT (Nov. 20, 2014), http://www.nortonrosefulbright.com/knowledge/publications/150410/renewables-face-daytime-curtailments-in-california (“The impact on individual generators depends on the terms of their power purchase agreements, but typically there is no compensation for curtailment that is ordered by the grid operator.”); “On one occasion, the maximum curtailment reached 485 megawatts of wind and 657 megawatts of solar.” Id.
  \item 111. \textit{More Idled Wind Turbines in China as Capacity Grows}, ENERGY & CLIMATE REP. (BNA), July 29, 2015, at 30–31 (“The rate of idled turbines was, on average, 15.2 percent . . . according to data from the National Energy Administration. That is almost 7 percentage points higher than the same period [in 2014].”).
  \item 112. SIMMONS ET AL., supra note 105, at 32.
  \item 113. See Puga, supra note 105, at 38 (explaining the types of limitations of natural gas combined cycle turbine facilities that “limit the fast startup and rampup capabilities of the gas turbine.”).
  \item 114. Cf. \textit{UNITED STATES MID-CENTURY STRATEGY FOR DEEP DECARBONIZATION}, supra note 15, at 51 fig. 4.8 (illustrating how a variety of energy sources can be employed to promote grid flexibility to fill gaps created by intermittent energy sources such as wind and solar energy).
\end{itemize}
greater maintenance expenses, and consequently, greater unavailability when operated in a mode to try to backstop the intermittency of other intermittent power generation resources. This so-called “ramping” up and down of fossil fuel power generation units can increase maintenance costs requiring earlier replacements of certain generation facility components. European data illustrate that their shift from traditional coal unit operation to more operation of natural gas-fired combined cycle power generation units, resulted in an increase in these units’ operation and maintenance costs, outages, and less availability to supply power to the grid.

Such “spinning” of fossil fuel units operating in a load-following backstop mode expel a more profligate profile of environmental emissions when operating in the “ready” mode at partial capacity. One analysis of coal-plant cycling against intermittent renewable power generation’s hourly variations found that emissions during such cycling were eight percent higher per unit of electricity produced for the regulated criteria pollutants of sulfur dioxide and ten percent higher for nitrogen oxides than emissions of the same compounds during constant operation of the equipment. Nitrogen oxides contribute to global warming. This will add to nitrogen oxides and carbon dioxide emissions to the atmosphere to alter the emission profile of existing resources from normal to “standby” modes. Transitioning from fossil fuels to low-carbon energy not only diminishes the amount of carbon dioxide emitted during combustion, but also reduces methane emissions associated with fossil fuel extraction.

115. Id.
116. RICKERSON ET AL., supra note 92, at 53.
118. See Puga, supra note 105, 37–38.
119. Id. at 38.
121. See Puga, supra note 105, at 38.
122. UNITED STATES MID-CENTURY STRATEGY FOR DEEP DECARBONIZATION, supra note 15, at 89.
2. Comparing Developing Country Trends

More than eighty percent of future energy consumption increase will come in and from developing countries.\footnote{123} By 2040, energy use in developing countries is projected to be more than twice as much as that in developed countries.\footnote{124} For comparison, coal is in rapidly declining use in the U.S. where coal-fired power generation has been steadily decreasing since its peak a decade ago, recently constituting approximately 29.9 percent of U.S. energy sources,\footnote{125} even though Americans consumed more energy overall.\footnote{126} In the next five years, under increasing competition from shale gas and the Environmental Protection Agency’s regulations affecting power plant emissions,\footnote{127} U.S. coal demand will fall to a thirty-year low. In Europe, weak economic growth, a shift to renewable energy, and improved energy efficiency will trim European demand for coal.\footnote{128}

In many developing countries, there is a contrary scenario: many large developing countries are building additional coal plants as fast as possible, rather than primarily developing renewable power as an alternative.\footnote{129} The international coal industry asked the United Nations to establish a part of the new U.N. Green Climate Fund to underwrite the more than 2,000 new coal-fired power plants planned or being built in Asia and Africa, which would deploy new technology to cut carbon
emissions by one-third compared to vintage coal plants, while adding fifty percent to the cost of the plants.\footnote{130}

Focusing on the largest GHG-emitting countries, China, India, and other developing countries are underwriting the largest push into more high-carbon coal-fired power production in world history. While less GHG-emitting natural gas use is increasing in the U.S. power sector as documented above, coal use dramatically is increasing internationally, as shown in Figure 7.\footnote{131} In many developing non-Organisation for Economic Co-operation and Development (OECD) countries, which include more than eighty percent of all world nations, coal use for generation is still the current choice for electric power expansion.\footnote{132} According to the International Energy Agency, global demand for coal has made it the fastest-growing fossil fuel internationally and its use will rise 2.1 percent annually, driven mainly by China, India, and other expanding Asian economies.\footnote{133}

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130. Mathew Carr, Coal Industry Looks to UN Green Climate Fund for Aid, ENERGY & CLIMATE REP. (BNA) (Oct. 8, 2015).
131. INTERNATIONAL ENERGY OUTLOOK 2013, supra note 19, at 70 (providing charts detailing past and projected coal consumption).
132. See INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 64–68 (describing the coal consumption of non-OECD countries).
133. Mitchell, supra note 87. India, averaging 5 percent annual coal demand growth, should pass the United States as the world’s second-biggest coal consumer by 2019. Id. China, the world’s biggest producer and importer of coal, should see coal demand grow 2.6 percent, or 100 million tons, per year to 2019, assuming it maintains an annual gross domestic product growth rate of about 7 percent. Id.
Among world nations, China dominates coal production and use today.135 Almost half of annual global extraction of coal occurs in China, where “since 2000, coal production by China has increased by 139%,” with India in second position.136 In 2007, China built more new coal-fired power plants than Britain—the seat of the coal-fired industrial revolution—built in its entire history of its industrial revolution.137 Recent trends are not encouraging: after dipping slightly in 2016, increased coal use rebounded in China and India in 2017.138

134. INTERNATIONAL ENERGY OUTLOOK 2013, supra note 19, at 68, 70 (providing the past and projected data used to create this chart).
136. See id.
138. See Mathew Brown & Katy Daigle, Coal on the Rise in China, U.S., India After Major 2016 Drop, CHI. TRIB. (June 26, 2016),
China, being the world’s largest coal producer and user, built one large coal plant per week in 2013. China replaced the United States as the world’s largest emitter of carbon dioxide in 2006. By 2010, China had the highest emissions in the world per unit of gross domestic product (GDP) by a factor more than double that of any other nation. In 2005, China’s energy consumption per unit of GDP was more than three times the level of the United States, more than five times that of Germany, and eight times that of Japan. This inefficient use of fossil fuel warms the planet.

China and India harbor around one-quarter of the world’s coal reserves and are deploying them rapidly to fire both existing and planned additional electric power plants. Coal is approximately forty-four percent of India’s energy source, and the power sector is one of the largest and fastest-growing areas. By the year 2030, “coal-fired power in India and China will add 3000 million extra tons of carbon dioxide to the atmosphere every


143. See Lord Ronald Oxburgh, Capturing the Moment, PARLIAMENTARY MONITOR, July 21, 2006, at 42 (“Together [India and China] have around a quarter of the world’s coal reserves, and coal-fired power stations will undoubtedly play a central role in their rapid economic development.”).


145. Id. (“India’s power sector is one of the largest and fastest-growing areas of energy demand, rising from 11% to 15% of total energy consumption between 2000 and 2013.”).
year.” Therefore, just the additional carbon dioxide emissions from the China and India electric power sectors, alone, will constitute approximately ten percent of all world carbon dioxide emissions from all sources. China and India are projected to account for 3000 million extra tons of annual carbon dioxide emissions to the atmosphere by 2030.

B. FOSSIL FUEL ALTERNATIVES IN INTERNATIONAL POWER SECTORS

Methane and ethane are the primary molecules in natural gas fuel. The main by-product chemical when burning natural gas is carbon dioxide, a major GHG, however, the amount of carbon dioxide produced per unit of electricity by burning natural gas is less than that oil and almost half as much as coal. When extracting natural gas, methane is released, including from hydro-fracking wells employing newly-used technology to extract gas from shale formations. Transportation of natural gas in underground pipe systems also can leak methane. This article next evaluates each of these

147. See id. at 23 tbl.1 (projecting the world’s global emissions in 2030 to be 36.868 gigatons).
148. Id.
150. See Carbon Dioxide Emissions Coefficients, U.S. ENERGY INFO. ADMIN. (Feb. 2, 2016), https://www.eia.gov/environment/emissions/co2_vol_mass.php (providing data that shows coal produces 210.20 pounds of CO₂ (million BTU), whereas natural gas produces 117 pounds CO₂ (million BTU)).
152. See infra Section III.
aspects of the fossil fuel methane chain, and how better management of these releases can be achieved.

1. The Issue Presented by Gas as a “Bridge” Fuel Fossil Fuel

Figure 8 shows that natural gas was the last developed of the fossil fuels, but it is now enjoying a new accelerating amount of extraction. Notwithstanding this recent surge, natural gas was burned in China in the Sichuan Province as early as the Han Dynasty in 200 B.C. to evaporate briny water. This application for natural gas was transported in bamboo pipelines and burned under large cast iron pans. In more recent times, global extraction of natural gas increased 1,000 percent between 1950 and 1970, and then doubled again by 1990. Natural gas is seventy to ninety-five percent methane molecules, with a minor amount of higher alkanes, including butane, propane, and ethane. For the production of plastics and synthetic nitrogen, natural gas is employed as the feedstock.

