Blue Ammonia Supply Green

Institute on Science for Global Policy (ISGP)

Energy Governmental Private

Storage Fuel Intensity Critical

Costs Decarbonization Options Standards

Global Pathways to Hydrogen Energy Futures — *Japan*

A program and conference organized, facilitated, and moderated by the ISGP in cooperation with and support from the AEM-METI Economic and Industrial Cooperation Committee (AMEICC), the Clean Fuel Ammonia Association (CFAA), Japan Hydrogen Association (JH2A), and Tokyo Gas

Convened by the ISGP at the Pacifico Yokohama Conference Center
in Yokohama, Japan
April 6 — 9, 2023.

Japan Environmental Transportation

Sustainability Hydrogen Communities

Public Investments Carbon Derivatives

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Global Pathways to Hydrogen Energy Futures — Japan
(GPHEF — Japan)

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An ongoing series of dialogues, critical debates, and extended caucuses examining the role of science and technology in advancing effective domestic and international policy decisions.

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Introduction

Preface

The contents of this book were taken from the material presented at the "Global Pathways to Hydrogen Energy Futures – Japan" (ISGP GPHEF – Japan) conference convened by the Institute on Science for Global Policy (ISGP) on April 6, 7, 8, and 9, 2023 in Yokohama, Japan. The ISGP GPHEF – Japan conference, structured on a critical debate/caucus format pioneered by the ISGP for over 15 years, was conducted using a modified hybrid platform (i.e., both in-person and online access). Approximately 100 internationally distinguished subject-matter experts, leaders, and stakeholders from governmental, private sector, and public advocacy communities participated in the conference. The GPHEF – Japan conference was a major part of the year-long GPHEF program conducted by the ISGP on behalf of the Japanese Ministry of Economic Trade and Industry (METI) and Japanese private sector associations.

As in all ISGP conferences, the GPHEF conference agenda focused on significantly improving the communication of credible scientific and technological understanding to stakeholders and policymakers responsible for major societal policy decisions and their real-world implementing actions. The GPHEF conference focused on how hydrogen energy, together with its derivatives, can provide major contributions to the overarching transitions in global energy systems now underway. Obviously, the relationship of the potential incorporation of any energy source, including hydrogen energy, into global energy systems needs to be evaluated with respect to its impacts on the rapidly evolving environmental changes being observed, and reasonably anticipated. The real-world effectiveness of transitions within the global energy system, historically dominated by fossil fuels, directly depends on accurately evaluated, evidence-based information. The GPHEF program *writ large*, and the GPHEF conference specifically, facilitated critical debate and extended caucuses designed to encourage participants to critically evaluate their views, priorities, and support for future decisions and actionable next steps against credible scientific and technical understanding.

Current realities

Many of the myriad challenges impacting the global energy system originate from the increasingly significant environmental changes being observed and anticipated throughout all global communities. Effectively addressing these complex, often interrelated, challenges require decisions that accurately reflect how energy is produced, transported, and utilized globally. Given the diversity of geographical, economic, political, and cultural priorities found at local, regional, and national levels, decisions correlating energy and environmental options and priorities require a new type of leadership in government, the private sector, and public advocacy communities. Broad societal consensus needs to be derived from candid debates concerning the practicality of specific real-world approaches as well as the predictive uncertainties associated with climatic events. Any consensus requires a balance between immediate and long-term goals. All decisions are challenged to incorporate credible scientific understanding into practical, actionable next steps for real-world conditions.

The potential benefits and risks for incorporating hydrogen energy into the global energy system require a comprehensive review and critical assessment examining how to integrate different technological options, economic planning, and policy directions best suited for the diverse local, regional, and national priorities found worldwide. Significantly different geographic, transportation, infrastructure, economic, political, and cultural conditions define the practical options for hydrogen energy production, distribution, and usage.

Paramount among these many decisions concerning hydrogen energy is the establishment of an evidence-based, publicly trusted certification of the impacts on environmental sustainability of hydrogen production (e.g., green v. blue v. gray), transportation, and storage options. Attention to public endorsement and sustained acceptance remains another critical issue to be considered.

A degree of urgency for these decisions and actions emerges from the unexpectedly rapid changes in global environments being observed. Such urgency has not been historically encountered in the past development of major technological transitions involving energy.

