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REVIEW ARTICLE

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How diplomacy saved the COP21 Paris Climate Conference, but now, can we save ourselves?

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Abstract To solve a problem, three things are necessary: awareness, means, and will. The 2015 COP21 Paris accord was a masterful, perhaps even world-saving, diplomatic advance toward making the world aware of climate change. Some of that success may have been because publications from the IPCC and the National Academy of Science were made available, on line, as prepublication offerings, in order to be widely viewed before the Paris Climate Conference. This provided diplomats and negotiators with the latest information about climate change, its nearness in time, its consequences, and how well current mitigation technologies can succeed. Whatever the reasons, the Paris Climate Conference, was a success. Leaders of 195 nations agreed that climate change is a real and present danger to life as is known to all. This important understanding was accomplished despite the presentation of well established scientific facts which, without very diplomatic handling, could easily have evoked overwhelming political opposition to an agreement and thus another COP failure. In this paper, the fact that how some scientific truths, written specifically to be overlooked, were presented in order to prepare COP21 participants for the conference is explained. Besides, the effectiveness and efficiency of currently favored mitigation policies, the extent of ongoing progress to better ones, and finally, how a new appreciation of climate change consequences can strengthen the will of nation states and industries to work toward solutions are evaluated.

Keywords COP21, Paris, climate, agreement, offsets, mitigation, IPCC

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1 Introduction

The purpose of this paper is to underscore scientific details that may shift the conversation for nations combating climate change through the COP (Conference of the Parties). Having participated in several of the climate conferences since 2008, it was clear that two held greater weight than all the rest. These were the 2009 COP15 in Copenhagen, and the 2015 COP21 in Paris. Only the Paris Climate Conference succeeded in getting leaders of 195 nations to agree that climate change is a real and present danger to life as is known to all. This remarkable, and long sought after objective was achieved by diplomatic, rather than scientific means, downplaying the eminent risks that discussion of all data would have made clear. This strategy appears to have been a calculated risk because one could assume that the positions of the relevant scientific communities [1,2], if not very diplomatically stated, could have evoked strong, and probably effective opposition to the COP21 Paris accord. With the agreement reached, goals were laid out with a target of limiting global surface temperatures to not more than 2°C above those of pre-industrial times, 1850 – 1900. However, with an inaccurate understating of timelines, there is the risk that the agreed upon plan of action will not be effective. One hope was that the Paris Climate Conference was important for getting nations to agree that climate change exists, then a recalibration at COP22 in Marrakech might be an opportunity to more deeply discuss existing data and recalibrate the response. Unfortunately, the conclusion of COP22 was to continue the COP21 decisions with no changes. Contextually, an additional concern is that a major political party in the USA still denies the reality of climate change, and fossil fuel companies risk restrictions on known reserves. It is hoped that this paper will help bring to light the information that may have been underemphasized in Paris in order to achieve a first stage diplomatic step, and, in so doing, help focus on more effective strategies while there is still time.

2 How were scientific statements and facts diplomatically presented before the COP21

Figure 1 illustrates how scientific statements and facts were diplomatically presented before the COP21. Figure 1 shown here, (the well known Fig. SPM6.1 of IPCC, 2014 [1], which was modified to Fig. 1, in NAS, 2015 [2]) shows the effects of two different emission rates: Representative Concentration Pathways (RCP) for greenhouse gas emissions, RCP8.5 (continued heavy emissions) and RCP2.6 (stringently restricted emissions).

