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THINK

VISION PAPER

ROADMAP FOR INCLUSIVE CUSTOMER-FACING HYDROGEN ECOSYSTEM TO EXPEDITE ENERGY TRANSITION

Task Force 10

SUSTAINABLE ENERGY, WATER, AND FOOD SYSTEMS

Authors

WAEL ALMAZEEDI, KATSUHIKO HIROSE, ARMAND HOLLE, EDGAR HOLLE, JAAP HOOGCARSPEL, BERT DEN OUDEN, WIM VAN DER VEEN

ورقة رؤية

خارطة طريق للهيدروجين في النظام البيئي الشامل لتسريع عملية التحول في مجال الطاقة

فريق العمل العاشر

نُظم الطاقة المستدامة والمياه والغذاء

المؤلفون

وائل المزيدي، كاتسوهيكو هيروس، أرماند هول، إدغار هول، ياب هوغ كارسبل، بيرت دن أودن، ويم فان دير فين

ABSTRACT

After almost three decades of stops and starts, hydrogen may have finally carved a role for itself in the energy transition: a flexible energy vector and an indispensable complement to renewable electricity for the deep decarbonization of the energy supply chain. However, industry stakeholders would need to ensure that the challenges of the outgoing energy paradigm do not become legacies of the new one. Failure to do so would undermine the pace and equity of the energy transition, impede the commercialization and scale-up of much needed energy technologies (including those related to hydrogen), and marginalize the role envisioned for energy citizens. The proposed roadmap is divided into three pillars: (a) create demand, (b) scale-up technology, and (c) facilitate financing. Each of these pillars has its own enabling mechanisms and is driven by eight guiding principles to enhance transparency, inclusiveness, and equity within the emerging hydrogen ecosystem.

بعد ما يقرب من ثلاثة عقود من التوقف والبدء، برز الهيدروجين كلاعب رئيسي في التحول في مجال الطاقة كونه ناقلاً مرنًا وعنصرًا لا غنى عنه للكهرباء المتجددة من أجل إزالة الكربون من سلسلة الإمداد للطاقة. على الرغم مما سبق, سيحتاج أصحاب المصلحة في هذه الصناعة إلى ضمان ألا تصبح تحديات نموذج الطاقة السابق إرثًا للنموذج الجديد. سيؤدي عدم الالتزام بذلك إلى تقويض وتيرة عملية التحول ، وإعاقة تسويق وتوسيع نطاق تقنيات الطاقة العالم في حاجة ماسة لها (بما في ذلك تلك المتعلقة بالهيدروجين)، وتهميش الدور المتصور للمهتمين بالطاقة.

تنقسم خارطة الطريق المقترحة في هذا الموجز إلى ثلاث ركائز: (أ) خلق الطلب. (ب) توسيع نطاق التكنولوجيا. (ج) تسهيل التمويل. ولكلّ من هذه الركائز آليات التمكين الخاصة بها، وهي مدفوعة بثمانية مبادئ توجيهية لتعزيز الشفافية والشمول والإنصاف داخل النظام البيئي الهيدروجين الناشئ.

CHALLENGE

The ongoing energy transition is currently driven by the growing electrification of the energy supply chain with an increased proportion of electricity being generated from renewable energy resources. However, despite its accelerated growth, renewable electricity will neither be sufficient on its own to meet the growing energy needs of hard-to-abate segments of the energy supply chain nor will it meet the timeline to achieve the energy decarbonization targets agreed under the Paris 2015 Agreement. The emerging energy paradigm will, therefore, likely be a blend of electricity-based and fuel-based options, with hydrogen playing a complementary role to electricity in the energy transition. Low- or zero-CO2 hydrogen can (a) generate low emissions electricity in turbines and fuel cells; (b) store energy in higher densities, lighter weights, and for longer durations than batteries; and (c) decarbonize high-temperature industrial processes. Unfortunately, the scaling up of low-CO2 (blue) and zero-CO2 (green) (together "low-carbon") hydrogen technologies faces numerous challenges, some of which generally inhibit the pace and transparency of the energy transition.

Barriers to Entry

Compared with other industries, the $6.0 trillion energy industry has significant barriers to entry owing to its much higher capital intensities, economies of scale, engineering capacities, and degree of government regulation. These together favor large well-capitalized industry players who often exploit these barriers to create monopolies.

