Guiding Principles for Climate-Aligned Hydrogen Deployment

Toward Cost-Effective and Equitable Deep Decarbonization to Limit Temperature Increases to 1.5°C

I) INTRODUCTION

The Marrakech Partnership Climate Action Pathways published in 2021 characterize how the energy sector can be transformed to realize net zero emissions by 2050 while limiting warming to 1.5 degrees Celsius and building a climate-resilient world. Drawing on expert stakeholder input and broad consultation, those pathways outline how fundamental drivers like deep energy productivity gains and direct, renewable electrification are complemented by structural change in the fossil fuel industry to embrace decarbonization strategies. Furthermore, stakeholders were aligned on the role of indirect electrification using renewable hydrogen as an energy source and feedstock in select sectoral pathways accounting for 10-20% of final energy demand in 2050, including the production of materials like aluminium and steel, chemicals like ammonia, long-duration energy storage, and fuels for maritime shipping and aviation and possibly in some cases heavy-duty transport.

Yet the prospect of renewable and low-carbon hydrogen as drivers of global energy system decarbonization has grown rapidly over the past few years to widely varying reception. Divergent assertions—borne of a wide range of assumptions about the present, and visions and expectations about the future—project either a widespread and central role for renewable and low-carbon hydrogen, or a narrow role in targeted applications. Cited by hydrogen prospectors as rationales for its adoption include the increasingly urgent need for immediate emissions reductions, estimates of the scale of energy supplies we will use, the lack of technology alternatives, and financial interests in existing energy and industrial infrastructure. Meanwhile, concerns have grown among civil society about hydrogen's implications for fossil fuel demand, which low-carbon hydrogen could extend; hydrogen's consequential implications for climate, and equitable health and economic outcomes; and the integrity and immediacy of hydrogen proponents' plans.

The divergence of these expectations as to the sources, uses, and extent of hydrogen needed to deliver a 1.5-degree Celsius-aligned and resilient global economy could imperil our realization of that outcome: certain beliefs and expectations can undercut actions required to pass through this delicate stage of initial technology emergence along exponential growth curves. Rather, building and setting shared expectations about what the future requires can unlock collaboration needed to realize it. These expectations are best grounded in three fundamental frames:

1. *sound evidence* about current and near-term technology performance and the science of climate change and its drivers;
2. *genuine investment and business plans* that are ready to deliver on our commitments and stated goals; and
3. *aspirations for better ways of organizing and collaborating* globally to meet our common needs in light of growing global challenges.

Within those frames, a multi-stakeholder engagement process facilitated by the High Level Champions for Global Climate Action of United Nations Climate Change process was held in response to interest from members of the Marrakech Partnership for Global Climate Action to improve convergence in this key moment for global energy transformation. This process developed guiding ‘principles’ to help inform the production and use of hydrogen in ways consistent with avoiding unintended consequences for public health, climate, and economy. These ‘principles’ aim to:

- Build trust through mutual understanding of diverse perspectives, from experts to civil society, from technoeconomic potentials to implied emissions outcomes;
- Break down and evaluate challenging issues and dynamics with implications for technology and infrastructure path dependence and global social equity
- Understand where our perspectives differ, the assumptions and variables that inform that difference;
- Characterize the immediate and targeted action needed to minimize delay;
- Find ground for convergence to support reliably climate-aligned and equitable action;
- Articulate key policy and regulatory guardrails that are critical to ensure that entrenched agendas do not challenge progress on mitigating climate change

As an outcome of collaboration among Marrakech Partnership stakeholders, these principles aim to support effective public, private, and civil society stakeholder engagement on the development of hydrogen strategies, policies and business cases. That engagement will be local, regional, and international in nature, and so will necessarily represent unique circumstances. Marrakech Partnership stakeholders’ aspiration is that these offer a reference point for deliberation in those fora, toward realization of a climate-aligned hydrogen sector.

II) PRINCIPLES FOR CLIMATE-ALIGNED HYDROGEN: A SUMMARY

Hydrogen policy and investment agendas, as well as near and long-term visions, must be commensurate with 1.5C socioeconomic pathways and evaluated on the basis of their expediency in delivering climate and public health goals.

Hydrogen has the potential to play a pivotal role in supporting deep decarbonization goals by offering a solution to the most challenging sectors of the economy. However, it is also characterized by a host of drawbacks that may shift its status from climate solution to climate challenge. Hydrogen production pathways may emit significant climate-warming GHG emissions, and the widespread and untargeted use of hydrogen may complicate the task of decarbonizing world economies on account of its higher costs and inefficiencies relative to other climate solutions such as direct electrification. Importantly, hydrogen offers a lifeline to fossil fuel incumbents who may see in hydrogen an opportunity and excuse to maintain and expand their gas and fuel-oriented infrastructure in a decarbonized future economy. Policymakers should aim to understand the unique advantages and limitations of hydrogen and be acutely sensitive to agendas of organizations with large stakes in hydrogen's widespread deployment in a manner inconsistent with 1.5C pathways. Policymakers should pursue evidence-based hydrogen policy and investment frameworks rooted in independent assessments and targeting the expedient achievement of broader climate and public health goals aligned with 1.5C pathways.