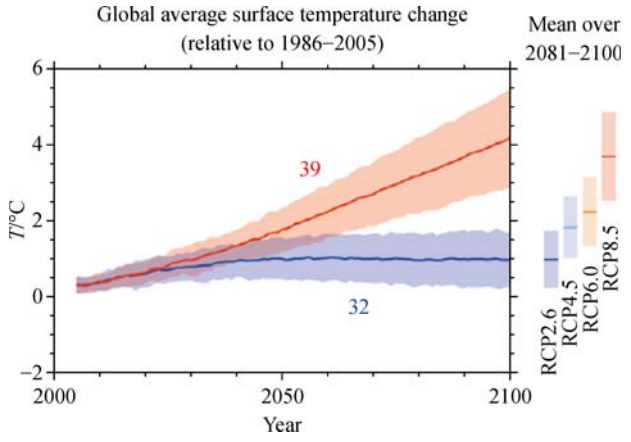

Fig. 1 Global average surface temperature changes resulting from Representative Concentration Pathways RCP8.5 (continued heavy emissions) and RCP2.6 (stringently restricted emissions), relative to 1986−2005 (Fig. SPM6.1 of IPCC, 2014, reprinted with permission)

However, not all viewers of that iconic figure would have noticed the parenthetical subtitle, "(relative to 1986–2005)" which is found in the Fig. 1 title. This subtitle means that the baseline in Fig. 1, shown here, is not that of preindustrial 1850–1900 times. Still fewer readers would have seen the footnote {2.2.1} [1] to the original figure which explained that "The period 1986–2005 is 0.61°C warmer than that of 1850–1900." This means that, if the real baseline, that generally considered as "preindustrial temperatures", were used, those of 1850–1900, not those of 1986–2005 shown in Fig. 1, it would reveal that, with RCP8.5, global surface temperatures will reach 2°C sooner, around the year 2040, 23 years from now, not the less alarming 39 years diplomatically implied in the graphics.

Of course, RCP8.5 assumes current emissions, will continue unabated, that is, "business as usual," but that may not be the case [3,4]. Energy-related CO_2 emissions in the US did decline > 10% between 2007 and 2013.

However, even if there are significant reductions in emissions, "…to limit anthropogenic global warming to, at most, 2°C relative to pre-industrial temperatures… requires that cumulative emissions from 2011 onwards have to stay below 1 trillion tonnes of carbon dioxide or 270 billion tonnes of carbon to keep global warming from overshooting the 2°C limit" [5]. This amounts to "a mere 9 years of current fossil fuel use…" [6].

2.1 How long would overshoots of 2°C last?

Another diplomatic presentation is that both Refs. [1,2] specifically state that exceeding 2°C above preindustrial temperatures will be "temporary." However, the duration of "temporary" overshoots was already suggested in Fig. 1 (which was originally Fig. SPM6.1 of IPCC, 2014). Note that, in Fig. 1, just beyond the right hand vertical axis, the data indicate that, as explained in footnote {2.2.1} [1], even intermediate levels of reduced emissions, RCP4.5, and RCP6.0, as well as RCP8.5, will all, on average, exceed preindustrial temperatures by 2°C, even in the period of 2081 – 2100. (Recall that the baseline from preindustrial temperatures is 0.61°C lower than that of 1986 – 2005). Thus, the use of the term "temporary" allows the reader to think that overshoots will be brief when, Fig. 1 indicates that they would last, at least to the year 2081. During that time, species will be lost, coastal areas flooded, populations forced to migrate, along with many other damaging changes, none of which will be recoverable.

2.2 Why will overshoots be functionally permanent?

1) Even if anthropomorphic GHG emissions could be stopped today and their levels were to begin to decline, the slow release of the heat already stored in the oceans will prevent atmospheric temperatures from declining significantly for centuries [7–9].

2) "If enough CO_2 were removed from the atmosphere to cause a decline in overall atmospheric concentrations, CO_2 would 'outgas'" from the ocean into the atmosphere [2].

3) "…even in RCP2.6 when surface temperatures are decreasing after 2100, … transport of heat by mean ocean circulations, will mean that thermal expansion of the oceans will force sea level rise for centuries" [10].

In other words, not only must emissions be slowed down, but the CO_2 already in the atmosphere must be reduced as soon as possible. This can be accomplished only through negative emission technologies (NETs). The possibilities of NETs were described before the congress [2], but, as is discussed below, also these were presented, factually correct but diplomatically, along with their very real limitations.