Deep Funding Gaps

The International Energy Agency estimates that $24 trillion will be needed in the period up to 2035 to finance the energy transition, of which, according to Bloomberg Energy Finance, $10 trillion will be needed for low-carbon technologies. There is not enough risk capital to develop early-stage pre-commercial technologies (Valley of Death I) or deploy and scale-up many later-stage commercially proven ones (Valley of Death II). This bifurcated funding gap has prevented many promising technologies from reaching the marketplace. For hydrogen, the large cost difference between "gray" hydrogen produced from fossil fuels (below $1.0/kg) and green hydrogen from electrolysis of renewable power (above $3.0/kg) has made it difficult for market and industry players to bridge the funding gap for demonstrating and commercializing green hydrogen technologies. Conversely, the scale-up of blue hydrogen ($1.5–$2.0/kg), a natural steppingstone to green hydrogen, has been stifled because of the absence of mechanisms to reward decarbonization of gray hydrogen (see below).

Lagging CCS Investments

Despite access to commercially proven technologies, investment in carbon capture and storage (CCS) capacity has been, and continues to be, grossly insufficient. In the absence of a major and immediate step change in CCS investments, the currently cheaper blue hydrogen cannot be scaled up, postponing the deployment at scale of hydrogen-based solutions until such time when green hydrogen becomes more competitive. With the exception of the EU's Emission Trading System, the US' Q45 tax credits regime (recently expanded), US cap and trade markets, California's Low-carbon Fuels Standard, and funding by several OECD governments of demonstration projects, most other countries do not have regulations, incentives, or emission allowances to reduce CO2 emissions. As a result, only 22 CCS projects around the world are currently operational, and they reduce CO2 emissions by an aggregate amount of 40 million tons/year, accounting for 0.1% of annual global emissions of 40 Gt/year. CCS features as an emissions mitigation option in the Nationally Determined Contributions (NDCs) submitted to the UN's Framework Convention on Climate Change by 10 (out of 195) signatories of the Paris 2015 Agreement, despite being applicable to at least 50 other countries with high-carbon intensity exports. Even so, these commitments remain voluntary and negotiations over certain critical clauses of Article 6 of the agreement, the operational part of the "Paris rulebook," remain open.

Absence of Technology Performance Tools

There is a lack of standardized performance measurement tools or metrics that accurately and transparently assess the commercial competitiveness, sustainability, and cost–benefit of energy technology solutions. This has led to substantial misallocation of private capital and misdirection of government policies. Metrics such as the levelized cost of energy, technology readiness levels, and cost-effectiveness tests have proven to be inadequate in providing an objective quantitative comparison among different technologies over their full life cycle.

Stance of Industry Incumbents

Oil and gas producers are ideally positioned to expedite the energy transition. Unfortunately, they have thus far been unable to adapt fast enough to the changes transforming their industry and face the prospect of declining demand for their fuels. This has exposed them to the risk of stranded reserves. Despite the existential threat to the value of their reserves and with few exceptions, international oil companies (IOCs) and national oil companies (NOCs) have been reluctant to fully leverage their vast oil and gas reserves and substantial competencies in gray hydrogen production to scale-up CCS and blue hydrogen. To complicate matters, some policymakers have started directing the bulk of their policy support mechanisms toward green hydrogen, relegating blue hydrogen to a potential transitionary role. Although there are several factors that could eventually tilt the balance toward green hydrogen, such policies will impact the investment appetite of oil and gas producers.

Marginalized Energy Citizens

Energy consumers/prosumers, individuals, and households are increasingly being viewed as one of the main drivers of the energy transition. Yet, they continue to be treated as price-takers with limited flexibility and little input over their energy decisions. Theoretically, the 3Ds currently transforming the energy industry (decarbonization, digitalization, and decentralization) should allow energy citizens to make informed decisions about their energy consumption. These examples range from purchasing efficient equipment and building net-zero energy homes and buildings (retrofit those which are not) to supplying demand-side flexibility, producing and storing their own energy, and selling what they cannot use to either the grid or to their neighbors. However, wealth disparities among and within countries; energy poverty; vulnerable consumers; as well as lack of enforceable regulations, consumer centric policies, funding models, unbiased expert advice, personal data, and privacy protection prevent energy citizens from being sufficiently engaged.

PROPOSALS

Our proposed roadmap builds on over 20 progressive and commendable hydrogen roadmaps and strategies developed by government agencies, think tanks, and advocacy groups in the Group of Twenty (G20) countries and beyond. These include roadmaps developed by organizations affiliated with the authors of this vision paper, namely Berenschot, the H-Vision Project, and DNV GL.

We developed our proposed roadmap in the context of an ongoing energy transition, in which hydrogen has the potential to become an integral component. Our proposed roadmap is divided into three pillars, each with its own enabling mechanisms comprised of public policies and market instruments, and is driven by eight cross-cutting "guiding principles."

I.	Create Demand	II.	Scale-up Technology	III.	Facilitate Finance

The roadmap would be implemented over a limited time horizon of 10 years (2020–2030), after which market forces should be allowed to shape the hydrogen industry's future trajectory. The roadmap is augmented by three charts for a hydrogen supply chain, a proposed value proposition, and an overview of sector coupling (see Figures 1, 2, and 3, respectively).