1. **Hydrogen deployment should be targeted in applications where other solutions do not currently exist. Stakeholders should provide a clear assessment to evidence that this is the case.**

Energy productivity gains are the most cost-effective and established solution by which to limit emissions and further stranded asset risk. To deliver toward the most ambitious, reliably near-zero carbon and capital-efficient scenarios to 2050, these gains must nearly triple across the economy in the next decade—possible, if unprecedented—through the convergence of emerging technologies and behavioral change. This would reduce the amount of hydrogen to between one-quarter and one-half most projections of hydrogen consumption in 2050. Specifically, electrification offers significant efficiency gains in most sectors and geographies, in particular building heating and passenger mobility. Hydrogen infrastructure deployment to serve demand in these sectors may in time become stranded or crowd-out more reliably zero-carbon alternatives that would advantage communities on those bases in the medium- to long-term, depending on local circumstances. Otherwise, a growing evidence base identifies hydrogen as offering promising potential to substitute for fossil fuels in applications where existing climate solutions that can decarbonize much of the economy face technical hurdles. Those include aviation, maritime shipping, steelmaking, long duration storage, and possibly long-distance freight trucking.

2. **Rigorous accounting of lifecycle emissions from hydrogen production, and ambitious ceilings on those emissions, are key to prioritize climate-aligned hydrogen deployment.**

   Rigorous accounting of lifecycle emissions and air pollution impacts of the range of hydrogen pathways, together with ambitious carbon intensity thresholds, are paramount to incentivize hydrogen forms with the highest climate, environmental and public health integrity**.** The range of hydrogen production pathways- including fossil, biomass and renewables-derived hydrogen- may have significant GHG emissions associated with the production, transport and use of the feedstock and/or energy source involved in the process. Policymakers must provide guidance, subject to public comments, prescribing methods for determining the lifecycle GHG emissions and public health impacts of the range of hydrogen production pathways and end-use applications. Both hydrogen producers and consumers should transparently communicate the resource, lifecycle emissions, and pollution intensity of their hydrogen production and use. Ambitious floors on lifecycle emissions reduction should be established by companies and policymakers substantiated by monitoring and regulatory measures to drive toward improved accountability. Rigorous carbon intensity thresholds are a fundamental building block to signal the hydrogen market towards resources with the highest climate and public health integrity

3. **Renewable hydrogen is the only option strictly aligned with a reliably 1.5-degree energy sector pathway.**

   Fossil-based hydrogen intrinsically faces a high burden of proof it must meet through credible, independent monitoring and regulation of lifecycle emissions for inclusion in a 1.5C-aligned hydrogen pathway. Different regional contexts will arrive at their own conclusions about the utility of hydrogen, in its varying production pathways, in light of renewable hydrogen's near-zero emissions profile and inherent health and resilience benefits. All regions will grapple with renewable hydrogen's advantaged economics as soon as 2030 with sufficient investment in most locations. Renewable hydrogen, especially as renewables' supply chains decarbonize over time, will not require stringent government regulation and supply chain transparency for educated procurement to realize near-zero emissions. In contrast, fossil fuel-based hydrogen intrinsically faces a higher burden of proof that lifecycle emissions can be, and are being, independently monitored, regulated, and controlled, for which rigorous independent and automated measurement and verification systems are needed to ensure high standards for emissions leakage prevention and capture. This burden of proof suggests that policies that further incentivize major energy and industrial companies to focus attention on renewable hydrogen production and use is not only appropriate but necessary to deliver reliable decarbonization pathways. Further, analysis suggests that structural cost breakthroughs may be accessible to renewable hydrogen this decade as with renewable energy that compete with fossil-based hydrogen later this decade.

4. **Hydrogen market designs and business models should seek to avoid overbuilding infrastructure, and inefficient re-purposing where a long-term role for renewable hydrogen is not clearly established, by adopting a medium- and long-term view on the trajectory of existing solutions.**

   Investments in long-lived hydrogen transport infrastructure—including new, dedicated hydrogen pipelines and the repurposing of existing gas pipelines—require further reflection. Detailed assessments of medium- and long-term technology trajectories may or may not support widespread hydrogen-related infrastructure expansion as the most cost-effective option, with implications for the utility of short-term retrofits. In particular, policymakers must also scrutinize efforts to expand fossil infrastructure in the near-term premised on the potential future repurposing to carry hydrogen. Critical uncertainties remain in relation to the medium and long-term scope of hydrogen in regional and international economies, as well as the geospatial distribution of hydrogen demand and supply centers, such that widespread near-term investments in new or the repurposing of pipelines may be premature. Importantly, such investments carry asset stranding risks or risks of dependence on inefficient pathways towards climate goals. Policymakers and regulators should exercise caution in relation to proposals for the near-term, large-scale buildout of new hydrogen pipeline networks. Policymakers should consider advancing hydrogen in hubs—where large-scale transport infrastructure is unnecessary—as a sensible and no-regret starting point for hydrogen scale up. Preparatory measures for long-term storage infrastructure, i.e. in salt caverns, should be initiated immediately near those prospective hubs.

5. **Time is crucial – policymakers need to focus on getting targeted projects off the ground and 'learning by doing'.**

   Deployment-oriented policies and initiatives should be prioritized to activate 'learning-by-doing' effects and cost reductions necessary to advance hydrogen in high-value applications. A combination of targeted RD&D in end-use applications and market transformation policies like tax credits and preferential procurement can stimulate technical and commercial advances in parallel. Initiatives and consortia offer opportunities for non-state actors to bandwagon together, kickstarting and reinforcing the process: as deployment drives down costs and improves performance, demand grows, further improving cost and performance as supply chains mature. Performance standards specific to challenging end-use sectors (e.g. emissions constraints applied to maritime shipping) would also create durable markets for hydrogen, and should thereby be considered as the basis for international calibration of domestic, sectoral decarbonization efforts in the future. A near-term focus on current and future 'clusters' of off-takers can offer scale for improved economics and risk allocation. Regulatory support will be especially important to ensure slow-moving enabling infrastructure planning and development (i.e. high voltage electricity lines) does not constrain this overall process across no-regrets locations and applications.