154. See id. at 142.
155. See id.
156. See Kevin A. Boudreaux, MOLeCULAR GALLERY, ANGELO ST. U., https://www.angelo.edu/faculty/kboudrea/molecule_gallery/01_alkanes/00_alkanes.htm (last visited Oct. 18, 2018) (“Natural gas is about 70%-95% methane depending on the location in which it is obtained.”).
157. See id. (“Butane . . . burns cleanly, and is used in LPG fuels (liquefied petroleum gas) for outdoor cooking . . . In [liquid form], it is used in cigarette lighters and lighter sticks.”).
158. See id. (“Propane is used as an industrial fuel, and in home heating and cooking. Both propane and butane are used as [liquefied petroleum gas] fuels for outdoor cooking, either in camping stoves or outdoor gas barbecue grills.”).
159. See id. (“[Ethane] is a minor component of natural gas (10%-30%, depending on the location of the source.”).
The recoverable amount of natural gas is dramatically expanded by employment of hydro-fracking technology. Greater supply affects the world price of the fuel. In the country leading the use of hydro-fracking, the price of gas decreased in the U.S. market, commensurately causing demand to increase. Figure 9 illustrates that in the most recent seven-year period, prices of natural gas prices fell by two-thirds of the

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161. Steven Ferrey, *Ring-Fencing the Power Envelope of History’s Second Most Important Invention of all Time*, 40 WM. & MARY ENVTL. L. & POL’Y REV. 1, 9, figure 2.
163. See infra Figure 9.
164. See Hodge, supra note 86.
2008 price.\textsuperscript{165} Gas prices now are very close to coal prices, as shown in Figure 9.\textsuperscript{166}

**Figure 9. Average Fuel Receipt Costs at Electric Generating Plants (2000-2016)**\textsuperscript{167}

Natural gas use for power generation is accompanied by reduced emissions of only approximately one-half the amount of carbon dioxide emissions compared to use of coal, as well as lower emission of criteria pollutants.\textsuperscript{168} This makes natural gas the “bridge” fossil fuel over which the transition from fossil fuels to renewable fuels will most likely traverse. More advanced combined-cycle gas turbines make the use of natural gas for power generation more efficient,\textsuperscript{169} incurring less maintenance expenses for units which burn cleaner natural gas than coal.

\textsuperscript{165} See infra Figure 9; see also Gail Teverberg, Why U.S. Natural Gas Prices Are So Low – Are Changes Needed?, OUR FINITE WORLD (Mar. 23, 2012), http://ourfiniteworld.com/2012/03/23/why-us-natural-gas-prices-are-so-low-are-changes-needed/.

\textsuperscript{166} See infra Figure 9.

\textsuperscript{167} Hodge, supra note 86.

\textsuperscript{168} See Environmental Benefits of Natural Gas, AM. GAS ASS’N, http://www.agas.org/environmental-benefits-natural-gas (discussing these lesser criteria pollutant emissions include particulate matter, SO\textsubscript{2}, and NO\textsubscript{x}).

\textsuperscript{169} See FERREY, LAW OF INDEPENDENT POWER, supra note 104, § 2.9.
While the combustion process for natural gas is cleaner, if methane leaks in the drilling or transportation process, there could be a net increase, compared to coal use, in the net global warming effect. 170

2. Fracking Technology and Methane

New technology changes the amount of gas supply, the amount of supply changes price, and price influences choice of power generation fuels worldwide. The U.S. now produces more natural gas than the two major suppliers, Russia and Saudi Arabia. 171 Hydraulic fracturing is a drilling technique to inject high pressure fluids to break up shale rock, releasing methane gas trapped in those rocks which can be extracted and collected to the surface by a pipe system. 172 Horizontal drilling methods allow expanded reach to more remote shale and its gas through single wells, improving drilling economics. 173

As a result of hydro-fracking technology, the U.S. now boasts the second largest supply of identified natural gas in the world, significantly located in its shale deposits and second only in gas supplies to those in Russia, 174 as shown in Figure 10. The key to not having use of more natural gas increase methane leakage to a warming atmosphere is the technology required (or not) during additional gas extraction and pipeline transportation to consumers. The margin for error is thin: Researchers Hogarth and Ingraffea at Harvard University document that if three percent or more of methane leaked from new hydro-fracked wells, the net effect from that leaked methane would be more warming to the environment than

172. See The Process of Unconventional Natural Gas Production, supra note 162 (defining perforated wellbore as a hole punched in the casing of a well to connect it to the reservoir).
additional carbon dioxide from coal burning.\textsuperscript{175} Showing measured gas leak rates of methane from shale drilling of 3.6 to 7.9 percent, as high as nine percent.\textsuperscript{176}

**Figure 10. Recoverable Natural Gas Reserves\textsuperscript{177}**

As gas is extracted, transported, and sold, there is the constant possibility of methane leaks at each phase of extraction and transportation in any country. The International Energy Agency notes that increasing world gas supply will cause downward pressure on gas prices, causing a projected increase of fifty percent in global demand for natural gas in the twenty-five-year period 2010-2035.\textsuperscript{178} Consequently, such an increased use of natural gas could increase cumulative concentrations of carbon dioxide in the atmosphere to 650 ppm, increasing world temperatures 3.5°C, exceeding the manageable threshold identified by climate experts.\textsuperscript{179} Therefore, international law and policy needs to

\textsuperscript{175} McKibben, *New Chemistry*, supra note 7.

\textsuperscript{176} Id.

\textsuperscript{177} Which Countries are the Largest Consumers and Producers?, INT’L ENERGY AGENCY, http://www.iea.org/aboutus/faqs/gas/.

\textsuperscript{178} See Wright, supra note 77.

appreciate and address the environmental challenges posed by new technologies for extraction of more conventional fossil fuels.

C. TRANSPORTATION OF GAS AND LEAKS

Methane is released into the atmosphere indirectly and unintentionally when natural gas is transported and stored.\(^{180}\) Transporting methane is a challenge distinct from transporting other fossil fuels such as oil or coal: One can’t see the methane in natural gas, as one can see coal and oil. Official estimates suggest that 0.35 to 0.70 percent of the gas carried in pipelines leaks to the atmosphere, a modest amount.\(^{181}\) However, upstream, methane also leaks during oil and gas well extraction. The total methane leakage in the entire natural gas process chain is estimated to be 2.4 percent from the point of production to consumption; if well managed, it remains below the methane released from new coal-fired plants with methane release equivalent to 3.2 percent.\(^{182}\) However, a detailed non-governmental report of a moderate-sized city in a developed country which applied regulatory controls, found\(^ {183}\) that there was gas escaping at high levels at which explosions can occur, and “[t]he costs of these leaks—about $38.8 million a year—are passed on to [retail] gas customers . . .”\(^{184}\)

The challenge is not one of technology, but one of regulatory law. From the initial point of drilling well pads through underground pipes carrying natural gas to consumers, it is possible to locate and repair gas leakage. However, even if a

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184. Id.
greatly reduced leak rate could be achieved, and it was accompanied by an increased dependency on natural gas as an energy source for heating homes and providing electricity, this could result in more net emissions with the resulting consequence of not achieving the international target of eighty percent reduction in GHG emissions by 2050.\footnote{185}{See \textit{Union of Concerned Scientist, Avoiding Dangerous Climate Change: A Target for U.S. Emissions Reductions} (2007), \url{https://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/ emissions-target-fact-sheet.pdf}.
}

Natural gas is not required to be delivered only by pipelines, and therefore is not restricted to transportation only across and within a contiguous land mass by pipes underground. Only one-third of all gas is traded across international borders, compared with two-thirds of oil traded internationally.\footnote{186}{See \textit{Wright, supra note 77}.
} With new fracked gas in the U.S. creating surplus supply, American liquefied natural gas (LNG) recently began shipment to overseas consumers by boat as an energy export commodity.\footnote{187}{See \textit{Wright, supra note 77}.
} While there is a world market in developed countries for LNG, there is not a world price for gas, like there is for oil.\footnote{188}{See \textit{Energy Charter Secretariat, Putting a Price on Energy: International Pricing Mechanisms for Oil and Gas} 26–27 (2007), \url{https://energycharter.org/fileadmin/DocumentsMedia/Thematic/Oil_and_Gas_Pricing_2007_en.pdf}.
} International gas markets have no uniform global price, as does oil which is priced in a narrow range in U.S. dollars.\footnote{189}{See id.
}

D. International Regulation to Manage Methane Leakage

1. Developed Country Policy

Managing methane gas leakage, with additional sustainable regulatory requirements, could yield a net financial gain to all stakeholders commensurate with societal gains for climate mitigation. Transportation leaks of gas are a major climate warming issue: in 2011 alone, gas distribution companies in the U.S. reported that they released sixty-nine
billion cubic feet of natural gas into the atmosphere.\textsuperscript{190} It is cost-effective to repair gas transportation pipeline system methane leaks.\textsuperscript{191} Advanced laser technology sensors now create images of methane leaks from oil-and-gas infrastructure in real time.\textsuperscript{192} The technology exists to locate and repair methane leaks across the entire natural gas process chain, from hydraulic fracturing well pads to pipelines.\textsuperscript{193} However, even a greatly reduced leak rate, if accompanied by an increased dependency on natural gas as an energy source for heating homes and providing electricity, could result in not achieving a necessary eighty percent reduction in GHG emissions by 2050.\textsuperscript{194}

Ultimately, within any given nation, natural gas transportation leak prevention must be implemented through decisions and actions of gas distribution utilities and energy regulatory agencies. Of note, methane emissions are economically and legally distinct from carbon dioxide emissions. First, methane has resale value as valuable fuel if captured, while carbon dioxide does not. Second, this cost is passed on to consumers: the U.S. now passes on to captive customers of gas utilities $20 billion per decade in costs attributed to leakage of natural gas.\textsuperscript{195}

In the leading gas fracking nation, President Obama had the Environmental Protection Agency (EPA) and DOE develop new measures to reduce gas pipeline methane leakage, establishing a goal of a forty to forty-five percent reduction of methane escape compared to 2012 leakage levels, to be achieved


\textsuperscript{191} See CRAIG AUBUCHON & PAUL HIBBARD, ANALYSIS GRP., INC., \textit{SUMMARY OF QUANTIFIABLE BENEFITS AND COSTS RELATED TO SELECT TARGETED INFRASTRUCTURE REPLACEMENT PROGRAMS} 15–16 (Jan. 2013), http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/benefits_costs_tirf_jan2013.pdf (explaining that leaks generate economic benefits by (1) reducing the amount of gas that utilities buy and charge ratepayers for, and (2) reducing the social impact of higher GHG emissions).