Guiding Principles

Our proposed roadmap is driven by eight guiding principles that, we believe, would enhance hydrogen's value proposition in the energy transition as well as the transparency, equity, and inclusiveness of its emerging ecosystem. The first two address challenges of the outgoing energy paradigm that, if not addressed, could become legacies of the new one.

Table 1. Guiding Principles

• Financial disintermediation	• Incumbents' role
• Technology benchmarking	• Gas synergies
• Electricity complementarity	• Energy Citizens' empowerment
• Color neutral	• Small and medium-size enterprise leadership

Benchmarking Technology: We must create a level playing field between different technology options and inte-grated solutions to (a) de-risk technologies for industry stakeholders (e.g., investors, financiers, regulators, project developers, and policymakers); and (b) provide end-use customers (commercial and industrial [C&I] customers and energy citizens) with ac-cess to unbiased expert advice on their technology choices.

Enabling Mechanism:

Technology rating agency for low-carbon energy technologies (including hydrogen)

Disintermediating Financing: We must disintermediate the financing of project equity and debt to reduce the deep and growing bifurcated funding gap that prevented many promising technologies from reaching the marketplace.

Enabling Mechanism:

Global energy transition exchange to finance projects that deploy low-carbon energy technologies (including hydrogen)

Leveraging Electrons and Molecules (ME2X) for the Energy Transition: Thus far, renewable electricity has been spearheading the energy transition. However, we must leverage both "electrons" and "molecules" to expedite it. There is an opportunity for both electrons from renewable energy resources (as electricity) and molecules from both renewable energy resources and fossil fuels (converted into green and blue hydrogen, respectively) to decarbonize energy and industry. We have identified an optimum place for hydrogen in the energy transition. In addition to decarbonizing hard-to-abate sectors, hydrogen can effectively complement electricity in all others, and this is where the competitive advantage and early use case successes of hydrogen exist.

Hydrogen can address several challenges facing the electricity sector, which is grappling with managing increased penetration of intermittent renewable energy resources, mounting network constraints, and inadequate and expensive battery storage options. Hydrogen can serve two functions: (a) provide flexibility services to transmission and distribution system operators (TSOs/DSOs) as well as to microgrids; and (b) enable sector coupling via power-2-additional applications (P2X) between electricity as the energy system backbone on the one hand and natural gas, heating/cooling, transport, and industry on the other. For hydrogen to deliver on its long-held promise, it will need to (a) match electricity in its "convenience of use," especially in terms of plug-and-play access, (b) piggy-back on the sweeping digitalization and decentralization transformations currently re-shaping the electricity industry, and (c) integrate itself into the electricity supply chain as a value-added complement.

Enabling Mechanism:

Hydrogen value proposition driven by P2X

Embracing both Green and Blue Hydrogen: We must support low-carbon hydrogen production pathways, irrespective of the source from which hydrogen is produced. We believe that the interplay between blue and green hydrogen could be reinforcing for both fuels. The currently lower cost of blue hydrogen could facilitate investment in critical transportation and distribution infrastructure, paving the way for the scale-up of green hydrogen. We propose creating common quality and emissions standards for low-carbon hydrogen backed by a transparent blockchain-enabled certification system that would be mainstreamed globally. The geopolitical dimension thereof cannot be underestimated. Green hydrogen offers long-term comparative advantages. However, excluding producers of blue hydrogen from policy incentives directed at green hydrogen would isolate certain industry stakeholders at a critical time in the evolution of the hydrogen ecosystem. It would also potentially lead to substantial impairments in corporate and institutional investment asset portfolios.

Enabling Mechanism:

Integrated business models + blockchain-enabled certification system for blue and green hydrogen

Facilitating a Role for Oil and Gas Producers: We must facilitate a proactive role for oil and gas producers in the hydrogen supply chain. Blue hydrogen offers a compelling value proposition to drivers of the outgoing energy paradigm, namely, the IOCs and NOCs, especially if they were able to scale-up CCS, a pre-requisite for the production of blue hydrogen. We propose structuring financial instruments to assist them in monetizing their CCS investments. In addition, we propose creating a framework that would appeal to institutional investors to allow them to kickstart a circular carbon economy—one in which the use of captured CO2 and solid carbon (produced from pyrolysis of natural gas) is initially directed to the manufacture of products currently being or expected to be used in energy transition applications. Among the many products we identified are polyacrylonitrile-based carbon fiber composites, the material of choice for the manufacture of compressed hydrogen fuel tanks in fuel cell electric vehicles (FCEVs), wind turbines, and certain energy storage systems and for which ammonia, a hydrogen carrier, is a feedstock. Other products include carbon nanomaterials such as carbon nanotubes, a replacement for carbon black, and graphene, a new two-dimensional breakthrough material earmarked for applications in energy storage, solar energy, water desalination, and superconducting.