The ISGP GPHEF – Japan debate/caucus model

The ISGP GPHEF – Japan Conference was conducted using a modification of the ISGP "critical debate/caucus" format to conform with a hybrid platform designed to include a broad range of participants from governmental, private sector, and public advocacy communities worldwide. The agenda and program included (i) three, concise (one-page) Position Papers presented and discussed by senior Japanese officials in a panel discussion, and (ii) nine, 90-minute debates of concise (3-page) Position Papers focused on critically evaluating credible scientific, technological, economic, and policy options for practical decisions in real-world societal environments. Each author was provided with five minutes to summarize the major points presented in their respective Position Paper. Following three subsequently conducted debates each day, 3-hour small-group caucuses involving approximately twelve participants were convened to identify areas of consensus (AoC) and actionable next steps (ANS). The AoCs articulated aspirational goals and each ANS described specific actions needed to pursue their fulfillment. All debates and small-group caucuses were moderated by ISGP staff and were conducted under the Chatham House Rule (no attribution).

In addition, the detailed views represented in the AoC and ANS, the ISGP prepared 10 Overarching Priorities and Perspectives (OPP), which defined central themes extracted from all aspects of the GPHEF program, including: (i) interviews and analyses, (ii) consultative meetings, (iii) Global Advisory Panel (GAP) inputs, (iv) Informal Advisory Panel – Japan (IAP – J) inputs, and (v) conference outcomes.

The longstanding commitment of the ISGP to not express any opinions, nor lobby on any issue, provided the neutrality required to organize and convene conferences focused on effectively addressing major societal challenges using the exceptionally diverse, evidence-based positions and priorities now routinely encountered worldwide. Since all participants were briefed on the Chatham House Rule and formally agreed to abide by its restrictions, the GPHEF – Japan debates and caucuses encouraged the candid exchange of ideas and criticism focused on identifying real-world decisions shaped by evidence-based information.

The organization of the ISGP GPHEF – Japan Conference began with more than 300 confidential interviews by ISGP staff with subject-matter experts and stakeholders from governmental, private sector, and public advocacy communities worldwide. Numerous consultations were held with the GAP and IAP – J to elucidate the major topics to be addressed in the conference and to identify the approximately 100 individuals to be invited by the ISGP to participate. The membership of the voluntary GAP and IAP – J for the GPHEF – Japan program is presented on the ISGP website (scienceforglobalpolicy.org). The debates and plenary caucuses were recorded and used as the basis for the ISGP staff to prepare not-for-attribution summaries of the debates and the statements of the AoC and ANS emerging from the small-group caucuses appearing in this book. The recordings were held in custody by the ISGP before being destroyed.

Consultative meetings

In preparation for the ISGP GPHEF – Japan Conference, a series of four consultative meetings were organized, convened, and moderated by the ISGP for subject-matter experts and leaders from the global scientific, technological, policy, and public advocacy communities having expertise and practical experience concerning hydrogen energy. These consultative meetings were executed to facilitate the communication of credible information and individual perspectives of globally distinguished leaders and stakeholders who are making and/or influencing major governmental and private sector decisions concerning hydrogen energy. The presentations and discussions within these consultative meetings provided opportunities to clarify evidence-based information and challenge perspectives from recognized subject-matter experts and leadership concerning actionable decisions on hydrogen energy being considered. These consultative outcomes were of critical importance in structuring the agenda and invitations to the debate/caucus ISGP GPHEF – Japan conference. Not-for-attribution summaries of the four consultative meetings can be found on the ISGP website (scienceforglobalpolicy.org)

Overarching priorities and perspectives

Prior to briefing leadership within METI and the energy ministers at the G7 Ministers Meeting on Climate, Energy, and Environment in Sapporo, Japan, the ISGP developed 10 Overarching Priorities and Perspectives (OPP), which represent a concise outcome emerging across ideas and concepts presented from the (i) GAP; (ii) IAP – J; (iii) Consultative Meetings; (iv) thematic analysis of the 300+ interviews; and (v) outcomes emerging from the debates and caucuses at the ISGP GPHEF – Japan Conference. The findings from each of these engagements with stakeholders and subject-matter experts representing governmental, private sector, and public advocacy communities worldwide are collectively reflected as OPP in full recognition that individual contributions reflect diverse, even conflicting, interpretations of credible scientific and technological understanding.