\textsuperscript{193} See id.

\textsuperscript{194} See UNION OF CONCERNED SCIENTIST, \textit{supra} note 185.

\textsuperscript{195} See MARKEY, \textit{supra} note 190, at 41.
by 2025. The EPA issued several reports, first sought comments on options to reduce methane emissions, and thereafter in 2016 issued rules to cause decrease natural gas leakage rate in new and existing gas infrastructure. The new U.S. rules will require technology that is already available: Pressurized natural gas powers all sorts of pneumatic devices throughout the oil-and-gas industry which “high-bleed” instruments can be replaced with new “low-” or “no-bleed” alternatives. The Trump administration is attempting to roll back Obama limits on methane that is leaked, vented or flared from oil and gas wells generally as well as those on federal


198. See U.S. ENVTL PROT. AGENCY, ACTIONS TO REDUCE METHANE AND VOC EMISSIONS FROM THE OIL AND NATURAL GAS INDUSTRY: FINAL RULES AND DRAFT INFORMATION COLLECTION REQUEST (May 2016), https://www.epa.gov/sites/production/files/2016-09/documents/epa-oilandgasactions-may2016_presentation.pdf; see also Robert S. Eshelman, Obama Administration Issues New Rules on Methane Emissions from Oil and Gas Industry, VICE NEWS: ENV’T (May 12, 2016, 2:40 PM), https://news.vice.com/article/the-obama-administration-issues-new-rules-on-methane-emissions-from-the-oil-and-gas-industry (describing the Obama Administration’s final set of directives targeting methane emission reduction in the oil and gas industry). Obama has committed to cutting United States methane emissions from the oil and gas sector by forty to forty-five percent (40–45%) from 2012 levels by 2025. Id. The EPA estimates that the new rule will reduce methane emissions by 510,000 tons in 2025, which is equivalent to the GHG emissions produced by nearly 2.5 million automobiles in a year. Id.

lands,\textsuperscript{200} and California and New Mexico sued to halt such roll back.\textsuperscript{201}

About seventy percent of the cost of the new rules promulgated at the end of the Obama Administration are expected to be devoted to the cost of finding and repairing the leaks, mostly in well pad equipment.\textsuperscript{202} EPA suggested that the environmental benefits will outweigh compliance costs by as much as $160 million by 2025.\textsuperscript{203} In theory, depending on implementation, this could be societally neutral in terms of net cost, because the gas saved by reducing leakage may be worth $100 million in recovered value, which would cover the capital cost of these capture-and-reuse programs.\textsuperscript{204}

Even though the U.S. may be responsible for approximately ten percent of world methane leaks,\textsuperscript{205} other countries responsible for the remaining ninety percent will need to contribute to arresting methane leakage in the environment. Methane, an emission produced in every nation, requires an international solution to be effective.


\textsuperscript{201} Kartikay Mehrotra, California, New Mexico sue Trump for axing methane-waste rules, Bloomberg Environment Reporter, Sept. 19, 2018.

\textsuperscript{202} See Roston, supra note 199. The initial regulations proposed in August 2015 would have incurred less cost than the final rules which require more frequent monitoring and repairs. Id. The rule requires new wells to develop leak monitoring plans and mandates that well site operators conduct an initial leak survey within a year or within sixty (60) days of startup and twice annually after that. Id. The rule requires that operators scan for leaks using optical gas imaging equipment or comparable monitoring methods. Id.

\textsuperscript{203} Id.

\textsuperscript{204} Andrew Childers & Anthony Adragna, New Wells Regulated, EPA eyes methane from existing sources, Bloomberg: Env’t & Energy Report (May 12, 2016), https://www.bna.com/new-wells-regulated-n57982072327/ (explaining the final rule amends 40 C.F.R. Part 60, Subpart OOOO and adds a new 40 C.F.R. Part 60, Subpart OOOOa. Further, the agency estimates it will reduce 510,000 short tons of methane in 2025 while providing climate benefits of $690 million in 2025, outweighing the estimated costs of $530 million in 2025. As part of the final rule, the EPA chose not to exempt low production well sites—hose that produce less than fifteen (15) barrels of oil equivalent per day—from the leak detection requirements).

\textsuperscript{205} See Roston, supra note 199.
2. International Implications

Canada’s Prime Minister, Justin Trudeau, with Canada among the four largest oil-and-gas producers in the world, agreed to make similar reductions in methane pollution that the Obama Administration pledged to implement.\(^{206}\) Mexico also later agreed to this goal.\(^{207}\) Projected in an international context, Figure 11 illustrates estimates of the U.S. DOE and EIA, on international growth of the sources of electric generation over the next approximately quarter of a century.\(^{208}\) The second greatest increase in fuel use for power production worldwide will be natural gas.\(^{209}\)

With the recent application of hydro-fracking technology, the amount of recoverable natural gas will increase in many countries, and greater supply will increase availability and commensurately decrease the price of natural gas.\(^{210}\) The greatest expected increase in source of power generation over the next quarter century is coal, surpassing nuclear power, solar, wind, and hydroelectric power, as shown in Figure 11.\(^{211}\) According to experts, “If the Harvard data hold up and we keep on fracking, it will be nearly impossible for the United States to meet its promised goal of a twenty-six to twenty-eight percent reduction in GHGs from 2005 levels by 2025.”\(^{212}\) This possible failure by the U.S. to achieve climate goals for GHG release mitigation because of greater methane leaks through fracking, could be replicated in countries around the globe as this technology proliferates.\(^{213}\)

\(^{206}\) Dean Scott, Obama, Trudeau Pledge Quick Paris Deal Implementation, 47 ENVT REP. 754 (Mar. 11, 2016).


\(^{208}\) INTERNATIONAL ENERGY OUTLOOK 2013, supra note 19, at 10, fig. 15.

\(^{209}\) See infra Figure 11.

\(^{210}\) See e.g., INTERNATIONAL ENERGY OUTLOOK 2013, supra note 19, at 44 (discussing global natural gas pricing mechanisms).

\(^{211}\) See infra Figure 11.

\(^{212}\) McKibben, New Chemistry, supra note 7.

\(^{213}\) See Id.
This requires that international policy must begin to meaningfully address fuel substitution, gas system leaks, and the pace of adoption of renewable energy alternatives in every one of the two hundred nations in the world. Use of new satellite, aircraft, and drone capabilities coupled with on-site continuous monitoring and automated infrared imaging, have the potential to greatly improve methane leak detection, monitoring, and repairs.\textsuperscript{215} The next section shifts from proactive policy for energy use in a climate-constrained world, to additional methane waste emissions internationally and the way that resources are managed or mismanaged.

\textsuperscript{214} International Energy Outlook 2013, supra note 19.

IV. INTERNATIONAL MULTI-SECTORAL WASTE METHANE

A. LANDFILL METHANE FROM ALL NATIONS

Every nation disposes of its waste, either with or without management of that waste. Methane escaping from waste mismanagement from landfills is a problem of international proportion. The per capita generation of municipal waste (MSW) is a function of both population and affluence. The largest amount of MSW is generated by OECD countries, and lesser amounts by less developed countries. Many world countries do not even keep MSW generation or management records. This is an ongoing and increasing problem that must be addressed by law, as the amount of MSW generated worldwide is expected to almost double to 2.2 billion tons annually by 2025.

Trash in landfills creates seventeen percent of all anthropogenic methane production—less than only livestock operations and natural gas production of methane, and more than wastewater management methane. Trash increases climate change because its organic materials decompose to methane under anaerobic conditions. Landfills in the U.S.


217. See id. at 11.

218. See id. at 8.


containing trash accounted for 6.9 million metric tons of methane emitted annually.222

Because waste is composed of a high percentage of organic materials, including paper, food scraps, and yard waste (see Figure 12), over time, bacterial decomposition of organic material, the volatilization223 of certain wastes, and chemical reactions within the landfill create copious quantities of gas.224 About two-thirds of the total is organic matter that will degrade to release methane under anaerobic conditions.225 The chemical future of the bulk of MSW is its degradation to methane molecules.226 Landfill gas is comprised primarily of forty-five to sixty percent methane, as well as carbon dioxide, while containing smaller amounts of non-methane organic compounds and some other trace organic elements.227 For comparison, pipeline natural gas contains about ninety-five to ninety-eight percent methane.228


223. See AGENCY FOR TOXIC SUBSTANCES & DISEASE REGISTRY, supra note 220, at 3 (explaining volatilization as the process when organic compounds convert from a liquid or solid into vapor).