3 How effective and efficient are major existing mitigation policies?

Prior to the COP21, the NAS [2] explored and evaluated

several interrelated technologies for climate change mitigation. Here just three of these will be discussed: carbon capture and sequestration (CCS), bioenergy CCS, (BECCS), and direct air capture CCS (DACS), their promise, limits, and consequent utility.

3.1 CCS

CCS, the first and most highly evolved carbon capture system, can take several forms (post-combustion, pre-combustion, oxy-combustion and more), but here the discussion deals primarily with the most widely researched system: post-combustion CCS and monoethanol amine (MEA) absorption of CO_2. Exhaust from power plants burning fossil fuels or biomass, contains 4% – 15% volume of CO_2 [11,12] and is exposed to a series of MEA solutions, each of which absorbs part of the flue gas CO_2. Recovery of CO_2 from flue gases is often limited to 85% because the energetic cost of extraction increases exponentially as the concentration of the remaining CO_2 declines [11,12].

The MEA is later heated to release the captured CO_2 for compression to 100 atmospheres and subsequent transportation to subterranean storage or industrial usage (such as enhanced oil recovery).

Each of these steps requires energy and, collectively, these "energy penalties" consume between 11% to 23% of energy normally produced by the power plant [13–15].

Coal burning power plants in the USA have an average thermal efficiency of 33% [16] and natural gas combined power plants (NGCCP) average 60%. Consequently, a power plant with a thermal efficiency of 50%, for example, will require 22% – 46% more fuel than it would one without CCS. This would increase the price of electricity by 70% – 80% [17,18].

One view of CCS is that "All components of CCS are operationally proven secure at the industrial scale." But "Policies of capex (capital expenditure) subsidy, over-supplied emissions certificates, weak carbon pricing, and weak emissions standards have all failed to develop large cost CCS mega-projects. New carbon certificates could link the extraction of carbon to an obligation to store a percentage of emissions" [19].

However, that reference to, "...a percentage of emissions…" should not be overlooked. Demonstration industrial CCS systems already do store a percentage of emissions, but, this is accomplished by increasing the fossil fuel consumption and thus total emissions. In fact, it may be that the limits of CCS are not policies but energy penalties. A recent survey lists 42 CCS projects which have been cancelled [20], each after large expenses [21].

For this reason, reducing the energy penalties of CCS has been intensively researched, and CCS is now listed as one the National Academy of Engineering Grand Challenges [22].

How far could energy penalties for CCS be reduced? The laws of thermodynamics set limits on many processes, including CCS. For example, the equation below [16,23] allows calculating the minimum energy costs ($E_{\min}$) of separating CO_2 from flue exhaust according to the change in Gibbs free energy (ΔG_{mix}) of a reversible separation process for an ideal gas mixture. G is Gibbs energy, T is the absolute temperature, Sisentropy (J/K), and R is the universal gas, constant with the value of 8.314 J/(mol·K) (See also Sandler [23]).

$$E_{\min} = \Delta G_{\text{mix}} = -T\Delta S_{\text{mix}} = --RT\Sigma_i(x_i \ln x_i)$$

$$= -RT[x_{CO_2}\ln x_{CO_2} + (1-x_{CO_2})\ln(1-x_{CO_2})].$$

This assumes that gases being separated contain equal moles of the two gases and that separation of the two is 100%. Therefore, with natural gas as fuel, allowance has to be made for flue gas concentration of 3.0% CO_2 with the rest being nitrogen (water and inerts being ignored), and separation is less than 100% [16].

This calculation indicates that the, "theoretical thermodynamic minimum energy" ($E_{\min}$), for separating CO_2 from nitrogen in flue gases will be 70 kWh/t of CO_2 separation. Furthermore, without knowing other energy costs of the separation (process energies in the power plant), it is assumed that the actual "target energy" is 5 – 6 times the theoretical minimum energy, that is 350 kWh/t of CO_2 captured (= 1.26 GJ/t) [16]. Compression of separated CO_2 to 100 atmospheres will consume another 3% of power plant output [24].