Enabling Mechanism:

Instruments to monetize CCS investments + investment framework for CO_2 conversion and utilization (CCU) to manufacture carbon-neutral products and fuels for the energy transition

Capitalizing on the Synergies with Natural Gas and LNG: We must leverage natural gas' infrastructure to scale-up hydrogen demand and the trading experience of liquefied natural gas (LNG) to commoditize it. For all intents and purposes, "hydrogen is the new gas." It can provide as much energy as natural gas (up to 20% of final energy consumption) and up to a certain blend ratio, use the natural gas infrastructure without major modifications. Equally important, industry expertise and skills are transferable. Hydrogen can also benefit from the evolution of the LNG industry and may follow in its footsteps. In addition, LNG import hubs are currently under development in several parts of the world, creating frameworks for multi-energy carrier systems (which could integrate hydrogen). Hydrogen is ideally positioned to replace natural gas as a fuel in repurposed gas pipelines, storage facilities, and retrofitted burners of combined cycle gas turbine plants.

Enabling Mechanism:

Hydrogen trading jumpstarted by injecting low-carbon hydrogen into gas grids

Empowering End-Use Energy Customers: We must enable C&I customers and energy citizens to drive the deployment of hydrogen products and solutions. The new energy paradigm is expected to be demand-side driven and increasingly decentralized. We are witnessing value creation in the energy supply chain moving from the commodity-driven upstream to the data-driven downstream. Moreover, multisided platform business models that dynamically aggregate demand with supply are increasingly proving to be superior in meeting end-use customer demand preferences than traditional vertically integrated supply ones. We propose institutionalizing and mainstreaming crowdfunding platforms to enable end-use customers to influence the development of products and use cases for which they would be the ultimate beneficiaries. We also propose promoting "hydrogen communities" to increase the acceptance of hydrogen, incentivize investment in local hydrogen solutions, and to provide flexibility to energy systems by integrating hydrogen into heating and mobility applications via home energy management systems and virtual power plant aggregator models.

Enabling Mechanism:

Crowdfunding for hydrogen startups and small projects + multi-victor hydrogen communities

Enable SME's in Developed and Developing Countries to Spearhead Innovation Ecosystems: We believe that entrepreneurs and their small and medium-sized enterprises (SMEs) should spearhead innovation within and become the backbone of the hydrogen ecosystem. Indeed, entrepreneurial companies and SMEs, and not large electric utilities, are currently spearheading innovation in the electricity sector. We believe that the same should hold true for hydrogen. It is the agility, entrepreneurial zeal, innovative stance, and customer focus of SMEs that differentiate them from large predominantly risk-averse companies whose interests are often aligned with the status quo. A recent analysis by Hydrogen Europe (2020) determined that, of the 280 companies actively developing hydrogen technologies in Europe, 170 are SMEs. Therefore, we must reduce barriers to entry to the best extent possible, including the potential crowding out, especially in developing countries, by large IOCs/NOCs, utilities, original equipment manufacturers (OEMs), and merchant family conglomerates.

Governments from both developing (technology importing) and advanced (technology exporting) countries must collaborate on formulating policies and incentives to enable SMEs in emerging/developing countries to acquire the pre-requisite capacity to drive the development of local hydrogen ecosystems. To assume such a catalytic role, SMEs would need to develop the capacity to deploy, operate, maintain, adapt, improve, and reproduce the imported hydrogen technologies as well as the capacity to invent new technologies and commercial solutions.

Enabling Mechanism:

Hydrogen technology demonstration co-funding facility to empower SMEs in emerging/developing markets