224. See id.; see also Basic Information about Landfill Gas, supra note 222 (explaining landfill gas accounts for approximately 14.1% of human-related methane emissions in the United States).

225. See OFFICE OF AIR QUALITY PLANNING & STANDARDS, supra note 221 (stating that in 2014, 14.6% of all waste sent to MSW landfills was food, 27% was paper, 6.2% was wood and 7.4% was yard trimmings); U.S. ENVT L PRO T. AGENCY, INVENTORY OF U.S. GREENHOUSE GAS EMISSION AND SINKS: 1999–2015, at 1–5 (2017), https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf (“Methane is primarily produced through anaerobic decomposition of organic matter in biological systems.”).

226. See ENERGY INFO. ADMIN., RENEWABLE ENERGY ANNUAL 1996, 99 (1997) (“As MSW decomposes, it produces a blend of several gases, including methane (about 50 percent).”).

227. See id. at 100, tbl.28; see also Basic Information about Landfill Gas, supra note 222.

Additional “fugitive emissions from landfills could be reduced by installing and maintaining bio-based systems such as bio covers or bio filters that oxidize methane emissions.” The organic material entering landfills, which decomposes to methane gas, could be reduced through food waste reduction. For example, food waste reduction and diversion programs cut the amount of organic waste decomposing in landfills. Looking at developed countries as one example, approximately 133 billion pounds of unconsumed food end up in landfills in the U.S. because it is either deemed cosmetically unfit or will not...
stay fresh long enough to be shipped far distances, making it the single greatest contributor to waste in municipal landfills. In 2015, the U.S. Department of Agriculture and EPA, along with many private sector and food bank partners, announced a national target to reduce food waste fifty percent by 2030, and “[m]ultiple states, including Massachusetts, Vermont, and Connecticut, have implemented regulations to reduce food waste from commercial sources.”

During the end of the Obama Administration, the EPA finalized more stringent standards to reduce methane emissions from new and existing landfills to result in the reduction of eight million metric tons of methane emissions annually by 2025. A new landfill is considered one that will be constructed, reconstructed, or modified after July 17, 2014. New landfills would only be allowed to release one-third of their methane emissions into the atmosphere. The remaining two-thirds would have to be captured and the new landfills will have until 2023 to meet this requirement. Existing landfills' requirements to capture and contain methane would be lowered from fifty metric tons (equivalent to fifty MG) of non-methane organic compounds per year in the current regulations, to thirty-four metric tons annually. The EPA estimates that 115 new landfills and 731 existing facilities would be required to install

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236. THE WHITE HOUSE, supra note 15, at 92.

237. Id. (citation omitted).

238. See id.


241. See id.

additional pollution controls under the final rules, to reduce methane emissions by 334,000 metric tons at an annual cost nationwide of $6 million in 2025.243

Consistent policy implementation can be fickle. In May 2017, the EPA, under a new Presidential administration, announced a ninety-day stay in enforcing the 2016 landfill methane regulations.244 In January 2018, the administration announced that it would not continue to stay these existing regulations.245 In March 2018, seven states threatened to sue EPA for not enforcing the 2016 Obama Administration rules for states to control landfill methane emissions by the end of 2017 the requirement.246

B. METHANE FROM HUMAN WASTE

In every country, human sewer wastewater creates methane from the decomposition of the organic matter in the waste.247 While not as significant as methane release from fossil fuel production, animal operations, and landfills, there is methane release occurring at wastewater treatment operations around the world which can be captured for productive purposes.248


248. See id. (detailing a project venture in the UK to turn the methane created from sewage sludge into renewable gas); Overview of Greenhouse Gases: Methane Emissions, supra note 6 (breaking down 2106 U.S. methane emissions
the ongoing international debate about which countries should participate in global warming gas emission reductions and which should be exempt from international compacts, there is little reason that any country should receive an exemption for management of methane emissions from its own human waste methane or landfill methane emissions.

The amount of methane created from human biologic waste corresponds generally to the size of a population in a country or a region. Methane emissions from human waste management do not directly correlate with the degree of development of a country, but rather with the size of its population which creates biological waste daily. Therefore, the responsibility to contain these types of fugitive methane emissions from human waste are distributed across the world proportionately as a responsibility of every country relative to its population.

There is better policy still to be implemented in developed countries, as well as in developing countries. Here is a concise overview at very modest control of waste methane in a developed country with data: in the U.S. today, there are 16,000 operating public wastewater treatment facilities. Of the total, less than 1,500, constituting less than ten percent, utilize anaerobic

by source: thirty-one percent from natural gas and petroleum systems, twenty-six percent from enteric fermentation, sixteen percent from landfills, ten percent from manure management, nine percent from “other,” and eight percent from coal mining).

249. See Steven Ferrey, Changing Venue of International Governance and Finance: Exercising Legal Control over the $100 Billion per Year Climate Fund, 30 Wis. J. INTL L. 26 (2012) (discussing the need for all countries to reduce GHG).


251. See id. (demonstrating that it is the increase in the size of the population of the city that increases amount of biological waste produced, not the development of the city). But see Chander Kumar Singh et al., Quantitative Analysis of the Methane Gas Emissions from Municipal Solid Waste in India, 8 SCIENTIFIC REPORTS 1, 1 (2018), https://www.nature.com/articles/s41598-018-21326-9.pdf (showing that total methane emissions are highly correlated with the gross state domestic product and gross domestic product of the country, both indicators of human well-being).

digesters on site to extract forming methane gas. Of this less than ten percent that employ methane capture, only about four-fifths of these, constituting about eight percent of all public wastewater facilities, employ the captured methane productively as a reusable fuel, rather than flaring it as a waste product. That means ninety-two percent of the public wastewater facilities in the U.S., one of the most developed countries, do not make productive use of the methane that their facilities create. In any developed or developing country, the technology to do so is available, and not new or exotic. The biogas produced by human or animal waste is sixty percent methane, forty percent carbon dioxide, and trace elements of hydrogen sulfide. The well-used technology of an anaerobic digester permits bacteria to convert organic material anaerobically, which thereafter is usable fuel for electricity generation or can be combusted for heat.

There are ancillary environmental benefits from employing a process to extract the usable methane forming from waste products. The amount of waste solids remaining to be disposed is reduced, odor of the material is reduced, and perhaps most important, climate-warming GHG emissions of the material are reduced by ninety-five percent when the methane is combusted. The remaining sewage solids can be landfilled, burned, or recycled, and must be handled in some form whether or not the methane is captured.

The energy potential of the residual solid waste materials sewage, in addition, can be heated anaerobically to the point of combustion, becoming syngas, a combination of carbon


monoxide, carbon dioxide, and hydrogen,\textsuperscript{258} which thereafter burns more efficiently in the gaseous form than the solid form as an electric or thermal energy source.\textsuperscript{259} This process of gasification improves efficient use of energy compared to otherwise extracting energy from the waste solids, and offers land-use benefits because the residual waste ash consumes less landfill space than the original waste sludge.\textsuperscript{260} Methane extracted from human waste can serve as the fuel for advanced fuel cell technologies to produce electricity for self-use or for wholesale export to the electric grid.\textsuperscript{261} Technology research is proceeding on a microbial fuel cell which will not only create electricity from the sewage, but also treat the residual waste material.\textsuperscript{262}

Methane emissions escaping to the atmosphere during wastewater treatment could be significantly reduced by 2050 through currently available mitigation options, including anaerobic digesters at sewage processing facilities added anywhere in the world.\textsuperscript{263} While the economics of capturing methane, alone, can be compelling, it is possible for every country to prescribe and implement standards for their public and private wastewater systems.\textsuperscript{264} Structured correctly, this

\begin{itemize}
\item \textsuperscript{260} See Brendan McAuley et al., \textit{A New Process for the Drying and Gasification of Sewage Sludge}, \textbf{148 WATER ENGINEERING \\& MGMT.} 18 (2001).
\item \textsuperscript{262} See Gayle Ehrenman, \textit{From Foul to Fuel}, \textit{126 MECHANICAL ENGINEERING} 32, 32–33 (2004). The device is a single-chambered Plexiglas device which is 6 inches long and 2.5 inches in diameter. \textit{Id.} at 32. Inside of the chamber “eight graphite anodes surround a cathode that’s made up of a carbon/platinum catalyst and proton exchange membrane layer fused to a plastic support tube.” \textit{Id.} A copper wire then connects to the circuit. \textit{Id.} The MFC captures electrons which are released by the bacteria as they digest the organic matter and converts this into energy, and also removes about eighty (80) percent of the organic matter from the wastewater. \textit{Id.} at 33. Since there is no oxygen used in the process this means that the methane does not need to be burned to produce energy, and therefore there can be more energy extracted from the process.
\item \textsuperscript{263} See \textit{THE WHITE HOUSE}, supra note 15, at 92.
\item \textsuperscript{264} See \textit{id.}
\end{itemize}
would make a significant difference in climate warming, and could result in a cost-effective and long-term measure for recapturing usable fuel from facilities that are necessary for public health management in every nation.  