6. **Developing a hydrogen sector must simultaneously focus on delivering public health, workforce and global equity outcomes.**

Equity considerations permeate the hydrogen value chain. A number of production pathways—including fossil and biomass-derived hydrogen—as well as hydrogen combustion in turbines and home boilers may emit harmful air pollution. If not adequately managed, those could have detrimental public health impacts on local communities situated in the vicinity of such projects. It is imperative that all hydrogen policy and investment frameworks layer in equity principles from the outset to avoid harm and maximize benefits for communities already overburdened by air pollution and infrastructure buildout linked to fossil fuel extraction, delivery and use. Policymakers should engage in meaningful dialogue and proactive consultation with environmental justice advocates and communities potentially impacted by hydrogen projects (as per Principle 7)—a foundational step that is critical to the success of a hydrogen agenda compatible with a sustainable and equitable energy future. Expanded hydrogen production may also seem to offer a smooth transition for workforces tied to fossil fuels. But this may be short-lived: in many cases, the relative economics of direct and indirect electrification coupled with changing social norms around emissions and climate change could likely undermine this incremental transition. Specifically, it neglects the potentially near-term potential for strong renewable resources to unlock emerging business cases for near-zero carbon hydrogen, its derivatives, and final products that may ultimately displace fossil fuel use. To proactively manage this, globally coordinated policy, business and investment can seek to support equitable workforce transitions in fossil fuel-dependent communities while encouraging green hydrogen as an export opportunity and leapfrog solution in developing countries.

7. **Hydrogen plans must be developed through transparent and accessible processes to ensure accountability to citizens.**

All investment is ultimately sourced from the final users of goods and services, and it is people that bear the consequences of climate-related environmental change and fossil fuel-related pollution. Local consultation of civil society, especially as regards to giving second life to fossil fuel infrastructure, are essential to secure both local and global buy-in as part of science-based decarbonization targets. Transparent planning and consultation can help to secure that contract assessing the relative effectiveness of solutions over the medium-term (i.e. 2030's) using metrics like cost and energy productivity (Principle 1), by clearly and transparently communicating hydrogen lifecycle emissions and externalities (Principle 2), and the utility of investment in potentially long-lived infrastructure (Principle 4).

III) PRINCIPLES RATIONALE AND STAKEHOLDER GUIDANCE

Hydrogen policy and investment agendas, as well as near and long-term visions, must be commensurate with 1.5C socioeconomic pathways and evaluated on the basis of their expediency in delivering climate and public health goals.

Background rationale:

- Hydrogen carries great potential to support deep decarbonization goals by acting as a substitute to fossil fuels in the most challenging sectors of the economy where existing climate solutions face technical hurdles; those include aviation, maritime shipping, steelmaking and long-distance freight trucking [Principle 1]. The realization of this potential is preconditioned on near-term investments to drive the necessary cost reductions in the production of largely nascent low-carbon forms of hydrogen together with the technological advancements necessary to develop hydrogen as solution in challenging sectors [Principle 5]. This suggests that this decade necessitates a set of robust policies and investments to jumpstart the hydrogen industry and prime it for climate-driven deployment in the next few years.
- However, hydrogen also carries a suite of pitfalls. A number of hydrogen production pathways can be linked to significant emissions and air pollution, and relative to existing climate solutions like electrification, hydrogen is an inefficient solution across the majority of sectors and applications where it is often proposed. Thus deployed in an untargeted manner, hydrogen can increase the costs, complexity, and timeline of achieving the most ambitious goals of the Paris Agreement to limit global average temperature rise to 1.5 degrees Celsius [Principles 1 and 4].
- Hydrogen also offers a second life to incumbents in the production, transport, and utilization of carbon-intensive energy sources, conferring an apparent opportunity to maintain and expand assets and infrastructure to support delivery of a decarbonized global economy [Principle 4]. As such, policy and investment agendas advanced by incumbents with stakes in the widespread deployment of hydrogen must be scrutinized for their degree of alignment with the public interest and compatibility with steps towards net-zero greenhouse gas production.

Stakeholder considerations:

- Policymakers should design and implement a rigorous and comprehensive policy and investment framework towards achieving net-zero GHG economies by or before 2050, commensurate with the urgency of progress along energy pathways limiting warming to 1.5 degrees Celsius (see Principle 1) [IPCC 2018]. Economy-wide policy frameworks such as these should be prerequisites to hydrogen strategies and are paramount to evaluating and designing hydrogen agendas on the basis of their expediency in delivering broader climate, public health and economic goals.
- Policymakers, academic institutions, and investors should be acutely sensitive to the background and views advanced by incumbents in hydrogen's indiscriminate

deployment, including energy and industrial incumbents with strong incentives for such deployment.
- Policymakers should pursue evidence-based decision-making which roots choices in independent assessments and evaluates hydrogen agendas against such assessments and on the basis of their alignment with 1.5C pathways.

