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The great energy transition of the 21st century: The 2050 Zero-Carbon World Oration☆

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ABSTRACT

Looking back from 2050, this article is written in the form of a fictional speech reflecting on the impressive progress made by 2050 towards achieving the global goal of zero net emissions. The speaker also highlights the severe and ongoing ecological damage and human suffering caused by the failure to reduce emissions with sufficient urgency in the first quarter of the 21st Century – and the ongoing challenge of implementing the actions required to bring global temperatures back below 1.5 degrees.

The speech identifies the following key drivers of the 'great 21st century energy transition'.

i) Sustained leadership from national and sub-national governments, business, civil society and the military in ratcheting up and accelerating implementation of the Paris Agreement.

ii) The escalating frequency and severity of catastrophic climatic events.

iii) Disruptive, game changing technological innovation including in energy efficiency, renewable energy, energy storage and distribution, transport, construction and agriculture.

iv) Disruptive, game changing innovation in social, economic and political institutions and relationships including:

- increasing recognition of the importance of reducing the global consumption of goods and services;
- an ongoing shift towards more distributed and collaborative economic paradigms and systems;
- growing popular and political support for the global climate justice movement;
- radical improvements in the transparency and accountability of democratic and governance processes; and
- the mobilization of millions of citizens driving transformational change in investment flows, electoral outcomes and political choices.

1. Introduction

Good evening. I am delighted to be with you tonight to deliver the *Zero-Carbon World Oration* for 2050. As you are aware this annual oration was inaugurated by the UN Secretary General in 2025 in order to inform and strengthen actions required to accelerate progress in creating a just and resilient zero carbon global economy.

In preparing tonight's 2050 Oration I have been acutely aware of the vision we are all seeing of the tragic loss of life from the most recent of the climatic catastrophes which continue to sweep across planet Earth – the Great Inundation of the Ganges Basin. I'm sure I speak for us all in expressing my profound sorrow and compassion for the many millions of lives overwhelmed by this terrible event.

The grim scenes we have seen in the cities and villages of India and Bangladesh over the last few weeks are one more stark reminder of the need to continue to accelerate progress in achieving our three crucial global priorities:

- creating and sustaining a just and resilient zero carbon economy;
- strengthening our capacity to efficiently and equitably sequester $C0_2$; and
- protecting and assisting the individuals and communities most vulnerable to the ravages of our climatically disrupted world.

☆ Transcript of the 2050 Zero-Carbon World Oration. Delivered by: Professor Teuila Apatu, Director, Global Institute for Climate and Energy Transitions, Auckland, Aoteroa New Zealand. This article is written in the form of a fictional speech delivered in 2050 by a fictional character 'Professor Teuila Apatu'. Other fictional characters referred to in the speech are also indicated in footnotes. The backcasting historical narrative of the 21st century energy transition described in the speech attempts to describe one plausible narrative of the way in which a rapid energy transition might unfold, informed by a range of modelling and scenario studies.

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My task tonight however is to focus on the first of these great challenges by addressing three key questions.

- How, despite facing so many tough ecological, economic and political challenges, have we made such remarkable progress over the last 30 years towards the creation of a zero-carbon economy?
- What have been the key turning and tipping points – the key events, decisions and actions – that have driven the global energy transition at such remarkable speed and scale?
- What actions do we need to take to keep repairing the damage caused by the failure of nation states to reduce emissions with sufficient urgency in the first quarter of the 21st Century?

I'd like to begin by sharing some brief observations on the way this challenge looked back in 2017 – at the beginning of the transition period. Following a summary overview of major energy transition trends and outcomes over the last 30 years I then move on to outline five key drivers of the great Energy Transition. My presentation concludes with some reflections on the significant challenges which still lie before us.

2. Turning the tide: from the Paris Agreement (2015) to the Jakarta Climate and Energy Summit (2025)

By 2015 the key elements of the post-carbon economy roadmap were well understood: rapid reduction in energy demand through improved energy efficiency and reduced consumption; comprehensive electrification of energy supply; rapid replacement of fossil fuels by renewables; low carbon agriculture and forestry; carefully managed bio-sequestration; and the actions needed to ensure that the energy transition was undertaken in an equitable and resilient way [1].