Concluding remarks

The ISGP GPHEF program, and specifically the Tokyo GPHEF conference and Sapporo briefings, were designed to assist the Japanese governmental and private sector communities develop policies and actionable next steps concerning how to effectively incorporate hydrogen, and its derivatives, into the global energy system. One message transcends the myriad scientific, technological, economic, and policy outcomes from the GPHEF program: the effectiveness and sustainability of transforming energy systems away from fossil fuels depend directly on the accurate public communication of the benefits and potential risks associated with specific actions. Responsibilities for establishing public confidence in the transformational changes underway in lifestyles and livelihoods are jointly shared by leadership throughout governmental, private sector, and public advocacy communities. It is foreseeable that failure to merit strong, sustained public trust can be foreseen to have significant negative societal consequences.

Overarching Priorities and Perspectives (OPP)

Introduction

This section provides the final Overarching Priorities and Perspectives (OPP), which represent a concise outcome emerging across ideas and concepts presented from the (i) Global Advisory Panel (GAP); (ii) Informal Advisory Panel – Japan (IAP – J); (iii) Consultative Meetings; (iv) thematic analysis of the 300-plus interviews; and (v) outcomes emerging from the debates and caucuses at the ISGP Global Pathways to Hydrogen Energy Futures – Japan conference*. The findings from each of these engagements with stakeholders and subject-matter experts representing governmental, private sector, and public advocacy communities worldwide are collectively reflected as OPP in full recognition that individual contributions reflect diverse, even conflicting, interpretations of credible scientific and technological understanding.

OPP 1: Widely endorsed, standardized measurements that accurately evaluate social impacts, energy content, impact on decarbonization strategies, and contributions to overall environmental sustainability worldwide are fundamentally critical to any meaningful comparisons of the costs of the production, transportation, storage, or use of hydrogen, ammonia, and hydrogen-based fuels. International endorsements and certification of these standards need to underpin the economic and trade agreements across all global energy systems. The "social costs" of any energy source need to be included in all evaluations.

OPP 2: The reliance on fossil fuels for the production of hydrogen is directly linked to the effectiveness, efficiency, reliability, and scale of carbon capture methodologies. Balancing the economic motivations supporting the fossil fuel production of hydrogen with its impact on environmental sustainability requires an accurate understanding of carbon capture methods.

OPP 3: As with historically significant technological advances, significant early-stage

*Membership of the ISGP GAP and IAP-J as well as the not-for-attribution summaries of the four Consultative Meetings are available on the ISGP website (www.scienceforglobalpolicy.org). Outcomes emerging from the debates and caucuses are presented as **ISGP GPHEF – Japan Small-Group Caucus Outcomes**: Areas of Consensus (AOC) and Actionable Next Steps (ANS).

societal economic investments are needed to ensure the integration of hydrogen energy as a component within the existing fossil fuel energy system. Given current private sector investments in fossil fuel, economic investments from society *writ large* can be anticipated to require an increasing recognition of the relationship between environmental sustainability and energy production and use.

OPP 4: Globally standardized and trusted methodologies for accurately quantifying the carbon intensity of hydrogen, and specific hydrogen derivatives, concerning production, transportation, storage, and usage (PTSU) need to replace the popular, but imprecise, color designations to quantitatively index the contributions of hydrogen energy to strategies ameliorating climate change impacts. An accurate understanding of these indexed contributions needs to be based on detailed analyses of measured carbon intensity data reflecting the entire lifecycle of all materials and processes utilized for the PTSU of hydrogen and hydrogen derivatives.

OPP 5: Practical, real-world economic priorities focus on the immediate commitment of significant resources and tailored policies (i) strengthening the economic viability of markets and incentivizing expanded financial investments, (ii) enhancing the effectiveness and stability of global supply chains, and (iii) expanding public confidence in the advantages of hydrogen energy underpinning the consumer economy. The often-prohibitive start-up costs and significant investment risks associated with the production, transportation, storage, and usage of hydrogen and hydrogen derivatives motivate many private sector interlocutors to strongly favor significant early-stage governmental financial commitments and policy frameworks to also ensure long-term energy stability.

OPP 6: The variability in the effectiveness of hydrogen energy applications in different industrial sectors (e.g., power generation, maritime, heavy transport, steel, paper, cement, aviation) needs to be a primary factor in economic investments and climate policies. The advantages of hydrogen energy applications need to be critically evaluated against other low carbon options. Adoption of hydrogen energy in specific sectors requires detailed cost-benefit analyses to justify public and private sector investments tailored to advance specific economic and environmental goals.