1. Hydrogen deployment should be targeted in applications where other solutions do not currently exist. Stakeholders should provide a clear assessment to evidence that this is the case.

Background rationale:

- Cost-effective, proven and reliable clean energy solutions- notably energy efficiency and the direct electrification of end-uses with renewable electricity - are readily available today for large-scale deployment across a vast suite of applications in all energy sectors- buildings, transportation and industry.
- The most ambitious and reliably near-zero carbon policy frameworks and measures will seek to triple energy productivity gains this decade, striving toward a 'low energy demand scenario' that provides equivalent quality of life through convergent technology and lifestyle changes, without the use of carbon capture and storage [IIASA 2018]. Requiring only 245 exajoules, or 40% less energy than today, this scenario would use one-quarter to one-third the hydrogen estimated to be required by other leading independent scenarios which project energy demand between 340 to 355 exajoules in 2050, of which 40 to 75 exajoules are provided by hydrogen [IEA 2021, IRENA 2021, ETC 2021]. This delta offers a reference point for assessing the implications for rate of energy productivity gains on the required scale of the hydrogen economy.
- Hydrogen could act as a valuable complement to established climate solutions where direct electrification currently faces technical hurdles. For some scenarios, energy sources other than electricity amount to 30% of final energy demand by 2030; there, hydrogen is slightly over 10% of final energy demand [ETC 2021]. For others, fully half of final energy demand is met by non-electricity sources, with 13-20% of final energy demand from hydrogen [IEA 2021, IRENA 2021]. This demand arises from chemical feedstock to drive a chemical reaction—as in steelmaking—or dense forms of energy to propel heavy equipment like vessels, aircrafts and possibly large trucks across long distances. Hydrogen also has the potential to bolster the reliability and resiliency of a highly renewable electric grid by acting as a long-duration form of electricity storage [Evans et al., 2020, Rosenow, 2020].
- Proposals for the widespread deployment of hydrogen as a decarbonization tool are emerging across regions [Collins, 2020; Lowes, 2020]. However, robust evidence in the form of independent assessments demonstrates that, in most places, hydrogen would be a decidedly more costly and inefficient large-scale decarbonization solution relative to direct electrification across a wide range of applications – notably, buildings heat, passenger cars and low to medium-temperature industry. This is due

to the high efficiency losses at each stage of the hydrogen value chain from production to end use. Those raise both the cost and risk profile of hydrogen-centric transition pathways, given the potentially challenging scale of infrastructure buildout implied but not justified by technical performance. For example, independent studies estimate that, in many cases, heating a home with a high-efficiency heat pump can be up to 6 times more efficient than heating the same home with a hydrogen boiler. [Collins, 2021; Fraunhofer, 2020; Rosenow, 2020; Volkswagen, 2020; Baxter, 2020; Evans et al., 2020; U.K. CCC, 2018].
- Therefore, widespread and untargeted hydrogen deployment may not be expedient to achieving economic and climate goals and may raise the complexity of achieving deep decarbonization goals.

Stakeholder considerations:
- Policymakers, regulators, and investors must prioritize the large-scale rollout of proven, cost-effective solutions such as energy efficiency and direct electrification that are readily available for deployment across the energy sector. Those will be central pillars of deep decarbonization. Accelerating progress in these vectors must be tracked to better assess the needed scale of hydrogen deployment.
- In parallel, policymakers, regulators and investors should focus hydrogen adoption in high-value applications where it’s best suited to the task and in a no-regret and climate-driven manner.
- Those opportunities should be identified by commissioning independent, robust, forward-looking, and transparent market potential studies and investigations of applications where hydrogen would be a more feasible and cost-effective option relative to readily available solutions like direct electrification. Such studies could then form the bedrock of a targeted hydrogen roadmap nested within a broader deep decarbonization strategy for the economy (Principle 0).
- Policymakers should implement a targeted policy framework for hydrogen centered on the hydrogen roadmap and channelling hydrogen deployment and investments into identified high-value applications. Examples include government subsidies offered to specific hydrogen projects which aim to demonstrate and advance the technology applicability as a zero-carbon jet fuel, as feedstock in steelmaking or in other such high-value applications. Other examples include implementing greenhouse gas emissions standards in challenging sectors creating a strong signal for hydrogen development to replace fossil fuel use.

2. Rigorous accounting of lifecycle emissions and air pollution impacts of the range of hydrogen pathways, together with ambitious carbon intensity thresholds, are paramount to incentivize hydrogen forms with the highest climate, environmental and public health integrity.

Background rationale:

- The range of hydrogen production pathways- including fossil, biomass and renewables-derived hydrogen- may have significant GHG emissions associated with the production, transport and use of the feedstock and/or energy source involved in the process. A rigorous accounting of the full lifecycle GHG emissions of the range of hydrogen production pathways is therefore paramount to quantifying the climate impact of various hydrogen sources and implementing policies and regulatory frameworks that would effectively incentivize the cleanest hydrogen sources commensurate with requisite climate action. In particular, coal and natural gas lifecycle emissions are a significant driver of climate change, accounting for 80 and 40 MtCH4 respectively [IEA 2020]. This reality underpins the potential climate risks of expanding the deployment of fossil fuel-based hydrogen. For instance, if all the projected 2050 hydrogen demand were derived from natural gas equipped with carbon capture, associated greenhouse gas (GHG) emissions would amount to more than 2 gigatonnes of CO2eq per year if upstream methane leakage remains at current levels [ETC, 2021]. This is the equivalent of nearly a third of U.S. emissions today.
- Hydrogen-importing countries may, effectively, export emissions by procuring hydrogen from countries with less rigorous or absent emissions abatement regulations and enforcement mechanisms. Such practice is not a sustainable approach to meeting domestic climate goals and should be avoided or pursued only for a limited time period set out in advance, in preference of certifiable, zero-carbon hydrogen alternatives.
- The extent of methane leakage associated with natural gas extraction and handling remains highly uncertain, although recognition of its significant climate forcing effects are increasingly well-understood [IEA 2021]. This is due to the low coverage and insufficient granularity of temporal, geospatial, and sensor resolution in ground-, air-, and satellite-based coverage of methane leakage from flaring, venting and other incidental leakages. Independent measurement and systems of accountability for methane emissions along the value chain can and must be significantly improved this decade [UNEP 2021].
- Critical knowledge gaps also remain about potential public health impacts linked to the range of hydrogen use patterns. For example, hydrogen combustion can result in elevated and potentially health-damaging emissions of nitrogen oxides, a phenomenon that remains not fully understood and bears on near- term investments in hydrogen-burning power plants and industrial boilers. Due diligence in the form of independent assessments are necessary to bridge those knowledge gaps [U.S. DOE, 2020].

Stakeholder considerations:

- Policymakers must provide guidance, subject to public comments, prescribing methods for determining the lifecycle GHG emissions and public health impacts of the range of hydrogen production pathways and end-use applications. Both hydrogen producers and consumers should transparently communicate the resource, lifecycle GHG emissions, and pollution intensity of their hydrogen production or utilization pursuant to such guidance.

- Policymakers and relevant stakeholders across countries should collaborate on establishing a global methodology for determining the lifecycle emissions of hydrogen production, informed by country-specific methodologies cited above; this is a critical prerequisite to certification and guarantees and origin schemes that are necessary to certify the climate and public health impacts of various hydrogen sources in the context of global hydrogen trade and ensure that such trade is compatible with 1.5C pathways.
- Policymakers should, in a transparent process open to public input and guidance, establish rigorous ceilings on lifecycle GHG emissions and air pollution impacts characterizing hydrogen sources deemed commensurate with 1.5C pathways. Incentives, financial support mechanisms, and market access should be limited to hydrogen sources that meet said thresholds. Rigorous carbon intensity thresholds reflecting very low methane leakage rates such as less than 0.2% and at least 90% capture rates, today, are fundamental to realizing a hydrogen market with climate and public health impacts, commensurate with 1.5C pathways, while exhibiting the most promising standards for long-term economic viability and scalability [ETC, 2021]. For methane leakage in particular, this translates to 75% reductions from current baseline in the course of fossil fuel production, transport and use in major emitters like U.S., Canada, Russia, and China, and a 50% cut from all other countries, to reliably exceed the UN estimate of required reductions of 40% by 2030 [ETC; 2021; UNEP; 2021].
- Policymakers should consider coupling lifecycle accounting frameworks and carbon intensity thresholds with regulations establishing rigorous, comprehensive and independent monitoring, measurement and verification schemes for methane leakage and other sources of GHGs involved in the hydrogen production process [Climate TRACE 2021]. Such schemes are key to ensuring the practical significance of lifecycle emissions analyses and their effectiveness in incentivizing the cleanest forms of hydrogen. In particular, policymakers should drive methane leakage reduction with a variety of regulations and the creation of differentiated markets that require adoption of new methods and technologies to minimize ongoing emissions from across fossil fuel supply chains [UNEP, 2021].
- In the case of fossil-derived hydrogen, policymakers, business, and community leaders should be clear-eyed about the practicality, probability, and timeframe of materially reducing emissions from fossil-derived hydrogen production pathways, even as they work to improve lifecycle GHG emissions measurement and prevention.

3. **Collective efforts can focus on renewable hydrogen to minimize and preclude further emissions and asset stranding in the short window to 2050.Renewable hydrogen is the only option strictly aligned with a 1.5-degree pathway. Fossil-based hydrogen intrinsically faces a high burden of proof it must meet**

through credible, independent monitoring and regulation of lifecycle emissions for inclusion in a 1.5C pathway.

Background rationale:

- Fossil fuel-based hydrogen production extends the present challenge of methane leakage at each stage of the supply chain as articulated in Principle 2. Hydrogen derived via the electrolysis of water powered by 100% zero-emitting electricity—or renewable hydrogen—may be characterized by emissions embodied in solar panels and wind turbines due to the carbon intensive energy used along their manufacturing supply chain; however, renewable hydrogen offers a robust pathway to zero embodied carbon as the global industrial sector increasingly moves to clean energy sources. This is in contrast to fossil-based hydrogen, which inherently contains risk of emissions linked to the fossil fuel feedstock that must be mitigated (as discussed in Principle 2).
- A number of projections estimate that with rapid technological advancement and scale-up, renewable hydrogen could be cost-competitive with fossil-fuel based hydrogen equipped with carbon capture in many locations by 2030 [ETC, 2021; IRENA, 2021], and in most locations after 2030 [BNEF, 2021]. This outlook depends on the pace and scope of cost reductions realized across the nascent renewable hydrogen value chain over the next decade, and the pace of crossing key thresholds in cost and performance ("tipping points") like USD 2 per kilogram, which is a function of investment and deployment. Meanwhile, more mature fossil-fuel based technologies inherently offer less cost reduction potential and could increase in cost as best fuel reserves are utilized and GHG regulations tighten, whereas renewable energy costs are widely expected to continue their cost decline. As a result, investment should be oriented towards accelerating improvements in technologies poised for continued cost reductions and characterized by a robust future economic outlook.
- Investments in fossil-fuel based hydrogen equipped with carbon capture, both greenfield and retrofit, should make clear the assumed payback periods on initial capital outlay. This can help to understand whether renewable hydrogen production will compete with newbuild fossil-based hydrogen assets within the initial payback period of the latter.
- As per Principle 2, integrated and independent systems for methane emissions tracking need significant development. Best efforts must be undertaken to improve measurement, tracking, and accountability protocols for methane leakage. These factors suggest that fossil-based hydrogen investments may be a markedly more limited feature of the global energy transition relative to near-zero-emissions, renewable hydrogen.
- A focus on renewable hydrogen production starting today requires proactively managing the implications of declining fossil fuel use in industrial sectors and their workforces, as described in Principle 7.