There was also widespread recognition that the most significant roadblocks preventing rapid de-carbonisation were social and political rather than technological. These roadblocks included:

- the power and influence of the fossil fuel industry and other vested interests;
- political paralysis and denial;
- social and technological path dependencies;
- financial, governance and implementation constraints; and
- the dominant neoliberal economic paradigm of unsustainable consumption and inequitable wealth distribution

I have two powerful memories from the period 2015–2017 which I'd like to share with you. The first, in Paris in December 2015, was a moment of genuine elation as I joined thousands of delegates in leaping to my feet to applaud the announcement by COP 21 Chair Laurent Fabius that 195 nations had approved the Paris Agreement [2].

Most of us at the time recognized that the Paris Agreement was far from perfect, sharing journalist George Monbiot's astute analysis that "by comparison to what it could have been, it's a miracle. By comparison to what it should have been, it's a disaster." [3]. We very well understood that the COP21 national emission reduction commitments would need to be rapidly strengthened if we were to have any hope of keeping global warming below 2°. Indeed, many of us were also increasingly aware that a strong emphasis on negative emissions would be required to have any real chance of keeping global warming to 1.5 or even 2°.

We were, however, hopeful that ratifying the Paris Agreement would send a powerful message to political leaders and global investors that the rapidly accelerating global shift from fossil fuels to renewable energy was now unstoppable. As a young climate activist I also remember being struck by a conversation with the UNFCCC Secretary at that time, Christiana Figueres, who highlighted the ways in which the Paris Agreement signaled a shift in the locus of power from nation states to sub-national governments and cities as well as to civil society, business and research communities.

My second, far more traumatic memory came only twelve months later, in November 2016, at COP22 in Morocco. I vividly recall the shocked faces of delegates receiving the news that Donald Trump had been elected President of the United States. To what extent, we wondered, would the election of this autocratic champion of climate change deniers and fossil fuel billionaires derail climate and energy action at the very moment at which it needed to be rapidly accelerated? Of even more concern, would the Trump Presidency drive a further deterioration in the erosion of trust in scientific methods and evidence? Reflecting back on this extremely challenging historical moment led me to reread some of the publications which I remember finding particularly useful at that time. I'd like to share a few observations from three of these.

The 2015 Report, *World in Transition: A Global Social Contract for Sustainability* produced by the German Advisory Council on Global Change brought together a broad array of research and analysis on the sources and drivers of large scale technological, social and economic transformations [4].

I remember being particularly struck by the Report's conclusion that "avoidance of dangerous climate change, and the aversion of other threats to humankind as part of the Earth system" would need to go "far beyond technological and technocratic reforms" and would in fact require the creation of "a new global social contract for a low-carbon and sustainable global economic system." This new social contract, the Report argued, would in turn require the creation of a "culture of attentiveness (born of a sense of ecological responsibility), a culture of participation (as a democratic responsibility), and a culture of obligation towards future generations (future responsibility)." [5].

The *2016 World Energy Scenarios* Report produced by the World Energy Council reminded us, on the other hand, just how hard it might be to bring about the political, economic and technological transformations required to actually construct and sustain such a social contract [6]. None of the scenarios outlined in this report envisaged emissions reduction pathways fully consistent with a 1.5C global temperature rise. They did however provide a provocative and prescient tool for understanding how the next 35 years might unfold. The 2016 Report proposed the following three energy transition scenarios.

- *Hard Rock:* The outcome in 2060 is a fractured world, with a diverse set of economic, energy and sustainability outcomes. Nationalist interests prevent countries from collaborating effectively on a global level, with limited attention to addressing climate change.
- *Modern Jazz:* The outcome in 2060 is a world with a diverse set of resilient and lower-carbon energy systems. A highly complex and competitive market landscape drives efficiency, innovation, open access to information and rapid deployment of new technologies.
- *Unfinished Symphony:* By 2060, the world is 'ticking on the same clock' and has shifted to a resilient, integrated, global low-carbon energy system. There is global unified action on security, environmental and economic issues, and global institutional and national governments support enabling technologies [7].

Informed by an increasingly sharp understanding of the urgency of the emission reduction task, many climate and energy researchers also focused closely on the speed with which large scale energy transitions could occur [8]. While the dominant view rightly noted the long timeframes generally required for large scale energy system transitions, we were also keen to learn from historical examples of relatively rapid technology transition narratives – the shift from horse power to the internal combustion engine for example or the extraordinary explosion in the use of mobile phones [9].