Table 2. Roadmap Summary

Roadmap Pillar	Enabling Mechanisms	
	Public Policies	**Market Instruments**
Create Demand Innovative product offerings and diverse end-use applications at customer level	• Increase hydrogen blending limits in gas grids • Enable sector coupling wherever possible • Provide grants and tax credits (similar to renewable energy) to low-carbon hydrogen end-users • Support rollout of refueling infrastructure for FCEVs • Support prosumer business models with a focus on energy communities • Enact stringent anti-trust and privacy protection regulations • Facilitate issuance of Energy Attribute Certificates for low-carbon hydrogen • Create socially inclusive criteria for providers of hydrogen products and services	• Crowdfunding platforms • Hydrogen infrastructure and trading platforms • Multi-vector hydrogen communities • Distributed and hybridized solutions • Corporate power/ hydrogen purchase agreements • Home energy management systems • Blockchain-enabled B2C and P2P transactions
Scale-up Technology Level playing field between technology OEMs and integrators	• Extend rules and quotas for renewable energy resources to low-carbon hydrogen • Redirect fossil fuel subsidies to low-carbon hydrogen and CCS projects • Create common quality and emissions standards for low-carbon hydrogen • Develop frameworks for development of regional capital-intensive projects • Support demonstration of low-carbon hydrogen technologies • Incorporate emissions reduction from hydrogen and CCS into country NDCs • Develop a new cooperative intellectual property rights regime for technology transfer	• Machine learning-driven technology benchmarking tools • Integrated business models • Blockchain-enabled certification (e.g., Energy Attribute Certificates, certificates of origin, and renewable energy certificates) • Virtual power plants
Facilitate Financing Disintermediation and reduced value extraction	• Provide loan guarantees and public equity co-investment (capital-intensive projects) • Issue public procurement for low-carbon hydrogen solutions (SME favored) • Structure multilateral facility for technology demonstration in emerging markets • Develop mechanisms to monetize carbon capture, utilization, and storage investments (Article 6 Paris Agreement) • Provide financial incentives for hybridized investments • Standardize disclosure reporting requirements for Scope 1, 2, and 3 emissions • Mandate incorporation of carbon externalities in economic appraisals of projects	• Energy Transition Infrastructure Exchange • Technology demonstration co-investment facility for emerging markets

Pillar I: Create Demand

Market Instruments

Crowdfunding (Overcome Valley of Death I, Boost Frontrunners, Enable Early Adoption)

We propose establishing equity-based crowdfunding platforms dedicated to investing in hydrogen technology startups and SMEs as well as in projects that aim to develop end-use applications and solutions. Crowdfunding will provide energy citizens with a unique opportunity to connect with entrepreneurs, access new products before they are commercialized (potentially contribute to the design of products at an early stage of their development), participate in the hydrogen value chain, and become part of a larger community of like-minded co-investors. Access to a technology rating as described in Technology Benchmarking Tools (see below) would mean that investors or energy citizens need not be technology savvy.

To increase its chances of success, crowdfunding could co-fund early-stage hydrogen companies and small projects in partnership with venture capitalists and/or corporate venturing arms of industry players, leveraging their professional and rigorous due diligence capacity and, thus, gain access to their deal flow. As it scales up its capacity, crowdfunding could co-finance senior debt tranches of limited recourse project financings.

Pre-requisite Public Policies

- Revise regulations for crowdfunding platforms to allow for increased capital raising limits (typically below $1.0 million)
- Develop regulations to protect investors from fraud, ensure that entrepreneurs satisfy certain competency criteria, and incentivize investors by providing tax incentives and promoting exit opportunities such as a secondary market

Hydrogen Infrastructure and Trading Platforms

We believe that hydrogen could develop into a globally traded commodity similar to natural gas. We propose creating a surge in demand for low-carbon hydrogen by injecting it into existing gas grids in major energy demand centers. No upgrades or retrofits would be required to gas transmission and distribution networks nor to end-use appliances if the hydrogen/methane blending ratio is kept to below 8–10%. The low-carbon hydrogen will need to meet strict “well-to-gate” greenhouse gas (GHG) emission as well as purity thresholds.

With minimum additional infrastructure investments required, the onus would be placed on hydrogen suppliers around the world who would compete to meet the requisite demand. The competition would spur an unprecedented wave of innovation to reduce the cost of hydrogen production and to commercialize and scale-up a variety of potential hydrogen carriers. Fortuitously, several LNG import hubs have started developing hydrogen import infrastructures and many gas utilities are preparing their grids for hydrogen injection.

Pre-requisite Public Policies

- Increase hydrogen blending limits in gas transmission and distribution networks to 8–10%
- Provide incentives to fuel cell heating systems in the commercial and residential sectors, including enabling the heating sector to become “hydrogen ready”
- Develop a common definition for low-carbon hydrogen that would encompass both blue and green hydrogen
- Facilitate the issuance of Energy Attribute Certificates for low-carbon hydrogen or extend the certificates currently issued for renewable electricity to hydrogen (These certificates are called certificates of origin in Europe and renewable energy certificates in the US)
- Allow bundling with Renewable Energy Electricity Energy Attribute Certificates linked to corporate sourced power purchase agreements and residential electricity purchases to facilitate trading among all market participants

Public Policies

- Enable sector coupling via P2X wherever economically possible, especially in areas where renewable electricity cannot be used directly;

- Provide incentives to replace fossil fuels with low-carbon–hydrogen in heavy industry, including carbon contracts for difference for steel and chemicals industries, blending of synthetic fuels for aviation, and developing a refueling infrastructure for FCEVs (preferably based on distributed models) ahead of an uptake in vehicle sales;