In recent studies, the specific energy consumption of the carbon capture has decreased from about 4.1 (GJ/t) CO_2 to 2.6 GJ/t CO_2. With development of new chemicals and use of them for specially mixed solvents, this energy requirement for CO_2 capture could be reduced further to 2.0 GJ/t [25].

Even though this level of energy requirement for capture could also be reduced further to around 1.1 GJ/t [26], new systems of CO_2 absorption [27] and entirely new processes such as the Allam cycle [28] are under development. But one cannot forget that the overall energy penalty of any new technologies and the laws of thermodynamics will not allow carbon negative reductions in emissions by means of CCS alone. CCS [with MEA] currently has an energy penalty of 30%, and even if a thermodynamically ideal CCS were developed, it would be only twice the thermodynamic minimum [22,28].

The implications of these studies become clear if the characteristics of a truly carbon neutral CCS system are considered. It would require energy to separate CO_2 from nitrogen in the flue gases, which would mean the consumption of additional fuel. The added emissions from that increased fuel consumption would require still more fuel consumption. Meantime, compression, transportation and sequestration would add to these requirements. Of course, energy demands for CCS could be reduced by capturing less than 85% of the emitted CO_2, but

this means not capturing all the CO_2 emitted, meaning the system would not be carbon neutral. For all of these reasons, the NAS states that, "CCS is at best a carbon neutral process" [2]. In keeping with minimizing undiplomatically definitive positions, this statement is found in the caption of Fig. 2 [2]. That quoted sentence indicates that CCS could serve only to reduce emissions, not capture CO_2 already emitted to the atmosphere. CCS is not a NET.

Nonetheless, CCS could have great value in reducing total current emissions from the coal and gas fired power plants which presently generate 67% of the US electricity supply [29,30] and furthermore, it is an essential component of two other mitigation systems, BECCS and DACS, discussed below.

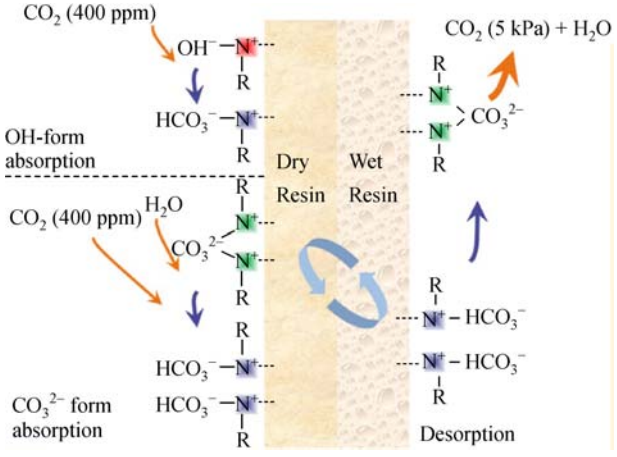

Fig. 2 Mechanism of the humidity swing system for carbon capture

3.2 BECCS

Current reliance on fossil fuels means that mitigating climate change requires finding alternatives to fossil fuel power sources, reducing emissions from fossil fuel power plants, and/or developing NETs. Recent research [31,32] suggests that biomass could be useful to this end. In many regions of the world, abundant biomass, considered waste material, is produced each year. Instead of being burned openly for disposal or left to decay, this biomass could be utilized as fuel, co-fired with fossil fuels. In those cases, some of the released CO_2 could be captured in CCS at fossil fuel burning plants. This process, termed BECCS, using otherwise decaying biomass, could allow sequestration of CO_2 recently withdrawn from the atmosphere by photosynthesis, thus reducing total CO_2 emissions.

To determine if BECCS could provide a transition to a carbon negative power supply system, a model of the electrical system in western North America was constructed based on "…a combination of harvested waste biomass, expanded renewables and generous carbon offsets as abatement costs… " [32,33].