In fact, as we now know, the energy transition of the last thirty years can best be understood as a fiercely contested, uneven and incomplete journey from 'Hard Rock' through 'Modern Jazz' to 'Unfinished Symphony'. As the great Indonesian energy and climate visionary,

Table 1
Key climate and energy transition milestones 2020–2050.[a]

	Extreme weather events	Key political and policy events and interventions	Energy transition milestones	Emissions trends
2020–2030	• 2022: Los Angeles Firestorm • 2024: Delhi Air Evacuation • 2025: Mexico City Water Crisis • 2027-2030: China-India 'Water Wars' • 2028: Cyclone Kali (Bangla Desh)	• 2020: Paris Agreement Review further strengthens energy transition goals and targets • 2024: *Climate Action Alliance* wins majority in US Congress. US *Climate Emergency Act* passed • 2025: *Jakarta Climate and Energy Summit* • 100 countries commit to 2050 carbon neutral economy • Comprehensive decarbonisation plans announced by all major cities and corporations • Cap and trade schemes in place in most jurisdictions • Carbon price rises $50–$150 a metric ton • Fossil fuel subsidies eliminated • Global moratorium on new unabated coal energy	• Renewables provide 50% of global energy mix • Energy storage and smart grids enable affordable management of renewable energy intermittency issues • Leading cities (eg. Copenhagen, Hamburg, San Francisco) carbon neutral • Internal combustion engines in new cars phased out • Decarbonisation of long distance transport through renewable fuels and electrification • Rail replaces air traffic for short haul freight and passenger transport • Coal exits global energy mix	• Land use emissions decrease to 2 $GtCO_2e$ pa • Gross CO_2 e emissions decline from 40 to 24 gigatons • Bio-energy with Capture and Storage (BECCS) and Direct Air Capture and Storage (DACS) technology removes 0.5 $GtCO_2e$ pa
2030–2040	• 2030: Central Africa Drought and food riots • 2035: East Coast Australia Firestorm • 2038: Collapse of Antarctic Larsen Ice shelf	• Carbon pricing expanded to cover all GHG emissions, including air travel and shipping • Carbon price rises to $300 per metric ton • 2030: *Cape Town Climate Justice Summit* mobilizes funds to address impact on most vulnerable populations of climate change and energy transition. • 2035 Delhi Climate Engineering Summit rejects proposals for atmospheric aerosol injections and ocean fertilization. Approves major expansion of funding for BECCS, DACS and CCS	• Renewables provide 75% of global energy mix • All building construction carbon neutral (including emissions free steel and concrete) • Electrification of all sectors in lead countries • Phase out of internal combustion engines • Aircraft fuel entirely carbon neutral • Oil exits global energy mix	• Land use emissions decrease to 1 $GtCO_2e$ pa • Gross CO_2e emissions decline to 14 gigatons • BECCS and DACS removing 2 $GtCO_2e$ pa
2040–2050	• 2040: Collapse of Atlantic fishing grounds • Siberian Methane Explosion • 2050: Ganges Basin Inundation	• 2040: *Paris Climate Summit* celebrates 25 years of progress on achieving Paris Agreement goals. Identifies key ongoing priorities with increased focus on importance of negative emissions and protecting cities and regions most vulnerable to climate impacts. • Carbon price of $400 per metric ton	• Renewables provide 95% of energy mix • All major European countries and US carbon neutral by 2040 • Electrification of all sectors in most countries • Most other nations carbon neutral by 2050	• Land use emissions decrease to zero • Gross $C0_2e$ emissions decline to 5 gigatons • BECCS and DACS removing 5 $GtC0_2e$ pa

[a]Some content in this table has been informed by the conceptual framework and scenarios outlined in J. Rockstrom, O. Gaffney, J. Roegelj, M. Meinshausen, N. Nakicenovic, J. Schellnhuber, A Roadmap for Rapid Decarbonisatio', Science, 355, (6331), 2017 1269–1271.