Stakeholder considerations:

- Overall, these parameters suggest that a strong focus on a renewable hydrogen route by policymakers, suppliers and consumers can notably reduce the risks of unabated and unaccountable climate-warming GHG emissions and stranded assets from current and new hydrogen production.
- Policymakers should also consider implementing a global incentive framework for sourcing renewable hydrogen with a low embodied emissions profile to catalyse the shift to a cleaner global industrial sector. This can drive a shift away from current dependence on emissions-intensive paths.
- Policymakers should consider the implementation of standards relating to water consumption involved in the electrolysis process, elevating industry best practices to the highest standards of water reuse and recycling. Research Development and Deployment (RD&D) should be strongly focused on advancing electrolysis technologies capable of running on seawater and other non-fresh water sources.
- In contexts where independent assessments evidence to decision-makers that hydrogen derived from fossil fuels equipped with carbon capture offers the more cost-effective investment, it is critical that policymakers institute robust policies, regulations, and systems of accountability to ensure a tight system in terms of its climate impacts and avoid unintended and harmful climate consequences; otherwise, fossil-based—notably gas-based—hydrogen production would be inimical to the achievement of global climate targets. Policymakers must institute:
    - Binding and durable regulations requiring that independently measured and verified methane leakage is minimized to near-zero levels, at least below .2% of production;
    - Independent monitoring and verification systems for methane leakage both within and across countries, considering the potential for global hydrogen trade;
    - Regulations requiring that carbon capture equipment operate at high efficiency (more than 90% carbon capture), at all hours of operation of a fossil-based hydrogen facility, with regular testing;
    - Regulations prohibiting the use of captured carbon for enhanced oil recovery and systems of third-party verification ensuring that the geological sequestration of carbon is permanent and characterized by near-zero carbon leakage;
    - Robust policy instruments, regulations and systems of compliance to offset residual GHG emissions from fossil-based hydrogen production with negative emissions measures, such as natural land sinks and carbon removal technologies;
    - Stringent air quality regulations protecting the public health of communities situated in the vicinity of fossil-based hydrogen projects.
- In the immediate, and especially in the absence of carbon pricing regimes, policymakers should explore provision of differentiated support for renewable hydrogen in the form of preferred and concessional funding support (short-term), technology RD&D, and fast-track interconnection, land use, and permitting measures. This policy support can extend to end-uses, where policy instruments

based on cost-sharing are effective at incentivizing end-use adoption of renewable hydrogen where other climate solutions don't exist (discussed in greater depth in Principle 5).

- Policymakers should prioritize the implementation of policy tools to incentivize the replacement of existing unabated fossil hydrogen production- serving current industrial uses- with renewable or low-carbon forms of hydrogen. Such an approach constitutes the most no-regret manner of scaling up cleaner forms of hydrogen and unlocking virtuous learning effects while avoiding the premature creation of new hydrogen demand centers in applications that are likely to be better served by other climate solutions.

4. **Hydrogen market designs and business models should seek to avoid overbuilding infrastructure, and inefficient re-purposing where a long-term role for renewable hydrogen is not clearly established, by adopting a medium- and long-term view on the trajectory of clean technologies. Detailed assessments of medium- and long-term technology trajectories may not support widespread hydrogen-related infrastructure expansion and re-purposing as the most cost-effective option, limiting the utility of short-term retrofits.**

Background rationale:

- Hydrogen is poised to be an effective decarbonization tool in a critical but narrow set of challenging applications [IRENA, 2021; IEA, 2021]. At the same time, it is being cited as grounds for continued investment in natural gas infrastructure, even as a 1.5 degree scenario requires slowing further fossil fuel infrastructure investments [IEA, 2021].
- The hydrogen market is still nascent and fundamental uncertainty remains as to the scope of the technology's long-term role in different national and regional economies as well as the mid and long-term landscape of supply and demand centers [Evans et al., 2020].
- The buildout of new hydrogen pipelines and the refurbishing of existing gas pipes to accommodate high shares of hydrogen constitute large investments in long-lived assets that require a clear near, medium and long-term vision for hydrogen and clear long-term demand patterns, both of which remain largely lacking as of today [Naschert, 2021].
- It follows that, absent a robust understanding of hydrogen's long-term role in the economy and further clarity around demand patterns, a non-targeted, near-term leap into hydrogen transport infrastructure—such as the buildout of new, widespread hydrogen pipeline networks and the repurposing of existing gas pipelines—risks costly infrastructure oversizing and misdirection of limited public and private capital into potential stranded assets. [Agora, 2021]