C. METHANE FROM THE COAL SECTOR

Although methane typically is associated with natural gas, it also is released in gaseous form from both active and abandoned coal mines. This sector is significant: ten percent of human-related methane emissions came from the coal mining sector.

While use is declining dramatically in the U.S., coal remains by far the predominate fossil fuel used for electric production worldwide. More than eighty percent of the energy consumption increase in the future will be attributable to developing countries. Approximately two decades from now, energy consumption in developing countries is estimated to be more than twice as great as that in developed countries. In coal mining, commercially available technologies now can recover and reduce methane emissions, including installation of drainage and recovery methane systems installed in the coal seam, destruction of ventilation air-methane, and use of recovered gas for electricity or thermal application.

A report by the IGSD highlighted regulating emissions from coal mining as an important measure to reduce global methane emissions by thirty-eight percent. Globally, half of the

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267. See THE WHITE HOUSE, supra note 15, at 6 (stating because of the greater warming potential of methane, this is equivalent to approximately 56 million tons of CO₂ emissions in terms of warming).
268. See INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 83 fig. 5–3.
269. See INTERNATIONAL ENERGY OUTLOOK 2013, supra note 19, at 9.
270. See id.
271. See THE WHITE HOUSE, supra note 15, at 90.
272. INST. FOR GOVERNANCE & SUSTAINABLE DEV., supra note 35, at 20–22 tbl. 1. Additional mitigation measures listed in the report include: (1) controlling fugitive emissions from oil and gas production; (2) controlling fugitive emissions from long distance gas transmission; (3) capturing gas from
identified coal mine methane measures could be deployed at a cost that is less than the value of the captured methane globally.\textsuperscript{273} The economics regarding methane are different than for other GHGs: Approximately two-thirds of potential reductions in methane can be financed at a cost less than $250 per metric ton captured, which is less than twenty-five percent the estimated value of climate change benefits accrued from climate mitigation, health improvements, and agricultural gains in production.\textsuperscript{274} A 2013 World Bank study also found that in developing countries alone, as much as 8.2 GtCO\textsubscript{2}-eq in methane emissions reductions are achievable by 2020 at less than $10 per ton in incremental cost financing.\textsuperscript{275}

The challenge is that traditional laws affecting coal mines are safety-based, rather than constructed to address environmental emissions. Coal-bed methane recovery technologies have been successfully implemented in Eastern Europe, Germany, Australia, Japan, and Great Britain.\textsuperscript{276} In the United States, efforts to capture and utilize coal-bed methane gas have intensified in the past ten years, and coal-bed methane development is now this country’s fastest growing natural gas resource.\textsuperscript{277} The successful measures include methane drainage and recovery systems, as well as control of ventilated air-methane with subsequent use of the captured methane as fuel.\textsuperscript{278}

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municipal waste and landfills; (4) capturing gas from livestock manure; and (5) and intermittent aeration of constantly flooded rice paddies.

\textsuperscript{273} Id. at 40.

\textsuperscript{274} Id. at 14.

\textsuperscript{275} Id. at 40.


D. AGRICULTURAL METHANE

In addition to human waste, there are significant agricultural methane emissions from livestock manure and enteric fermentation. 279 Animals emit methane from their manure and their diets. 280 Lack of manure management in all countries is a major cause of methane releases, 281 accounting for more than 8 percent of U.S. methane emissions. 282 As with wastewater treatment of human waste, anaerobic digesters, if they were deployed, would capture methane from agricultural waste to be used as a marketable energy fuel. 283

Certain low-tech options exist for any country: “[s]afe food additives like certain types of algae have the potential to significantly reduce methane production in livestock. Small-scale anaerobic digesters can capture methane from waste and supply renewable energy for electricity and on-farm equipment.” 284 However, the challenge for international policy is that the agricultural sector of the economy in most nations is very disaggregated and competitive, and with a large number of agricultural actors involved in the sector, achieving broad implementation internationally can be difficult. 285

In light of the multi-stakeholder, competitive, and disaggregated nature of the agricultural sector even in a developed, post-industrial economy, there has been limited action and related limited results. 286 Despite demonstrated cost-effective renewable biogas technologies, policy has not created traction for their implementation:

Biogas systems are proven and effective technology to process organic waste and generate renewable energy. They can reduce the risk of potential air and water quality issues while providing additional

280. See id.
283. THE WHITE HOUSE, supra note 15, at 91 (explaining that these practices have also raised questions about lower agricultural yields and profits).
284. Id.
285. Id.
286. Id. at 6.
revenue for the operation. Yet, there are still relatively few digesters in operation on farms across America.287

More than 250 anaerobic digesters throughout the U.S. convert some of this waste to usable methane, which is then used to produce heat, power, and electricity.288 Animal manure is heated in a tank without oxygen, causing bacteria to break down and transform chemicals in the waste.289 The residuals include nitrogen-rich fertilizer.290

Because of increasing world population and increasing demand for food, the prospect of reducing worldwide agricultural emissions of methane before 2050 in a very competitive world agricultural market must rely on technological innovation in animal diets, fertilizer use, and manure management.291

V. INTERNATIONAL METHANE CONTROL MECHANISMS

A. INVERSION OF INTERNATIONAL RESPONSIBILITY FOR METHANE

Methane is a much more central and prominent carbon actor in real-time warming than the conventional international world view has calculated or acknowledged.292 Accurately monitoring methane emissions is a large part of the challenge, since sources are geographically and technologically diverse.293 Equally important is correctly calculating the amount of warming associated with methane in real time that causes actual climate-related damage.294

In international law, to reduce global warming gas emissions, there is a demarcation of responsibility negotiated

287. Id.
291. THE WHITE HOUSE, supra note 15, at 90.
292. See id. at 89 (explaining that “at trapping heat . . . methane is 28-36 times more powerful than CO2”).
293. Id. at 3, 88, 90;
294. Id. at 3.68, at 3.
between developed and developing countries in the world. And in these international negotiations, the political and legal dynamics are different. Recent carbon dioxide emission increases principally are linked to escalating fossil fuel use in developing countries; flipped in responsibility, recent increases in methane emissions are substantially a developed country phenomenon, related to increased natural gas usage, and an international multi-country phenomenon related to lack of climate-conscious waste management across the world. To the degree that greater methane release is associated with new fracking of natural gas in the past decade, technology-sharing of new horizontal fracking technologies with other countries may greatly exacerbate gas extraction and associated methane leaks worldwide, resulting commensurately in greater climate change from that methane release and the burning of more fossil fuel.

1. The Kyoto Protocol and the 2015 Paris COP-21 Agreement

There is a multi-decade-long debate between developed and developing countries as to whether developing countries should have to participate at all or on a commensurate level in global warming mitigation. One can legitimately argue, and many countries do, about whether the challenge of carbon dioxide mitigation should be placed on developed countries or on all countries, including developing nations. The former emit more emissions per capita; however, the latter are responsible for the 21st century’s current and projected expected dramatic increases in total GHG emissions.

Carbon dioxide and methane emissions are covered by the U.N. Framework Convention on Climate Change in 1992 and the Kyoto Convention of the Parties in 1997. The Kyoto Treaty on

295. Id. at 93–98.
296. Id. at 6.
297. See INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 9 (explaining that “with the newly available natural gas resources...from 2012 to 2040, world natural gas demand increases in all end-use sectors”).
298. See infra Section V.A.2.
299. See INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 139.
300. CHRISTIAN N. JARDINE ET AL., ENVTL. CHANGE INST., METHANE AND CLIMATE CHANGE, 10–12 (describing The Kyoto Protocol, which was adopted in 1997 at the third session of the Conference of the Parties (COP 3) associated with the United Nations UNFCCC in Kyoto, Japan); See Kyoto Protocol to the United Nations Framework Convention to Climate Change, Dec. 11, 1997, 1771 U.N.T.S. 107.
GHGs requires reduction of six GHGs, which include methane, nitrous oxides, carbon dioxide, HFCs, PFCs, and sulfur hexafluoride.\textsuperscript{301} Carbon dioxide and methane were agreed to be reduced to seven percent below their 1990 baseline levels by 2012.\textsuperscript{302} The world is already well past 2012, and GHG emissions have increased significantly worldwide rather than decreased.\textsuperscript{303}

Under the Kyoto Protocol, thirty-seven “Annex I” states, consisting of industrialized countries and the European community (including twenty-seven members of the European Union, plus eight other non-European Union nations in Europe including Belarus, Iceland, Liechtenstein, Norway, Switzerland, and Ukraine), as well as Australia, Canada (which subsequently withdrew from the Protocol in 2011 before the end of Kyoto’s second phase ending in 2012),\textsuperscript{304} Japan, New Zealand, and Turkey, initially imposed GHG emission limitation and reduction commitments.\textsuperscript{305} The remaining 155 developing countries among the 192 Kyoto Protocol signatories, including the largest GHG emitter among all nations, had non-binding generic undertakings to limit emissions.\textsuperscript{306} Emission trading among industrial nations is allowed to realize these goals.\textsuperscript{307}

\begin{footnotesize}
\begin{enumerate}
\item \textsuperscript{301} Id. at 9.
\item \textsuperscript{307} See \textsc{United Nations Framework Convention on Climate Change, Essence and Goals}, The Kyoto Protocol, https://www.mtholyoke.edu/~danov20d/site/goals.htm (last visited Oct. 21, 2018); See also Natural Capital Partners, \textsc{Project Browser},
\end{enumerate}
\end{footnotesize}
Internationally, as one examines GHG emission reduction, there is a risk of emissions “leakage” as similar or substitute products instead are produced in the 155 non-regulated countries rather than the 37 regulated Kyoto Protocol countries, particularly for high-trade manufactured, agricultural, and forestry products which trade internationally.\(^\text{308}\)

The 155 not-compelled Kyoto Protocol signatories have resisted any binding GHG emission reduction or stabilization commitments; at the 2009 Copenhagen COP conference, China, India, and other developing countries refused to support any international climate compliance mechanisms affecting them.\(^\text{309}\) During the G8 international summit in 2009, India and China rejected any enforceable controls on their rapidly inflating carbon emissions.\(^\text{310}\) Since then, neither the COP-16 in 2010 in Cancun, Mexico, nor the COP-20 in Lima, Peru in 2014, nor the COP-21 in Paris, France, nor the COP-22 in 2016 in Marrakech, nor the COP-23 in Bonn in 2017, nor the COP-24 in Poland in 2018 (at which it was deemed essential as the deadline to work out all details), were successful in agreeing to any enforceable requirement on countries for emissions of climate warming gases to ensure compliance of any nation that fails to achieve its reductions or violates any provision of the Protocol or the Paris Agreement.\(^\text{311}\) The Kyoto Protocol and its 2015 Paris Agreement

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\(^{308}\) \textit{The White House}, supra note 15, at 96.