President Asoka Hartano,[1] noted in her opening speech to the 2025 Jakarta World Climate and Energy Summit:

> "Many commentators at the time saw the Trump/Pence Presidency as heralding the final triumph of globalized fossil fuel corporations overseeing a fractured, feudalised world of nuclear armed kleptocracies. We can now see that this was, in fact, the last gasp of a dying world order. The financial, technological and political momentum driving the shift from fossil fuel world to a clean energy economy was too great. The divisions between the champions of the old and new economy were too deep. The political resistance of the Climate Emergency and Energy Justice movements was too determined. This great gathering, to be known from here on as *Jakarta 2025,* will, I believe, be seen as a game changing tipping point in the transition to a new earth system informed by a profound sense of responsibility to all human beings of current and future generations; to other species and to the Earth's ecology which sustains us all."

The third document I'd like to refer to is *A Roadmap for Rapid Decarbonisation* published in the journal 'Science' in March 2017 [10]. This paper, authored by some of the most well informed climate science analysts of that time, summarized key actions required to create a 40% probability of keeping global warming below 1.5 °. Importantly the article began by highlighting the importance of ensuring that emissions peaked by 2020 and of continuing to halve gross CO_2 emissions every decade until 2050. It was, in fact, rising global alarm at the slow progress towards achieving these targets, combined with the tragic impact of several catastrophic extreme weather events that triggered the global citizen movement leading to *Jakarta 2025*.

3. The great energy transition 2020–2050

The handout provided to you (Table 1) provides an overview of key energy transition milestones in the last 30 years. It is striking to note that these have generally followed a similar – although slightly slower – trajectory to the priority actions proposed in the *Deep Decarbonisation Roadmap* article. Evidence continues to mount that the ongoing implications of this delay have included a faster than hoped for rise in emissions and global temperatures; a higher incidence of extreme weather events – and an increased reliance on negative emission interventions.

4. Key drivers of the great energy transition

While in no way underestimating the enormous climatic challenges still ahead of us, it is, I believe important to remember and reflect on the key actions and decisions which have driven the Great Energy Transition thus far.

4.1. Sustained leadership from national and sub-national governments, business, civil society – and the military – in ratcheting up and accelerating implementation of the Paris Agreement

As noted earlier, ratification of the *2015 Paris Agreement* provided a clear and powerful signal that governments representing the vast majority of the world's population were firmly committed to decisive climate action. While the commitment of particular national governments has varied over time, there has been crucial and sustained leadership from countries responsible for the largest proportion of emissions including China, Germany, India, Indonesia – and, after a slow start, the United States. International agreement and co-operation to support a rapid rise in the price of carbon (reaching $400 a ton in 2040) has been fundamental to the achievement of an energy transition at such an impressive speed and scale.

Sub-national governments and cities, from California to Scotland and from Shanghai to Stockholm, have also played a critical role in demonstrating the feasibility and desirability of zero-carbon pathways and partnerships. The courageous role which the Californian Government played in countering the initial destructive impact of US withdrawal from the Paris Agreement is, of course legendary. Step one was the announcement that California would lead ratification of the Paris Agreement by US States and other sub-national jurisdictions. Step two was the formal declaration by the Governor of California of a 'Climate Emergency' and the passage of the Californian Climate Emergency Act (2022), "authorizing the deployment of military resources and expertise required to i) address climate change risks and impacts and ii) to ensure the implementation of energy transition and emissions reduction actions at the speed and scale fully required to achievement the Paris Agreement targets".

Climate and energy leadership from high ranking US military officers also played an important role in triggering the final collapse of the Trump Presidency. Historians correctly point to the multiple factors leading to the election as US President of General Eleanor Martinez on a platform focused on an emergency speed energy transition[2] [11]. Unprecedented levels of grassroots protest, civil disobedience and demonstrations; the recognition by investors that the economic tipping point from fossil fuel to renewables had now arrived; the impact on the US economy of Chinese, EU and Indian trade sanctions were clearly all important. There is also no doubt that the emotionally charged Address to the Nation by General Martinez in her role as Commander in Chief of the Los Angeles Firestorm Taskforce played a significant role in flicking the switch to emergency speed climate action – in the United States and beyond.

4.2. The escalating frequency and severity of catastrophic climatic events

Tragically, the history of the first half of the 21st century is as much a history of catastrophic climate driven disasters as it is of transformational change in social, economic and technological systems. The devastating impact of cyclones Katrina, Tracy and Haiyan; the great droughts in Somalia and California and the heatwaves and wildfires which swept Australia, Chile, Canada and Russia were only the first of many climate wake up calls which too many of us continued to ignore for too long.