When the model was set to mandate an 86% reduction in CO_2 emissions (−86%) below those of 1990 by 2050, the analysis indicated that co-firing fossil fuel with 15% biomass would reduce emissions and the power plant would be rewarded with abatement credits, thus reducing cost of electricity produced (other things being equal). The effect of any mandate on electricity prices could thus be tested in a variety of different scenarios. These could include allowing or not the addition of biomass to coal fuel, allowing or not CCS to capture on emissions, allowing or not CCS to capture emissions from only biomass.

The results indicated that:

1) If, in 2050, carbon emissions are capped at 86% of those in 1990 (−86%), the cost of electricity without biomass and without CCS would be about $220/MWh (2013US$), 63% higher than without BECCS. Without BECCS, there is no sequestration and the power plant would not receive the abatement benefits, thus raising the cost of electricity.

2) If CCS is available but without biomass, or if there is no CCS, the cost of electricity would be about $187 or $185/MWh, 37%−35% higher than the case with no biomass and no CCS.

3) If only the CO_2 from biomass is sequestered, the cost of electricity would be 6% higher than the case with no biomass and no CCS, about $145/MWh.

4) If both electricity production and sequestration include biomass, the cost of electricity would be about $135/MWh. This is the lowest price for electricity among these combinations, $135/MWh, attained when biomass generates electricity and CCS sequesters CO_2 from both biomass and fossil fuel.

These results reveal that "the value of BECCS lies primarily in the sequestration of carbon from biomass, rather than electricity production." Furthermore, since BECCS power plant operators could be paid for every ton of CO_2 sequestered (offset), they will thus be incentivized to install and operate BECCS technologies [31]. In fact, in most scenarios, the offsets produced by BECCS are found to be more valuable to the power system than the electricity it provides [32]. These aspects of BECCS technologies and economics could thus enable a transition to low-carbon energy. (Sanchez et al. 2015, supplement data [32]). "However, these outcomes depend on the availability of carbon caps (abatement costs, offsets), and CCS technologies with a default capture efficiency of 85%, (being) available for installation on biomass integrated gasification combined-cycle (IGCC) systems, coal and natural gas technologies after 2025."

The proposed system would be profitable with abatement costs as low as US$74/t$CO_2$, and, although this is more expensive than afforestation (US$22.5/t$CO_2$), biochar (US$35/tCO_2), and cellulosic biofuel ($35/t$CO_2$), yet, it is much less that DACS ($1000/t$CO_2$) [32]. Despite extra cost, "BECCS would have a wide application at preexist-

ing power plants," enabling a transition to low carbon power sources. However, the cost of biomass will increase as do abatement costs, putting food and fuel into competition [31,34]. It is important to recognize that "Carbon caps and (CCS) technology availability are the primary drivers of cost of electricity for our results" (Sanchez et al. 2015, Supplement Fig. S2 [32]). A corollary of this is that the abatement prices needed for BECCS, and other systems will stimulate also alternative energy sources and conservation, thus speeding the transition to a low carbon society.

However, BECCS remains "unproven and its wide spread deployment in climate stabilization scenarios might become a dangerous distraction" [35].

An important insight came from a study conducted by the European Academy of Sciences. It concluded that research and development of BECCS should be actively pursued. His approach could contribute to reducing emissions, but the effect will be no silver bullet [36].

On this point, the NAS position is clear: "Large-scale deployment of BECCS would have risks and complications; it is not materially relevant until such time as fossil fuel use is limited and linking CCS with bioenergy use has a net benefit to the climate" [2]. Fortunately, the recent study demonstrates that, BECCS can indeed reduce emissions, even now, by substituting new biomass for fossil fuel, to the extent that it reduces both the consumption of fossil fuel and emissions from power plants [32]. It thus could facilitate a transition away from fossil fuels upon which we are currently strongly dependent [37].

3.3 DACS

The third CO_2 capture system considered here is DACS. Initially, this system was considered to be unworkable because the concentration of CO_2 in the atmosphere is low [2], and the cost of extracting CO_2 with MEA absorbents is high [32,38,39].