- Keep behind-the-meter energy transactions regulation light to reduce barriers to entry, allow for integration of hydrogen solutions into home energy management systems, and support B2C and P2P platforms, which are ideal use cases for blockchain technologies;

- Enact stringent anti-trust and data protection regulations to prevent the concentration of power (intended or otherwise), protect customer privacy, and enable end-use consumers to freely engage with date-driven energy aggregator platforms;

- Extend similar renewable electricity grants and tax breaks offered to C&I and residential customers to prospective hydrogen customers in the heating/cooling, industrial, and transport sectors;

- Support prosumer business models by providing grants and tax credits for hardware, building pre-requisite infrastructure, developing product standards (including potential interoperability with electricity systems), and enabling energy communities, while encouraging end-use customers to participate in policy setting processes; and

- Create a set of socially inclusive criteria for hydrogen product and solution providers to ensure that end-users and local communities do benefit from their deployment, including demonstrating positive impacts on the local economy, providing opportunities for financial participation by end-users, and reducing environmental impacts.

Pillar II: Scale-up Technology

Market Instruments

Technology Benchmarking Tool

We propose the development of a predictive analytics engine (the "Engine") to benchmark in near-real time the performance, competitiveness, sustainability, and cost/benefit of state-of-the-art and next generation energy technologies and solutions (including those relating to hydrogen), each for their designated application in end-use markets. The Engine will capitalize on recent advancements in data science (e.g., machine learning algorithms and big data) and established life-cycle cost analysis frameworks. The Engine would create a level playing field among technology providers, de-risk technologies for investors, and provide certified solutions to end-users, thereby creating much needed market pull and expediting time to market. The Engine would provide independent third-party technology risk assessments based on which projects and technology companies would be rated prior to investment. If successful, the Engine could form the basis for the world's first energy technology rating agency, analogous with credit rating agencies such as Moody's, S&P, and Fitch. While these credit rating agencies provide independent political, financial, regulatory, and technical risk assessments for some projects in the context of limited recourse project financings or bond offerings, no similar service is available in the marketplace for technology risks. An independent technology rating—a missing piece of the project finance puzzle—would, for the first time, allow investors, irrespective of their financial sophistication and engineering prowess, to make informed decisions regarding emerging and state-of-the-art hydrogen technologies.

Integrated Business Models

We propose developing integrated business models to leverage the strengths of green and blue hydrogen to their mutual advantage.

Flexible blue hydrogen to buffer variations in green hydrogen production: Green hydrogen production is dependent on intermittent renewable electricity, while end-use customers demand stable supplies of low-carbon hydrogen. Blue hydrogen is fully dispatchable and, thus, able to compensate for the fluctuations of green hydrogen production without the need for expensive local hydrogen storage. Therefore, green and blue hydrogen can be combined in a common hydrogen infrastructure to reduce cost for end-use customers.

By-product oxygen of electrolysis to improve efficiency of blue hydrogen production: Producing blue hydrogen via autothermal reforming (ATR) or partial oxidation (POX) requires significant amounts of pure oxygen produced by costly and energy-intensive air separation processes. The high-purity oxygen produced by electrolysis as a by-product could be used in ATR and POX plants, optimizing the hydrogen production process and monetizing the oxygen by-product.

Public Policies

- Extend rules and quotas currently in place for renewable energy resources to low-carbon hydrogen.

- Redirect fossil fuel subsidies and tax breaks to low-carbon hydrogen and CCS projects.

- Create common quality and CO2 emissions standards for low-carbon hydrogen (blue, green, and turquoise).

- Issue public procurement calls for low-carbon hydrogen solutions.

- Promote frameworks for development of regional projects (e.g., similar to European Commission's Regional Projects for Common Interest) to pool resources and create economies of scale for capital-intensive segments of the hydrogen supply chain (e.g., pipeline infrastructure and CCS).

- Incorporate CO2 emissions reductions to be realized from low-carbon hydrogen and CCS projects into NDCs.

- Develop a new cooperative property protection rights regime for the efficient and equitable transfer of low-carbon hydrogen technologies to emerging/developing markets.

Pillar III: Facilitate Finance

Market Instruments

Energy Transition Exchange (Overcome Valley of Death II).

We propose setting up a global exchange (the "ET Exchange") for the trading of standardized units of project equity and debt to bridge the Valley of Death II funding gap. The ET Exchange would provide an early exit opportunity for project developers and lenders to recycle their illiquid investment upon a project commencing its commercial operations, while eliminating project pre-completion risks for new investors. The ET Exchange would standardize and streamline project due diligence, which includes the identification, assessment and mitigation of political, regulatory, financial, and technical risks. Access to a technology rating (see above in Technology Benchmarking Tools) would boost investor confidence. The objective is to make the risk/reward profile of projects appealing to a substantially wider investor base than is currently the case in the specialized, clubby, and capital constrained project finance market. The ET Exchange would provide a level of transparency that is lacking in today's project finance market, encourage governments to issue progressive calls for proposals to allow for the deployment of new state-of-the-art technologies, and incentivize equity investors and project finance lenders to push the technology envelop. Early projects could target low-carbon hydrogen solutions for end-use applications in industry, heating and transportation, as well as business use cases created by sector coupling.