\(^{309}\) See generally David Hunter, Implications of the Copenhagen Accord for Global Climate Governance, 10 SUSTAINABLE DEV. LAW & POLY 2, 4 (2010).


progeny, after three additional COP international conferences since Paris in 2015, remain voluntary and unenforceable.\textsuperscript{312}

With warming, where impacts are global rather than local, the world is wrapped in a complex and simultaneous climate equation. Climate change mitigation must truly be a global effort of every nation: Even if all OECD countries could achieve a Herculean reduction of eighty percent of their prior GHG emissions by 2050, this would not achieve the Kyoto Protocol or Paris 2015 targets or goals without similar vigorous participation by developing countries.\textsuperscript{313}

\textsuperscript{312} The Kyoto Protocol has no compulsory mechanism to enforce any restriction or penalty against any signatory country that fails to achieve its carbon quota. See generally UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change, (1998), http://unfccc.int/resource/docs/convkp/kpeng.pdf (stating the program is lacking enforcement mechanisms).

The current climate commitments of U.S. trading partners are displayed in Figure 13, from most significant to least significant, moving clockwise around the figure. The commitments of different countries are stated in very different and non-comparable metrics, ranging from reductions by different countries from the 2005, 2000, or 1990 baseline emissions amounts, to a reduction measured against a yet-to-be-determined business-as-usual baseline. The GHG reduction pledges from the recent Paris Agreement are in different baselines, metrics, and time periods that are difficult to compare: “They’re very difficult to quantify, they’re difficult to compare and they’re very difficult to aggregate.” In light of

314. THE WHITE HOUSE, supra note 15, at 94 fig.7.1.
315. Id.
316. Id.
317. Andrew Childers, Climate Harm ‘Inevitable,’ More Cuts Needed, Holdren Says, ENERGY & ENV’T REP., (July 12, 2016),
each national goal and commitment being voluntary and unenforceable, international realization is far from assured.318

In 2009, the U.N. forecasted the seriousness of coming “tipping points that are irreversible within the time span of our current civilization.”319 Waiting two or three years from present day, 2019, to stop the “growth of greenhouse gas emissions” could make it nearly impossible to avoid catastrophic effects of warming.320 According to Dr. John Holdren, Director of the White House Office of Science and Technology Policy during the Obama Administration, if U.S. GHG emissions somehow had been proactively addressed so as to have plateaued by 2015, instead of continuing to increase globally, we would already have reduced our chances of avoiding climate catastrophes by fifty percent.321 Recent data shows that GHG emissions have not been demonstrably reduced in some major world economies even after the recession of 2009.322

The Paris Agreement of the Conference of the Parties, which included 186 world countries in December 2015, agreed to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.”323 This holding may be moot before it is implemented; to reach this goal would require an estimated investment of $12 trillion.324 The world is not on pace to

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318. See e.g., Kyoto Protocol to the U.N. Framework Convention on Climate Change, supra note 312 (lacking compulsory mechanisms to enforce any restriction or penalty against any signatory country that fails to achieve its carbon quota).
319. New Science and Developments in our Changing Environment, supra note 2, at 21.
321. Id.
maintain anything close to a 1.5-2°C temperature increase, but is rather on a path to reach a temperature increase of at least 4°C.325

2. The Kyoto International Clean Development Mechanism

Certain secondary international mechanisms still link developed and developing countries. 326 The UNFCCC Kyoto Protocol Clean Development Mechanism (CDM)327 allows projects which reduce GHGs in developing nations to earn tradable certified emission reduction credits (CERs) for each ton of carbon dioxide-equivalent of GHG reduced by a qualified and pre-certified investment activity.328 Those CERs are then traded or sold to regulated entities conducting activities in UNFCCC Annex I developed countries which require emission credits and which, through this CER purchase, simultaneously increase their countries’ emission caps allocated in the international Protocol.329 CER credits generate value for a maximum of seven years with two renewals (twenty-one total years), or in the

325. THE WHITE HOUSE, supra note 15, at 4; Climate Action Tracker, 2100 Projections (December 2018) (“In the absence of policies global warming is expected, to reach 4.1 °C – 4.8 °C above pre-industrial by the end of the century....optimistic scenario... median warming estimate is 3.0°C... There remains a substantial gap between what governments have promised to do and the total level of actions they have undertaken to date. Furthermore, both the current policy and pledge trajectories lie well above emissions pathways consistent with the Paris Agreement long-term temperature goal,”), https://climateactiontracker.org/global/temperatures/.


329. See Kyoto Protocol to the UNFCCC, supra note 312, at art. 12(3)(b); See also Marrakesh Accords, supra note 328, at ¶ 15(a)-(b) (deciding that share of proceeds shall be two percent of CERs issued for a clean development mechanism activity were eligible to be carried over to the second phase of implementation after 2002).
alternative, for a maximum of ten years with no renewal.\textsuperscript{330} Under the Kyoto Protocol, CDM CERs can be used to satisfy up to two percent of a European Union country regulated industry party’s GHG annual emissions under E.U. law.\textsuperscript{331}

Despite this design, worldwide sustainable renewable energy projects account for approximately twenty-eight percent of CDM CERs; nineteen percent of CERs are for methane flaring projects that produce no electricity, mostly located at large landfills, coal mines, and concentrated animal feeding operations.\textsuperscript{332} Developers of CDM projects in developing nations are trapping methane emissions, which are a usable fuel, and flaring it, without using it for renewable electricity in the process, because the CDM system does not require such renewable energy use best practices.\textsuperscript{333} “Even in the U.S., methane is being flared to garner various Clean Air Act offsets, even though such flaring is not ‘additional’ and could create power resources rather than being flared as a waste material.”\textsuperscript{334} “Because one receives 2100 percent or more greater CDM credits by simply flaring methane to convert it to by-product carbon dioxide,”\textsuperscript{335} many certified CDM projects do this with agricultural

\textsuperscript{330}  See Marrakesh Accords, \textit{supra} note 328, at ¶ 49(a)–(b).


\textsuperscript{333}  See \textit{id}. There are 74 registered CDM projects that utilize methane flaring (methodology ACM0001); roughly only a third utilize the flaring for energy production. UNFCCC CDM Project Activities, http://cdm.unfccc.int/Projects/projsearch.html (last visited October 21, 2018).


methane, thus taking the credits rather than making the effort to use the methane as a renewable/waste fuel source.\textsuperscript{336} In the flaring process, it is not used to produce electricity, which is otherwise locally supplied, typically by traditional fossil-fuel-fired sources.\textsuperscript{337}

The international miscalculation regarding the importance of methane emissions on climate warming has contributed to the incentives in the international CDM program which includes failing to achieve the most cost-efficient and long-term capture and use of methane. By valuing methane reduction at the traditional and incorrect approximately twenty-one-times multiplier compared to the reduction of carbon dioxide emissions, real-time accurate financial incentives for methane reduction within the CDM program are reduced by two-thirds of their true, actual climate-changing value to the environment and climate control.\textsuperscript{338} In the CDM program, the private investment that finances each project is attracted to the most mathematically lucrative carbon reduction, which is dramatically understated for methane and dramatically undervalues methane’s climate impact.\textsuperscript{339}

The Kyoto CDM credits only provide financial benefits within the international Protocol for ten to twenty-one years,\textsuperscript{340} which happens to correspond exactly to the range of the actual time line of methane’s real effects in the atmosphere.\textsuperscript{341} Improper calculation of methane’s real-time warming impact creates a misaligned existing international climate system, creating incorrect financial incentives for the wrong climate mitigation options.\textsuperscript{342}

\begin{itemize}
  \item \textsuperscript{336} \textit{Id.} (quoting \textsc{World Bank, International Trade and Climate Change: Economic, Legal, and Institutional Perspectives} 91 (2008).
  \item \textsuperscript{337} \textit{Ferrey, When }1 + 1\textit{ No Longer Equals }2, \textit{supra} note 334.
  \item \textsuperscript{338} \textit{See supra} notes 27–34 and accompanying text (discussing the major policy miscalculation of methane due to incorrect math and science and the failure of creating a sufficient platform).
  \item \textsuperscript{339} \textit{Id.}
  \item \textsuperscript{340} \textit{See Kyoto Protocol to the U.N. Framework Convention on Climate Change, supra} note 312, at art. 12.
  \item \textsuperscript{341} \textit{See Romm, \textit{supra} note 5.}
  \item \textsuperscript{342} \textit{See Steven Ferrey, Cubing the Kyoto Protocol: Post-Copenhagen Regulatory Reforms to Reset the Global Thermostat, 28 UCLA J. ENVTL. L. & POLY} 343 (2010) (discussing a four-sided approach and model of governance that will put into place the ideals of the Kyoto Protocol).
\end{itemize}
Currently, and likely forever, energy use is and will remain the principal driver of climate change. More than eighty percent of future energy consumption increases will come from developing countries. By 2040, energy consumption in developing countries is projected to be more than twice as much as that in developed countries. In the next five years, there will be a massive investment in electrification projects in developing nations to satisfy demand. Once installed, those power facilities will remain in place operating for thirty to forty years at least.