Finally, however, the escalating frequency and severity of extreme weather events overwhelmed the carefully constructed defences of our wishful thinking and denial − not to mention the patience of investors in the world's largest insurance companies. The Los Angeles Firestorm (2022); the Delhi air quality evacuation (2024); the Mexico City water crisis (2025); the India-China 'Water Wars' (2027–2030); the Central African 'Famine Wars' (which reached their darkest hours in 2030); the Dengue fever epidemic sweeping downwards through Australia; and the collapse of the Atlantic fishing grounds all played important roles in strengthening support for further acceleration of the energy transition. Increasing understanding of the link between extreme weather events, food insecurity, refugee flows and military conflict has also further strengthened support for the adaptation and resilience investments needed to protect vulnerable populations.

4.3. Disruptive, game changing technological innovation

The most visible drivers of transformational change have inevitably been technological: cascading, and disruptive innovations in energy efficiency; solar, wind, tidal and geothermal energy; energy storage (batteries and pumped hydro); electrified and autonomous transport systems; startling breakthroughs in aviation bio-fuels, low carbon construction materials and digital fabrication have all played important

[1] President Asoka Hartano is a fictional character.

[2] General Eleanor Martinez is a fictional character.

roles as have new technologies for recording and exchanging value such as bitcoin and blockchain [12].

Smart grids and integrated transmission networks have significantly enhanced the scale and efficiency of energy distribution systems. Heroically ambitious engineering projects linking renewable energy producers with consumers in North Africa and Europe; North and South America; and Australia and South-East Asia have all made major contributions as have impressive improvements in long-distance high-voltage DC electricity transmission. At more local scales, urban smart grids have enabled and accelerated lateral energy trading between local households and businesses.

Dramatic improvements in soil science, livestock feeding practices, forestry and savannah management have all played an important role in reducing land use emissions. These advances have been augmented by a slow but continuing cultural shift towards reduced demand for meat, a decrease in the wastage of food and an increase in consumption of locally grown food.

And then there is the profoundly important – and profoundly troubling question – of negative emissions. 30 years ago I led debates highlighting the ecological and political risks of an over-reliance on Bioenergy with Carbon Capture and Storage (*BECCS)* technologies [13]. My key concern, which I still believe was correct, was that, even if it was possible to deliver large scale BECCS solutions at affordable cost, the implications for the capacity of the planet to produce sufficient biomass for human and animal consumption would be unacceptable. BECCS solutions were also consistently being inserted into emissions reduction scenarios as a 'get out of jail card' to avoid tough decisions about changes in lifestyle and consumption.

Both these concerns have turned out to be well founded. It is now very clear that the failure to act with sufficient speed to reduce emissions in the first half of this century has had the long term effect of further intensifying arguments for expanding investment in BECCS – and further intensifying pressure on the biodiversity and carrying capacity of the Earth's eco-systems. These pressures have only partially been offset by advances in Direct Air Capture (DACS) and Carbon Capture and Storage (CCS) technologies. I can also not finish this section of my presentation without mentioning the most bitter of all Climate Summit debates – the 2035 Delhi Climate Engineering Summit which, by a very narrow margin, finally rejected proposals for the most dangerous large scale geoengineering initiatives such as atmospheric aerosol injections and ocean fertilization.

4.4. Disruptive game changing innovation in social, economic and political systems

I have spent my whole life working shoulder to shoulder with the most brilliant engineers and scientists of my generation. I have the highest admiration for the ingenuity and dedication they have brought to the mission of designing and building the extraordinary breakthrough technologies we have seen brought to scale over the last fifty years. However my personal view remains that the most powerful drivers of the great energy transition have been radical and disruptive transformations in our social and economic systems − and in the cultural values and political institutions that underpin these systems. Let me highlight five of the key trends in social, economic and political values and practices which have, in my view been particularly influential.