Public Policies

We propose structuring a multilaterally managed facility to co-fund hydrogen technology demonstration projects in emerging/developing markets. The proposed facility would issue calls for proposals that are not tied to any particular technology provider or OEM. The funding would be contingent on participation and continued involvement after completion of local SMEs, who would participate in bidding consortia (as co-developers or service providers), as well as on an equitable treatment of intellectual property rights.

- Provide loan guarantees and equity co-investment to capital-intensive projects across the hydrogen supply chain;

- Issue public procurement calls targeted at SMEs for low-carbon hydrogen solutions;

- Develop mechanisms to monetize carbon capture, utilization, and storage investments to be integrated into Article 6 of the Paris Agreement. The mechanisms to be considered include a CO2 storage crediting scheme based on tradable carbon storage units proposed by researchers at King Abdullah Petroleum Studies and Research Center; and

- Mandate incorporation of carbon externalities in economic appraisals of projects as a condition for funding eligibility.

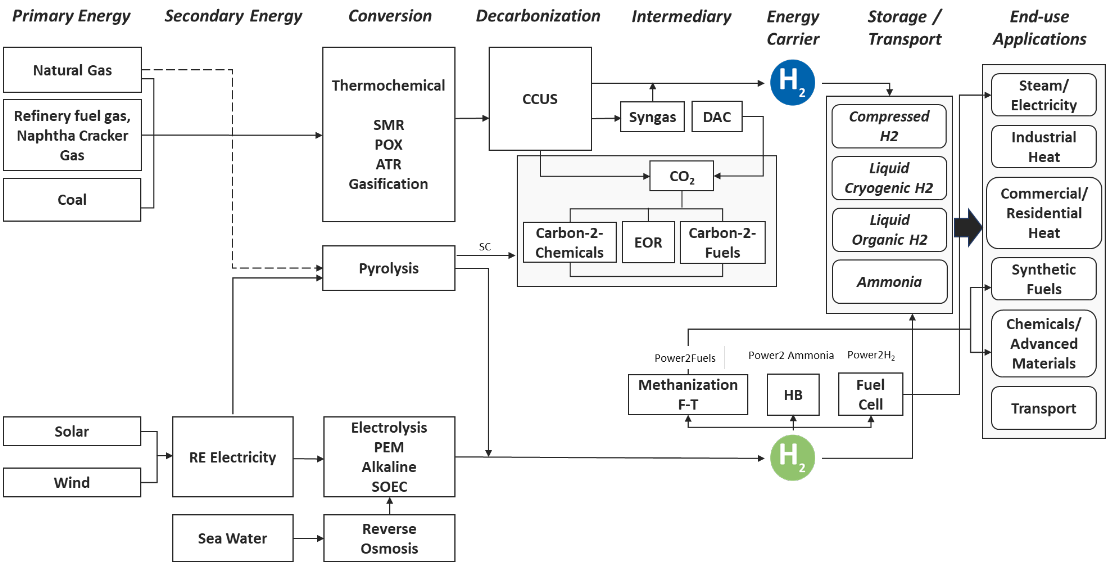

Figure 1. **Hydrogen Supply Chain**

Source: **Advance Labs.**

Note: **SMR: Steam Methane Reforming/ POX: Partial Oxidation/ ATR: Auto Thermal Reforming/PMS: Plasma Methane Splitting/ PEM: Proton Exchange Membrane/ SOEC: Solid Oxide Cells/ EOR: Enhanced Oil Recovery/ CCUS: Carbon Capture Utilization & Storage/ F-T: Fischer-Tropsch Synthesis/ HB: Haber-Bosch/ SC: Solid Carbon/ DAC: Direct Air Capture.**