However, both of these issues are overcome with a system which is driven by changes in humidity, (or pressure, or temperature) [40]. These are described as "swing" systems.

In the humidity swing system discussed here, the CO_2 absorbent consists of a polypropylene surface coated with an amine-based anion exchange resin in alkaline form (Fig. 2 [41]).

"R + represents the quaternary ammonium ion in the resin. Because the resin is never entirely dry under ambient conditions with vapor pressure present, the water consumed …can be provided by the hygroscopic resin. The net reaction of …that converts bicarbonate and hydroxide into carbonate and water may occur through states in aqueous solution." [41].

When this absorbent is dry, it will spontaneously absorb CO_2 from a stream of dry ambient air passing over it. When this CO_2 enriched absorbent is later exposed to moist air (or water), it spontaneously releases CO_2 but at a partial pressure of $5-10$ kPa. That is about 200 times higher than that of ambient CO_2 (0.04 kPa). This concentrated CO_2 can then be compressed for sequestration, etc.). Re-exposure of the absorbent resin to dry air prepares it for new CO_2 absorption.

Since all steps occur spontaneously, (absorbing CO_2 onto dry resin, desorbing CO_2 in moist air, and drying resin in dry air), the free energy change of the combined reactions must be negative, that is, an input of energy is required. In the humidity swing system, the source of free energy is the evaporation of water. "The evaporation of water vapor absorbs heat from the environment. The desorption step only provides liquid water and some ambient heat is consumed as CO_2 enters the gas phase [42].

An obvious advantage of this system is the great reduction in energy penalties compared to those of CCS and BECCS. "Whether the system is driven by water evaporation or by low grade heat, the cost of the thermodynamically-required energy can be as small as $1 to $2 per metric ton of carbon dioxide" [42], a low cost even allowing for the expected 5 times that for target energy. "Thermodynamics does not pose a practical constraint on the implementation of air capture but leaves quite some leeway for unavoidable inefficiencies in practical systems" [42].

Another unique characteristic of this system, one which reduces energy penalties still further, is that the source of CO_2 being extracted in this system, the ambient air, although containing only 400 ppm, is being continuously refreshed, always at 0.04% CO_2. This is in contrast to CCS/MEA extractions of CO_2 from flue gas ($4\%-15\%$ volume of CO_2) [11,12]. Those require a long series of energy demanding extractions [43], from an ever diminishing fraction of the flue gas CO_2. Thus the DACS system is said to "skim" the CO_2 source while the CCS/MEA system "scrubs" the CO_2 source [11,12].

DACS thus avoids much of the energy penalty which characterizes the CCS separation of CO_2 from the flue gas in fossil fuel or biomass burning power plants where 97% of the energy penalty is for gas separation [22].

All systems, however, CCS, BECCS and DACS, would incur additional energy penalties, approximately 3%, for compression to 100 atm [24] plus more for transportation and sequestration.

Furthermore, DACS does not consume biomass and thus avoids competition for land use or food production. Finally, DACS differs from CCS and BECCS in that it is not limited to point sources of CO_2 such as power plants. Ideal sites for DACS plants would thus be at or near sites for CO_2 storage in geological reservoirs, especially those providing abundant solar energy to power the DAC process machinery, including compressors, and, finally

abundant dry air. Probably this explains why the NAS pointed out that the Bureau of Land Management would make approximately 10^8 acres of land available for DACS in SW, USA, (See Table 2 in Ref. [2]), possibly for solar panels to pay for the process costs for DACS.