343. See supra Figure 5; See also Climate change-driving forces, EUROSTAT (Feb. 2017), http://ec.europa.eu/eurostat/statistics-explained/index.php/Climate_change-driving_forces (explaining how GHG emissions have decreased since 1990 mainly due to energy efficiency and less carbon intensive fuels such as renewables); supra Section III.A.

344. INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 9.

345. Id.

346. Wara, supra note 332, at 1790–92.

347. See HC Science and Technology Comm., Meeting UK Energy and Climate Needs: The Role of Carbon Capture and Storage, at 2, HC 1036 (April
value and accurately motivate sustainable energy choices in developing countries so that these forty-year energy infrastructure investments, as shown in Figure 14, will be motivated to reflect actual real-time protection of the climate.

The World Bank in 2013 announced that it would provide money for new, greenfield coal-fired power stations “only in rare circumstances,” such as where countries have no feasible alternative to coal and lack financing for coal power, or where coal projects will incorporate carbon capture and storage. The U.S. Senate, by a vote of sixty-four to twenty-nine, overturned an Obama Administration regulation that allowed the U.S. Export-Import Bank to deny an application for financing based on the source of energy used for the project, designed to not fund new coal-fired power plants overseas. Henceforth, U.S. support cannot be blocked from developing country preferences for new coal-fired power plants, even as coal use quickly declines dramatically in the U.S.

Two factors provide both the economic and policy mechanisms needed to cause a shift in electric energy generation infrastructure from use of coal to renewable power. First,

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348. *THE WHITE HOUSE*, supra note 15, at 45 Figure 4.4.


351. Id.

352. Steven Ferrey, *International Alchemy within the Post-Copenhagen World: Transforming Critical Infrastructure Across Two Hundred Divergent Economies*, 34 HASTINGS INT’L & COMP. L. REV. 303, 308 (2011) [hereinafter Ferrey, *International Alchemy*] (discussing the science and international legal protocol of global warming while charting the proven and successful ways in which fast growing Asia has used certain template techniques). *See also* Tom Randall, *Fossil Fuels Just Lost the Race Against Renewables: This is the Beginning of the End*, BLOOMBERG NEWS ENTERPRISE (Apr. 14, 2015, 3:27 PM), https://www.bloomberg.com/news/articles/2015-04-14/fossil-fuels-just-lost-the-race-against-renewables (discussing how the world has been adding more capacity for renewable power each year). *See generally* STEVEN FERREY WITH ANIL CABRAAL, *RENEWABLE POWER IN DEVELOPING COUNTRIES: WINNING THE WAR ON GLOBAL WARMING* (2006) (discussing how six developing Asian
there is a demonstrated and proven template to implement sustainable renewable energy policy and deployment in developing countries, and the template’s legal and regulatory structure is documented.\footnote{353} This template has been applied successfully for two decades in several diverse developing countries which employ a wide variety of government systems, utilize different sources for power generation, and have different types of structures for their utilities.\footnote{354} Second, since 2013, the world has added more electric capacity from renewable and nuclear power each year than from coal, natural gas, and oil combined.\footnote{355} With current subsidies, “the price of wind and solar power continues to plummet, and is now on par or cheaper than grid electricity in many areas of the world.”\footnote{356} Moreover, the largest international wealth transfer in history is pledged to developing countries to begin in 2020, which could be targeted to support renewable power infrastructure, as examined next.\footnote{357}

3. Unprecedented International Financial Transfers

To finance GHG mitigation and adaptation mechanisms in developing countries, developed countries have committed to the largest sustained international transfer of wealth in history: A commitment of an additional $100 billion/year of foreign aid continuing indefinitely for the explicit purpose of dealing with global warming risk.\footnote{358} The U.N. Conference of Parties in Copenhagen set a goal of mobilizing $100 billion per year by 2020 to support mitigation and adaptation activities in developing countries, plus $30 billion USD in “fast start” finance during 2010–2012.\footnote{359} This was reinforced in the 2015 Paris Conference of Parties Agreement, and is an unprecedented amount of wealth transfer.\footnote{360} For context of the magnitude of this, the total annual United Nations budget is $1.9 billion

\begin{itemize}
\item \footnote{353} Ferrey, International Alchemy, supra note 352 at 311.
\item \footnote{354} Id. at 312.
\item \footnote{355} Randall, supra note 352.
\item \footnote{356} Id.
\item \footnote{357} U.N. Secretary-General, Report of the High-level Advisory Group on Climate Change Financing, ¶ 7, (Nov. 5, 2010).
\item \footnote{358} Id. ¶ 3.
\item \footnote{359} Id. ¶ 7.
\item \footnote{360} See The Paris Agreement on Climate Change, NRDC (Dec. 2015), https://www.nrdc.org/sites/default/files/paris-climate-agreement-1B.pdf.
\end{itemize}
annually, and added peacekeeping operations raise annual expenditures to $15 billion.\textsuperscript{361}

Others suggest that even this massive transfer will not be enough: richer nations need to provide $400 billion to $2 trillion a year to the developing world by 2050 to help cut GHGs and fight climate change, according to a study by the London School of Economics.\textsuperscript{362} Wealthier countries, in 2017 before the U.S. announced its planned withdrawal from the Paris Accord, promised to deliver an annual $100 billion by 2020, from private sources as well as public sources.\textsuperscript{363} India, the world’s third most significant emitter of carbon, offered to make sharper cuts in emissions only if rich nations pay it to do so.\textsuperscript{364} United Nations Secretary-General Ban Ki-moon stated that “Investors and businesses that redirect resources to low-carbon, climate-resilient growth will be the economic powerhouses of the 21st century.”


362. Alex Morales, At Least $400 Billion in Climate Aid Needed for Developing Nations a Year, Study Says, BLOOMBERG L. (Mar. 16, 2015, 11:00 PM), https://www.bloomberglaw.com/document/XA9FHB7C000000?bna_news_filter=environment-and-energy&jsearch=BNA%252000000016071d7de0fa5f03ffab1b0000#jcite.


364. Uni Krishnan, India Tells Developed World It Will Impose More Cuts in Exchange for Cash, Technology, BLOOMBERG ENV’T (Mar. 26, 2015, 11:00 P.M.), https://news.bloombergenvironment.com/environment-and-energy/india-tells-developed-world-it-will-impose-more-cuts-in-exchange-for-cash-technology India’s Environment Minister Prakash Javadekar stated that he may present the world with a choice ahead of the December Kyoto Protocol Conference of the Parties with the proposition that “The world has to decide what they want. . . . Every climate action has a cost. I can’t make my poor pay for somebody who has polluted the world.”
Those that fail to do so will be on the losing side of history.\textsuperscript{365}

The Financial Mechanism for the 2015 Paris COP Agreement does not cover the entire inflow and outflow of the $100 billion in annual funding; funding from countries can proceed, at donor discretion, through bilateral and multilateral channels.\textsuperscript{366} Since management of landfill and wastewater methane release issues have existed since the beginning of recorded history and show no signs of being eliminated,\textsuperscript{367} devoting funds to landfill and wastewater methane emission mitigation is an ideal application of funds. Every country could be held responsible to manage its waste activities that create GHG releases.

Limiting global warming to a no more than 2°C increase from pre-Industrial Revolution levels will require stabilizing and reducing GHG concentrations in the atmosphere.\textsuperscript{368} An official with the IPCC concluded that developed nations will need to slash carbon dioxide emissions almost entirely by eighty to ninety percent by 2050 to hold GHGs to 450 ppm in the atmosphere.\textsuperscript{369}

The ability of the U.S. to influence the rest of the world on climate change, either by example or through its financial influence, is not clear and remains to be determined. For example, President Obama ordered a bar on U.S. Export-Import Bank funding of overseas coal-fired power plants in developing nations unless they capture and store their carbon dioxide.\textsuperscript{370} This did not survive: The Obama order on the Export-Import

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\textsuperscript{367} See U.N. Secretary-General, \textit{supra} note 357, at 62.

\textsuperscript{368} See \textit{FERREY, ENVIRONMENTAL LAW, supra} note 25, at 249. At such modest levels, the degree of warming is not expected to result in radical loss of ice sheet, sea level rise, and shift of agricultural areas. \textit{Id}.

\textsuperscript{369} \textit{FERREY, The Failure of International Global Warming Regulation, supra} note 335, at 72.