1. *Increasing recognition that reducing the global consumption of goods and services an essential basis for decreasing energy demand and addressing sustainability and climate change challenges*. There has also been a belated and contested, but, in my view, crucial shift in understanding that the long working hours and high stress lifestyles required to accumulate an endlessly expanding wish list of material possessions are incompatible with sustained improvements in health and wellbeing. This realization has triggered and been informed by multiple experiments exploring localized, low consumption systems of energy, food, transport and housing production and consumption. In thinking about the distance we still have to travel on the road to a more sustainable economic paradigm I am often drawn to this reflection from an old Bhutanese friend of mind: "expanding the time we have to spend with our friends and family or the time we have to explore our creative goals may in the end be far more important than spending more and more time at work in order to further expand the size of our houses and our cars."
2. *Increasing popular support for the global Climate Justice movement, informed by growing awareness that ever-increasing levels of inequality are economically counterproductive, socially corrosive and ecologically unsustainable as well as ethically unjust*. These were the arguments which informed the central resolutions of the 2030 *Cape Town Climate Justice Summit*, approving comprehensive new measures to mobilize funds to address the impact on the most vulnerable populations and communities of climate change and energy transitions.
3. *An ongoing shift towards more distributed and collaborative economic paradigms and systems characterised and driven by open source, peer-to-peer networks of technological knowledge and skills* [14]. As a number of insightful analysts have usefully noted the 'age of information and telecommunications' which began to emerge in the early 21st century can be usefully understood as a 'fifth revolution' in techno-economic paradigms, building on four earlier 'ages': the first Industrial revolution (characterised by the introduction of mechanized production systems); the age of steam and railways; the age of steel, electricity and heavy engineering; and the age of oil, automobiles and mass production [15]. This transition to a more collaborative and distributed economy has created enormous opportunities for the acceleration of the knowledge and innovation driving the Great Energy Transition.
4. *Radical innovation in governance arrangements improving the transparency and accountability of economic and political institutions and relationships.* Legal and regulatory interventions mandating far tougher corporate standards for the transparent disclosure of climate change and energy transition risks were a crucial driver in shifting investment from fossil fuel to renewable energy industries. At the same time increasing concern about the political influence of vested interests (particularly in the fossil fuel industry) and a corrosive decline in public trust for politicians led many governments to significantly tighten – or in many cases ban outright – corporate donations to political parties.
5. *The mobilization of millions of citizens imagining and creating a diverse array of fossil fuel divestment, consumer boycott, trade sanction and civil disobedience resistance strategies*. In hindsight the huge demonstrations, such as the *People's March for Climate Change* and the *March for Science*, which rippled across the United States in response to the Trump administration's assault on climate action were just the first wave of a far broader global mobilization. So perhaps, my mentor from those times, Christiana Figueres was indeed correct in her wry Twitter response: "Thank you Trump. You have provoked an unparalleled wave of support for Paris and determined resolve on climate action. Deeply grateful." [16].

5. The zero carbon energy transition: a great leap forward on a long and challenging road

In concluding this speech I am delighted to announce that the *2050 World Energy Report* to be released tomorrow will show that we are indeed on track to achieve a net zero carbon economy by 2060. This is an extraordinary achievement and one which I must say has far exceeded even my most optimistic expectations in the difficult years following the signing of the Paris Agreement.

Many profound challenges and tough questions however remain.

Despite the remarkable speed of the Great Energy Transition,

further acceleration in negative emissions innovation will clearly be required to bring long term global warming trends back below 1.5°. The question we still have no answer to is: how can negative emissions at this scale be achieved without overwhelming the capacity of the biosphere to feed 9 billion people?

Despite the progress towards the achievement of a zero-carbon global economy too many crucial economic decisions with profound implications for the future lives of all the species on the planet are still made in ways which are largely invisible and unaccountable. The complex social and cultural pathways leading to a genuinely sustainable, genuinely equitable post-growth economy have yet to be traversed.

Despite the passionate commitment and creativity of so many inspiring scientific, political, business and community leaders over the last 50 years I am still unable to provide my grandchildren the simple, essential gift I most wish to give them: the ecological conditions which enable human beings to continue to thrive and prosper – alongside the many species with which we share this extraordinary planet.

The rapidity of the 21st Century energy transition does however provide a timely reminder of the potential for human imagination and ingenuity combined with ethical and visionary leadership to drive transformational change at remarkable scale and speed. I look forward to working with you all on the next steps in meeting the great challenges which lie before us.

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