3.4 A comparison among reviewed mitigation systems

The three carbon capture systems discussed here, CCS, BECCS, and DACS are all capable of capturing CO_2 for sequestration in appropriate sites, but each has strengths and energy penalties. (See Table 1, NAS [2]). CCS will reduce emissions from power plants, but the energy penalties of this system, already approaching thermodynamic minima, would raise the cost of electricity very significantly. BECCS will also reduce emissions from fossil fuel burning power plants, suffers the energy penalties inherent in CCS, but, by replacing some fossil fuel with biomass, which, in itself, can be carbon negative [32], reduces the total emissions of the power plant. This allows a transition toward a carbon neutral future [44–46]. But here too, the cost will be significant. In fact, the abatement benefits granted to such systems will be worth more to the fossil fuel burning industry than will be the electricity they produce. This will incentivize the power companies to substitute biomass for fossil fuel. However, there are concerns about the negative impacts of large-scale biomass production for fuel on food security and biodiversity [40].

The third mitigation system reviewed here, DACS, does have the potential of carbon negativity, that is, capturing more CO_2 than that emitted during operation and capturing CO_2 already emitted to the atmosphere. Furthermore, DACS would not consume biomass.

Of the three systems, CCS is the most established, now approaching theoretical thermodynamic limits [22], BECCS is evolving quickly [32] as is DACS [47].

Each of the three mitigation systems is necessary, but no one will be a silver bullet. Meanwhile, in addition to DACS [41,42,47] and other NETs [48,49] mitigation can move forward. This issue now is how to "incentivize" movement toward carbon neutral energy sources (solar, wind, etc.) and carbon negative technologies, discussed below.

4 Confronting realities

To solve a problem, three things are necessary: awareness, means, and will. The COP21 made the world aware, and some of the means of mitigating climate change have been known for many years [49].

In addition to an understandable inertia, the challenge has been the lack of sufficient will. Mitigating climate change will be expensive, and presently, the resulting external costs and damages of climate change are shared globally while economic benefits, such as avoiding expenses in controlling emissions, are not. For example, it has been calculated that fossil fuel reserves currently available are approximately US$27 trillion. "A potential bursting of the 'carbon bubble' … would result from the adoption of ambitious climate policies, leading to severe devaluations of fossil-fuel reserves" [50,51].

However, enlightened self interest is now receiving increasing attention. For example, largest emitter nations, "US, China, Russia, Germany, and Canada are those most likely to suffer land loss from sea level rise, excluding Small Island Developing States [52]. Furthermore mitigation policies will be incentivized as emitters begin to be held liable for the effects GHG emissions [52]. Perhaps most effective of all could be the realization that effective climate change mitigation programs will reduce potential for very real damage to global non-bank financial assets [53,54], calculated in 2013, to be US$ 143.3 trillion (See Table 2).

With business as usual (RCP8.5, continued heavy emissions, BAU), there is a 99% chance that 0.46% of global non-bank financial assets will be lost with climate change. The calculated value at risk (Climate VaR) of this is US$ trillion 0.66. With BAU, there is a 1% chance that 16.86% of global non-bank financial assets, US$ trillion 24.18, will be lost. With mitigation to limit warming to 2°C, there is a 1% chance that the loss will be reduced by

Table 1 Cost of electricity, ($2013US/MWh) +/− Biomass and +/− CCS*

	Cost of electricity ($2013US/MWh)(−86)	Change in cost of electricity relative to cost with both electricity& sequestration from biomass and fossil fuel
Yes fossil fuel, No biomass, No CCS	$220	63% increase
Yes fossil fuel, No biomass, Yes CCS	$187	37% increase
Yes fossil fuel, Yes biomass, No CCS	$187	37% increase
Yes fossil fuel, Yes biomass and CCS for sequestration but only on biomass	$145	6% increase
Yes fossil fuel, Yes biomass Yes CCS on biomass and fossil fuel. Electricity &sequestration from biomass &fossil fuel	$135	This is the base by which other treatments are compared.

Notes: *—Data derived from Fig. S6 in Supplement available from Sanchez et al., 2015 [32].