OPP 7: The development and application of efficient Carbon Capture, Utilization, and Storage (CCUS) is fundamentally critical to the high carbon-indexed PTSU of hydrogen and hydrogen derivatives, especially in hard-to-abate industries (e.g., steel, paper, chemicals, cement). Consensus on the efficiency and effectiveness of CCUS remains under discussion and evaluation to the continued use of fossil fuels and other high carbon content sources for energy production as a strategy for reducing the risks of climate change.

OPP 8: Effective communication that accurately characterizes the advantages, and potential risks, of hydrogen energy as a significant component of the major transitions underway within global energy systems is the joint responsibility of leadership throughout governmental, private sector, and public advocacy communities. Communication and messaging need to be derived from evidence-based outcomes provided by subject-matter experts having credible scientific and technological expertise and real-world experience.

OPP 9: Ammonia, recognized as essential to the development and implementation of hydrogen energy, both as a direct source of energy and in facilitating safe, efficient maritime transport, needs to be prioritized in funding decisions and within policy strategies concerning the incorporation of hydrogen energy and climate change decisions.

OPP 10: Multi-stage, multi-year frameworks co-designed by local, regional, and national stakeholders from throughout governmental, private sector, and public advocacy communities, are essential to shaping strategic global roadmaps optimizing infrastructure investments, economic development, and ensuring sustained public support for the efficient incorporation of hydrogen energy at all levels of society. Frameworks need to be compatible with, and supportive of, international agreements and priorities concerning environmental change.

ISGP GPHEF – Japan Small-Group Caucus Outcomes: Areas of Consensus (AoC) and Actionable Next Steps (ANS)

AoC 1: Expedite bureaucratic permitting procedures required to approve and fund energy transition decisions

Bureaucratic barriers within procedures and overlapping regulatory responsibilities found throughout local, regional, national, and international entities interfere with the efficient transfer of information needed for policy decisions influencing the incorporation of hydrogen-based energy within the global energy system. Significant improvements for the efficient transfer of research data and analyses throughout regulatory and licensing entities interfacing among governmental, private sector, and public advocacy stakeholders are essential to expediting the permitting and funding of hydrogen energy-based projects. Currently, bureaucratic hurdles directly hinder the initiation of hydrogen energy-based projects viewed as integral to addressing the challenges emerging from the global transitions in energy systems.

- **ANS 1.1:** Enact streamlined governmental procedures for permitting and funding commitments for specific energy transition decisions, especially for hydrogen energy projects. Revisions need to rely on evidence-based data and analyses and incorporate input from private sector and public advocacy stakeholders. Each step in the procedure needs to engage credible officials and stakeholders certified to accurately evaluate the scientific, technological, regulatory, and policy requirements for energy transition projects. Transparently sharing the entire procedure with the public *writ large* is essential for garnering the broad, sustainable endorsement and support for the resulting decisions.
- **ANS 1.2:** Survey industry representatives and investors to learn what specific obstacles exist to market formation with respect to energy transition projects.
- **ANS 1.3:** Ensure policymakers and decision-makers take coordinated, multilateral actions to address the surveyed needs of industries and investors as effective policies are established.
- **ANS 1.4:** Create efficient bureaucratic procedures and flexible standards within institutional policies, especially regarding the environmental impact assessments and land acquisition requirements (i.e., for low-carbon hydrogen projects) to reduce the time needed for wide-scale deployment and adoption.

AoC 2: Promote public financing to encourage market investment and adoption

Reducing the cost of low carbon hydrogen and hydrogen derivatives production is essential for large-scale adoption across multiple commercial sectors. Using policy to accelerate market investment and adoption without relying on public subsidies alone would be critical to prolonged economic stability during a large-scale energy transition. Hydrogen production pathways need to be market driven. Governmental policies designed to incentivize the production of hydrogen via carbon-neutral methods need to focus on meeting nationally determined environmental sustainability goals that are consistent with global priorities.