Bank was overturned in July 2015 when the U.S. Senate voted, sixty-four to twenty-nine, to bar the U.S. Export-Import Bank from denying an application for financing based on the source of energy used for the project.\(^\text{371}\)

And methane emissions, as the second most important (and underappreciated) warming chemical,\(^\text{372}\) must participate in proportionate amount with carbon dioxide to achieve such an unprecedented and massive amount of reduction. This will require a sharp reduction of emissions over the next generation, and to “near zero by 2100.”\(^\text{373}\)

B. LEGAL IMPLEMENTATION FULCRUM POST-PARIS

Methane must no longer be miscalculated in setting international policy and law.\(^\text{374}\) There are now atmospheric concentrations of GHGs at levels that have not been seen for almost a billion years.\(^\text{375}\) The Paris Agreement had the world agree to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels.”\(^\text{376}\) However, there was no mandatory mechanism to institutionalize the Agreement.\(^\text{377}\) Now more than three years later, notwithstanding the Agreement, many world nations are now off-track from reaching that pledge; the world is on-track instead to reach a temperature increase of at least four degrees Celsius.\(^\text{378}\) This would represent a huge climate warming policy underachievement.

Methane has been the critical missing chemical variable not realistically or appropriately factored into international climate

\(^{371}\) See Dean Scott, supra note 350, at 1.


\(^{373}\) Id. at 735.

\(^{374}\) See discussion supra Section II.

\(^{375}\) See Intergovernmental Panel on Climate Change, supra note 47, at 11 (showing the highest levels of the atmospheric concentrations of GHGs in at least the last 800,000 years).

\(^{376}\) Paris Agreement, supra note 23, at art. 2.1(a).

\(^{377}\) See, e.g., Ferrey, The Green Climate Fund, supra note 4, at 65 (criticizing that the intended nationally determined contribution (INDC) pledges that different countries submitted are not legally binding and that there are no international enforcement mechanisms to penalize any country for noncompliance in its GHG emissions varying from its pledge).

\(^{378}\) Wang et al., Climate Change of 4°C Global Warming above Pre-industrial Levels, 35 ADVANCES IN ATMOSPHERIC SCI. 757, 757 (2018).
policy. Its warming impact in real time, vis-à-vis carbon dioxide, has been significantly underestimated to the degree of significant multiples by international officials and policymakers. Rather than being responsible for sixteen percent of climate warming changes over a hypothetical 100-year period, as traditionally regarded in international policy, methane actually is responsible for 200–300 percent more than this until-now-assumed percentage of world climate impact in real time over any decade.

Jason Bordoff, founding director of Columbia University’s Center on Global Energy Policy, noted that the 2017 study by the International Energy Agency “reminded us how poor our understanding of the global [methane] issue is.” Analyzed correctly in real time, correct calculations elevate methane policy to the front line of international climate law. When every molecule of GHG emissions matters, international legal policy cannot continue to overlook up to forty percent of real-time global warming impact from the release of methane molecules.

Methane control is now elevated as a pressing climate issue, and unlike for carbon dioxide, for methane there are cost-effective market solutions that can pay for its costs of implementation in various sectors of the world economy. Methane molecules are distinct from all other GHG molecules in that they are not a waste product to be discarded, but instead constitute a valuable energy resource to power the modern

379. See generally Romm, supra note 5 and accompanying text.
380. THE WHITE HOUSE, supra note 15, at 89.
382. See McKibben, supra note 7 (explaining that understanding the methane data calculation will encourage different countries to reorient their climate policies to address methane leaks associated with fracking and to develop renewable energy sources).
383. CAL. ENV’T PROT. AGENCY, supra note 9.
384. See Aubuchon & Hibbard, supra note 191, at 1–2 (explaining that by capturing leaked natural gas that contains methane and other GHGs, natural gas distribution companies are able to supply gas a reducing rate and mitigate the social costs of carbon); see also supra Figure 4 (illustrating that reducing methane losses or gas pipeline leaks generates economic benefits by reducing the amount of gas that utilities buy and charge ratepayers for). See also, text at supra note 271.
When burned for fuel, captured raw methane is converted to carbon dioxide while also displacing the need to combust other fossil fuel resources, the cumulative net effect on climate is reduction of chemical warming of the atmosphere by ninety-eight to ninety-nine percent. The essential first order of international law and policy regarding methane is to understand the numbers and science. More accurate monitoring of methane emissions across the globe is an essential priority and prerequisite for effective sustainable climate policy, given that methane emission sources are geographically dispersed in every country and technologically diverse in different sectors of the world economy. The monitoring technology is available: use of new satellite, aircraft, and drone capabilities can document methane leak detection and monitoring. The Environmental Defense Fund, a non-governmental private organization, announced on April 11, 2018, that it will build and launch a satellite, planned for 2021, which will “measure major global sources of methane” emissions, including Concentrated Animal Feeding Operations discharges and emissions from landfills. Other methane monitoring satellites are already in orbit: the European Space Agency launched a sensing satellite in October 2017, and a Quebec company launched a carbon dioxide and methane sensing satellite in June 2016. Once on-the-ground data are obtained, equally important is correctly calculating the amount of warming.

385. See id.

386. See Romm, supra note 5 (documenting that methane is twenty-eight to thirty-six times more warming than carbon dioxide over a 100-year time scale); see also Patti Nyman, Methane vs. Carbon Dioxide: A Greenhouse Gas Showdown, ONE GREEN PLANET (Sept. 30, 2014), http://www.onegreenplanet.org/animalsandnature/methane-vs-carbon-dioxide-a-greenhouse-gas-showdown/ (comparing the global warming potential of methane to that of carbon dioxide).

387. See generally Fay, supra note 11 (demonstrating that with more accurate monitoring of carbon dioxide emissions, international players are able to set up long-term objectives and craft comprehensive policy packages).


389. Roston, supra note 381.

390. Id.

391. Id.
associated with methane in real time that causes real climate damage. The ultimate challenge is legally implementing methane control, not a challenge of creating new technology.392

The Institute for Governance and Sustainable Development report identified regulating emissions from coal mining as an important methane control measure.393 Coal mining occurs in many developing economies.394 Additional mitigation measures listed in the report include (1) controlling fugitive emissions from oil and gas production; (2) controlling fugitive emissions from long distance gas transmission; (3) capturing gas from municipal waste and landfills; (4) capturing gas from livestock manure; and (5) intermittent aeration of constantly flooded rice paddies.395 While each sector of methane emissions is distinct, this action protocol applies to any country in which fossil fuels of natural gas, oil, and/or coal are utilized, as well as to every country which has landfills and generates wastewater from human waste.396 Implementation of all these mitigation measures could provide immediate results and is capable of reducing methane emissions by approximately thirty-eight percent.397

In the history of the use of modern energy sources, natural gas, with its methane molecules, was the last of the fossil fuels developed.398 Figure 6 tracks the use of all energy sources over the last 240 years spanning before and after the Industrial Revolution.399 Natural gas did not become a significant energy source compared to the other fossil fuels of coal and petroleum, until after World War II.400 Prior to that, natural gas emerging

392. See supra note 377 and accompanying text.
393. INST. FOR GOVERNANCE & SUSTAINABLE DEV., supra note 35, at 20 (explaining that such measure is “capable of reducing global methane emissions by ~38% and emissions of black carbon by ~77%).”.
394. INTERNATIONAL ENERGY OUTLOOK 2016, supra note 18, at 9–10.
395. INST. FOR GOVERNANCE & SUSTAINABLE DEV., supra note 35, at 20.
396. Id. at 21 (analyzing that many of these identified measures can be “implemented with a net cost savings averaged globally”).
397. Id. at 20.
398. 15 U.S.C. § 717 (2005) (showing that the Natural Gas Policy Act, imposing federal regulation over interstate gas pipelines to distribute gas, was not enacted until 1938).
399. Supra Figure 6.
from oil wells was allowed to escape into the atmosphere, or in certain instances, was flared.\textsuperscript{401} It was not retained for its own energy value.\textsuperscript{402} Energy markets are now international: Even if U.S. coal use now decreases, there will likely not be a similar decrease in developing countries with which the U.S. participates in the coal export market.\textsuperscript{403} As long as some countries in the world continue or increase coal use, as many do, other countries will export climate-warming coal to them.\textsuperscript{404} Because of increasing world population and increasing demand for food, the prospect of reducing worldwide agricultural emissions of methane before 2050 in the extremely competitive world agricultural market must rely on technological innovation applied in every country to animal diets, fertilizer use, and manure management.\textsuperscript{405} All of these essential reductions in methane emissions in each economic sector are possible only if the true real-time duration of methane and its impact are recognized by all relevant international bodies, and international law adapts to require implementation of fugitive methane reduction.

\textsuperscript{401} https://www.eia.gov/energyexplained/index.cfm?page=natural_gas_environment (last updated Feb. 12, 2013) (explaining that after World War II, the nation started building gas pipelines because of improvements in metals, welding techniques and pipe making).

\textsuperscript{402} Id.


\textsuperscript{404} Warrick, \textit{supra} note 403.

\textsuperscript{405} See \textit{THE WHITE HOUSE}, \textit{supra} note 15, at 90 (asserting that “without additional technological innovation, agricultural methane emissions will likely remain a significant GHG source in 2050”).
Time and space matter. In terms of time, an accurate “clock speed” of actual atmospheric climate change related to time and duration in the atmosphere must be assigned to the methane molecules emitted to the atmosphere globally by the approximately two hundred world nations, as set forth in this article. In terms of space, we live in a finite environment, and “the Earth is where we make our stand.”  