Table 2 Values at risk of global financial assets from climate change between 2015 and 2100

	Probability of minimum loss to Climate VaR/%				
	99	95	Mean	5	1
Emissions scenario					
BAU RCP8.5 (expected warming of 2.5°C in 2100)/%	0.46	0.54	1.77	4.76	16.86
Climate VaR/US$ trillion	0.66	0.77	2.54	6.83	24.18
Mitigation to limit warming to 2°C with 2/3 probability/%	0.35	0.41	1.18	2.92	9.17
Climate VaR/US$ trillion	0.50	0.59	1.69	4.19	13.15

Notes: This table differs from that of Dietz et al. 2016 [53] in that it shows minimum probability of occurrence, rather than its reciprocal, the probability density. It also gives dollar value for each climate VaR.

nearly one half, that is, only 9.17% (US$ trillion 13.15) will be lost.

5 Current progress

As a result of global understanding of climate change dangers, an energy transition is underway. "Market-based carbon policy schemes are spreading worldwide, with about 40 national or subnational systems for emissions trading or taxing green house gas (GHG) emissions have been implemented to date" [55].

Furthermore, "…renewables contributed almost half of the world's new power generation capacity in 2014 and have already become the second-largest source of electricity (after coal), …(and) are set to become the leading source of new energy supply from now to 2040. Their deployment grows worldwide, with a strong concentration in the power sector where renewables overtake coal as the largest source of electricity generation by the early 2030s" [56].

Furthermore, according to the IEA predictions [56], "the coverage of mandatory energy efficiency regulation has expanded to more than one-quarter of global energy consumption. Renewables-based generation reaches 50% in the EU by 2040, around 30% in China and Japan, and above 25% in the United States and India."

Problems of intermittency for wind and solar energies, can be resolved by regional sharing, thus reducing carbon dioxide emissions from the US electricity sector by up to 80% relative to 1990 levels, without an increase in the cost of electricity, with current technologies and without electrical storage [57].

The available data indicate that temperature increases and resulting damage, now underway, will not be reversed in the foreseeable future. Furthermore, every delay will increase the cost and effort needed to mitigate climate change and resultant damage [58].

New studies [53,54] should motivate all players to push for immediate mitigation efforts, Plan A [39,48]. This would involve, as quickly as possible, the many partial solutions which are available now.

6 Conclusions

The Paris Climate Conference succeeded in doing what no other climate conferences had done, namely, persuading leaders of 195 nations to agree that climate change is a real and present danger. They did so, in part, by obfuscating some of the scientific data and presenting current realities in a manner that allowed for broad agreement across the parties. The existing data, however, indicate that serious climatic effects are closer than was clearly indicated at the Paris Conferences and the consequences of climate change will be, not be a matter of a short-term "overshoot," but irreversible for centuries. It was hoped that the diplomatic accomplishments of COP21 would be followed by greater scientific rigor at COP22 which would lead to pairing solutions with more accurately targeted goals; this did not happen. To assure that the Paris Climate Conference results in more than just an agreement, concrete and effective actions must be taken; and for these solutions to work, their application must be calibrated with a clear understanding of the climate realities. Possible major mitigation programs, CCS, BECCS and DACS, can all help, but the first of these is approaching immovable thermodynamic limits, the second will serve to reduce emissions in a needed transition from fossil fuel, and DACS, highly promising, has yet to be implemented. Perhaps more promising still, the rapid expansion of renewable [56], conservation efforts [51], and other mitigation programs [39,48] point to the true value of the COP21 efforts. In summary, the success of the COP21 created a global awareness of climate change as an actionable concern. Existing technologies, if implemented in concert and at scale, can provide successful mitigation programs. Both require the will of the scientific and diplomatic communities as well as industry to fund and carry out the work ahead. This will not be easy because, even in Byzantium, it was recognized that, "… when in political difficulty, … emperors and courtiers ventured to commit acts that would have been unthinkable for the mass of Byzantines" [59]. Today, denying the validity of well established peer reviewed scientific conclusions should be similarly unthinkable but it seems

some leaders are willing to do so. Fortunately, long-term economic considerations [53,54] will help moderate that dangerous possibility.

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