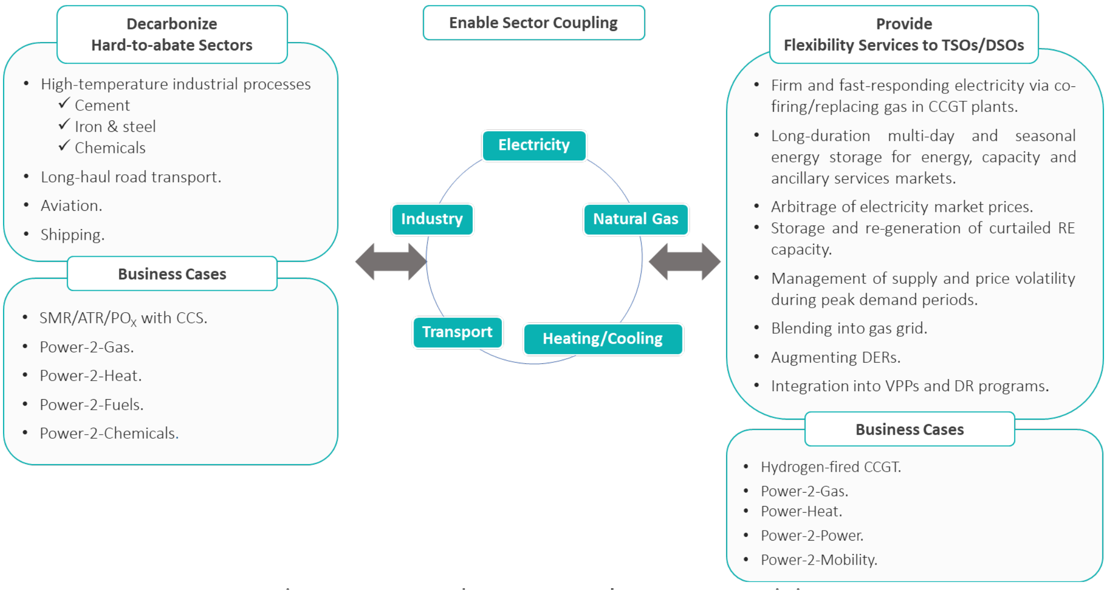

Figure 2. **Hydrogen Value Proposition**

Source: **Advance Labs.**

Note: **CCGT: Combined Cycle Gas Turbine/ DER: Distributed Energy Resources/ SMR: Steam Methane Reforming/ ATR: Auto Thermal Reforming/ POX: Partial Oxidation/ CCS: Carbon Capture and Storage/ TSO: Electricity Transmission System Operator/ DSO: Electricity Distribution System Operator.**

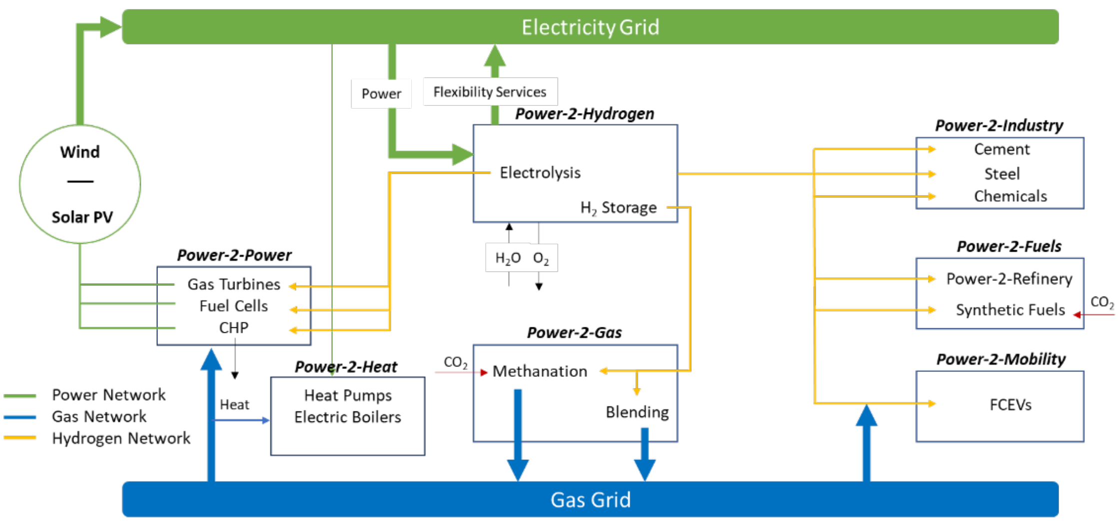

Figure 3. **Sector Coupling Overview**

Note: **CHP: Combined Heat and Power/ FCEV: Fuel Cell Electric Vehicles**

Source: **Adapted from The Fuel Cell and Hydrogen Joint Undertaking (FCH JU).**

Disclaimer

This policy brief was developed and written by the authors and has undergone a peer review process. The views and opinions expressed in this vision paper are those of the authors and do not necessarily reflect the official policy or position of the authors' organizations or the T20 Secretariat.

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AUTHORS

Wael Almazeedi
Advance Labs, FATE Consortium

Katsuhiko Hirose
Advance Labs

Armand Holle
Advance Labs

Edgar Holle
Advance Labs

Jaap Hoogcarspel
Advance Labs

Bert den Ouden
Advance Labs, Berenschot

Wim van der Veen
Advance Labs, DNV GL