- The above considerations also extend to interventions that would look to blend low percentages of hydrogen in existing gas grids, with a stated intention to scale up the market for zero or low carbon hydrogen and deliver quick emissions reductions in existing gas applications. Indiscriminate blending of low percentages of hydrogen in existing grids constitute sub-optimal pathways for the use of hydrogen from a cost and efficiency point of view as they would likely only deliver marginal emissions reductions; a 20% hydrogen blend by volume—generally accepted as the upper bound of the amount of hydrogen that could be blended before prompting sizeable network upgrades—would only deliver 7% emissions reductions in delivered gas. Indiscriminate hydrogen blending could also risk creating a lock-in effect—under scenarios of substantial investment into the gas grid to accommodate hydrogen blends—in sectors like building heating, where hydrogen is not likely to play a major role in the future excepting marginal circumstances. [ETC, 2021, P. Martin, 2020]

Stakeholder considerations:

- Policymakers must scrutinize and be acutely sensitive to efforts to expand fossil infrastructure in the near-term premised on the potential future repurposing to hydrogen. The success of such efforts could exacerbate the complexity of achieving climate goals and carry risks of costly asset stranding.
- Policymakers and regulators should exercise caution in relation to proposals for the near-term, large-scale buildout of new hydrogen pipeline networks and the repurposing of existing gas infrastructure to avoid costly oversizing and the potential stranding of assets. Policymakers and regulators should develop regulatory mechanisms to govern such proposals on the basis of climate, public health, and equity criteria.
- Stakeholders should consider the near-term strategy of advancing hydrogen use in hubs—or a cohort of hydrogen suppliers and off-takers situated in close proximity such that large-scale hydrogen transport infrastructure is unnecessary—and commission independent assessments investigating where new hydrogen networks or repurposing measures would be cost-effective, secure investments that carry low risks of becoming stranded.
- Stakeholders should focus on a near-term, localized buildout of hydrogen pipelines or repurposing measures around what are expected to be secure long-term hydrogen demand centers, provided that such investments are corroborated by the assessment described in Principle 1 and developed with community buy-in and participation. As an example of this, some experts are now advocating for such "no-regret" near-term investments in hydrogen transport infrastructure [Agora, 2021; Evans et al., 2020]. In parallel with such near-term investments, stakeholders could assess the possibility for future network expansions as hydrogen supply and demand ramp up and evaluate potential regulatory and financial barriers that may require addressing if such expansions are ultimately necessary [IEA, 2021].
- There is a possible important near-term transitional role in leveraging existing gas grids for the deployment and delivery of hydrogen to specific sectors where hydrogen constitutes a no-regrets option, but policymakers should give careful consideration to

potential impacts of hydrogen blending on household energy cost, industrial end-user gas quality, greenhouse gas mitigation benefits and possible lock-in risks. Safeguards could include requiring independent and rigorous assessments of the need for hydrogen blending, setting low and binding caps on the permissible share of hydrogen blends to avoid short-lived network upgrades, and evaluations of the manner in which near-term blending supports the long-term hydrogen vision as defined in Principle 1 [ETC, 2021].

5. Deployment-oriented policies and initiatives should be prioritized to activate ‘learning-by-doing’ effects and cost reductions necessary to advance hydrogen use in high-value applications.

Background:

- In pathways to net-zero by 2050, the vast majority of the potential demand for clean hydrogen is linked to end-uses which are not commercial yet and that require a significant effort in innovation and demonstration in this decade [IEA 2021]. Technologies like the direct reduction of iron using pure hydrogen for steelmaking, the use of hydrogen-based fuels such as ammonia and synthetic jet fuel to power shipping vessels and aircrafts, and the use of hydrogen as a seasonal form of electricity storage all require a strong innovation push to ready them for commercialization by the 2030s, when the imperative to decarbonize those applications comes into full effect.
- Market transformation policies such as tax incentives for wind and solar projects in the US were paramount in stimulating the then previously renewable market and delivering substantial cost reductions linked to increased deployment and economies of scale [Trancik 2019].
- Performance standards such as end-use sector-specific or multi-sectoral carbon emissions standards such as the Regional Greenhouse Gas Initiative in the US, Emissions Trading Scheme in Europe, and Energy Efficiency Resource Standards in the US have successfully created durable markets for clean energy technologies and stimulating continued cost reductions linked to deployment.

Stakeholder considerations:

- Policymakers, academic institutions and private corporations should invest in proactive and targeted RD&D in this decade to meaningfully advance hydrogen applications in high priority, low readiness sectors such as aviation, maritime shipping, steelmaking and seasonal electricity storage such that those are primed for broad commercialization by the 2030s. International businesses, policymakers, academic institutions and customers should share emerging learnings and best practices to accelerate knowledge diffusion on the required timeline.
- In tandem with robust RD&D initiatives, policymakers should explore and implement market transformation programs to stimulate and de-risk early adoption of hydrogen in high-priority applications such as shipping vessels, aircrafts, steel plants, and long-

duration power decarbonization. Preferential private sector procurement for intermediate and end products will also play a significant role. Such programs could include supportive mechanisms like tax credits, contracts for differences, government procurement standards and other cost-sharing tools aimed at reducing the cost of switching to hydrogen for aforementioned applications. Labelling schemes offer an additional effective and proven tool to differentiate between high and low carbon products and stimulate climate-driven consumer demand for the latter (e.g., a “green steel” label).

- Policymakers should consider and institute performance standards to create durable markets for clean hydrogen within a broader technology-neutral framework focused on emissions reductions. Policies include GHG emissions standards (e.g. European ETS), low carbon fuel standards (e.g. California LCFS), and minimum sales targets (e.g. minimum zero emissions vehicle sales for the heavy duty truck sector) specific to hard-to-electrify applications where hydrogen is likely to be a leading climate solution.

6. **Pursuit of equitable health and economic outcomes for communities using hydrogen is essential. This includes dedicated attention to health impacts of fuel combustion and coordinated efforts to realize the near-zero-carbon industrial opportunity in developing countries.**

Background and rationale:

- Important equity implications permeate the hydrogen value chain and must be meaningfully considered to mitigate harm to local communities in proximity to hydrogen projects. This is a major consideration as efforts to ramp up the deployment of hydrogen across economies accelerate. For instance, a number of hydrogen production pathways- notably, fossil fuel and biomass-based hydrogen- and end-use applications- notably, hydrogen combustion in power plants and industrial boilers- emit criteria air pollution that, if not adequately managed, could have detrimental public health impacts on local communities situated in the vicinity of such projects [Milford et al., 2020].
- Hydrogen is poised to offer large employment opportunities. The large job creation potential could help address fossil job losses and harmful community impacts linked to the transition away from a fossil-based economy [NextEra, 2020, Foresight, 2020].
- These employment opportunities are especially strong in developing countries home to strong renewable resources as a proportion of overall energy demand. For example, most countries in Latin America, Sub-Saharan Africa, and South and Southeast Asia would need far below 1% of their total land for solar energy to meet their current energy demand [Carbon Tracker, 2021]. In other words, in most such countries, renewable technical energy potential is between 1,000-100,000 times current demand.
- Developing economies with those renewable resources could produce renewable hydrogen locally to generate economic opportunities, increase resilience, and

improve energy security by reducing exposure to fossil fuel price volatility and supply disruptions [World Bank, 2020]. Further, it will be competitive: over the next ten years, 90% of this renewable energy potential will be economically competitive with fossil fuel-based alternatives, growing from roughly 50% today [Carbon Tracker, 2021]. Developing countries' extensive renewable energy resources alongside continued improvement in renewable technologies should support an estimated USD 1 trillion annual investment required by 2030 to deliver net zero trajectories [IEA, 2021].

- Social dialogue processes can proactively manage economic transitions and uncertainties to help workers and the trade unions that represent them hold and create rewarding healthy and decent jobs [ILO, 2016]. Given the disruptive potential of renewable hydrogen, both domestic and international dialogues could help to address tensions and proactively address impacts.

Stakeholder considerations:

- Policymakers must engage in social dialogue and transparency in developing their hydrogen vision as a pillar of any hydrogen strategy. Meaningful dialogue and proactive consultation with environmental justice communities and those impacted by hydrogen projects is critical to the success of a hydrogen agenda that is compatible with a sustainable and equitable energy future.
- Stakeholders must ensure that hydrogen projects- ranging from hydrogen-burning power plants to pipelines- have secured community buy-in and the delivery of clear benefits to communities living in the vicinity of such projects.
- Policymakers should commission macroeconomic and labor force modeling and engage in social dialogues to develop hydrogen investment roadmaps that prioritize employment and investment opportunities for communities most harmed by the transition away from a fossil economy and those which have not benefited from past economic growth [ILO, 2016].
- International collaboration among policymakers, businesses, and communities should aim to diversify economic development models—especially in countries that have relied on fossil fuels for income —to include renewable hydrogen production and use [IEA, 2021].
- Support from development finance institutions and concessional funds for renewable hydrogen is essential to deliver an inclusive global transition. It could play an important role in accelerating adoption of green hydrogen in developing countries, increasing capacity and creating the necessary policy and regulatory enabling environment [World Bank, 2020].

7. Policy and corporate planning should be conducted transparently to increase accountability to citizens and end-consumers, especially on issues critical to emissions reduction and long-term investment.

Background rationale:

- Citizens and hydrogen end-users are the ultimate source of funding for energy infrastructure, suggesting that their voices should be clearly heard in policy and infrastructure planning processes.
- As hydrogen could require an estimated USD 11 trillion investment [BNEF, 2020] in potentially long-lived and regional infrastructure assets, effective consultation processes with industrial users, local governments, and local citizens will be essential to create a durable social license for this new energy carrier.

Stakeholder considerations:

- Policymakers, regulators and investors should engage in proactive dialogue with voters and hydrogen end-users in relation to hydrogen investments and offer them clear opportunities to weigh in on the relative costs and benefits of such investments, in all their forms.
- Policymakers, regulators and investors should consider developing new methods and processes for appropriate, timely, and binding public consultation in relation to hydrogen projects and investments. These methods could build on existing platforms in utility sectors but seek to evolve them to ensure emphasis on squaring investment cycles with a 1.5 degree and net- zero by 2050 trajectory.
- In particular, hydrogen sourcing should be independently certified, tracked, and validated in a transparent process and labelling system. Full transparency on the full lifecycle emissions and non-economic costs of hydrogen purchased by industrial consumers can empower effective decision making and support differentiated valuation of hydrogen sources.

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