- **ANS 2.1:** Increasingly invest government funding and personnel resources in the development of technologically sound infrastructure consistent with advanced energy options (e.g., hydrogen energy).
- **ANS 2.2:** Incentivize private sector efforts, especially in startup phases, to aggressively pursue the practical options offered by low-carbon technologies (e.g., hydrogen-based energy) and pursue nationally endorsed environmental sustainability benchmarks.
- **ANS 2.3:** Expand market demand for low-carbon hydrogen applications through financial instruments (e.g., low-interest loans), tax regulation (e.g., tax credits), and regulatory policies (e.g., expedited licensing, incentivizing investments) with a focus on rewarding early-stage investments, stabilizing long-term economic prosperity, and advancing environmental priorities.
- **ANS 2.4:** Establish pricing guidelines and certification protocols applicable across international markets and financial institutions and examine practical options for enforcement mechanisms.
- **ANS 2.5:** Expand the use of robust cost-benefit analyses supporting efforts to minimize risks and optimize sustainability of governmental policies (e.g., insurance regimes) and financial investments (e.g., joint funding, rebates) used to launch early-stage projects focused on the introduction of hydrogen and hydrogen derivative production with low-carbon intensities.
- **ANS 2.6:** Incorporate contributions of maritime transport in cost-benefit analyses used to determine the net economic and environmental impacts of energy from hydrogen, hydrogen derivatives, and ammonia (e.g., International Maritime Organization studies on decarbonization of international shipping).

AoC 3: Recognize climate as a forcing factor on decisions for energy transitions

Credible, evidence-based analyses of observational data have established that deterioration of environmental quality currently associated with worsening climatic conditions can be reasonably anticipated to accelerate if energy decarbonization is not rapidly achieved on a global scale. The significant transitions in energy production, transportation, storage, and usage required to implement global energy decarbonization present unprecedented challenges to stakeholders across governmental, private sector, and public advocacy communities, and especially in the public *writ large*. Significant changes in lifestyles and livelihoods (e.g., employment disruptions, workforce retraining, energy price fluctuations, changing living standards) can be expected to occur with societal adjustments to the low-carbon intensity, net-zero emission activities, and policy constraints needed for environmental sustainability. The forcing factor from the need to establish environmental sustainability places historically unprecedented pressure on the global energy transitions underway.

- **ANS 3.1:** Ensure infrastructure addresses the specific impacts of energy from hydrogen, hydrogen derivatives, and ammonia on needs for (i) new local, regional, national, and international trading and supply train relationships, (ii) generational shifts in workforce skills, (iii) consequences of altering energy availability in populations with increasingly diverse demographics, and (iv) communication modalities designed to obtain public endorsements and sustained support for lifestyle.
- **ANS 3.2:** Invest in comprehensive reviews and critical evaluations of communication strategies and messaging with a coalition of governmental, private sector, and public advocacy leaderships to obtain public trust and support for the often-significant disruptions in lifestyles and livelihood accompanying environmental sustainability.
- **ANS 3.3:** Engage the public *writ large* in decision-making processes required to effectively implement energy transitions, especially by accurately articulating relationships among mitigation strategies, deteriorating climatic conditions, and societal viability.
- **ANS 3.4:** Work with fossil fuel producing countries to leverage economic and cultural cooperation to increase low carbon intensity options.

AoC 4: Prioritize transparent messaging on safety, economic costs, and societal impacts of energy from hydrogen and hydrogen derivatives

Information transparency regarding the safety (e.g., potential risks, best practices) associated with the adoption of hydrogen energy encourages sustained public and political support for transitions to hydrogen energy sources at local, regional, national, and global levels. Effective communication of evidence-based information accurately characterizing the advantages and potential risks of hydrogen energy is a shared responsibility of leadership throughout governmental, private sector, and public advocacy communities. Harmonized safety metrics, certification standards, and enforcement procedures applicable to all aspects of the commercial production, transportation, storage, and end use of hydrogen, hydrogen derivatives, and ammonia need to be established with global endorsements as an integral part of an effective energy supply chain, trading system.

- **ANS 4.1:** Require that commercialization of energy from hydrogen, hydrogen derivatives, and ammonia use a uniform system to accurately inform the public *writ large* of all evidence-based assessments of safety data and public health impact associated with the energy sources.
- **ANS 4.2:** Ensure commercialization policies for production, transportation, storage, and usage for hydrogen and hydrogen derivatives accurately reflect the societal benefits and potential risks to promote public acceptance of renewable energy sources.
- **ANS 4.3:** Collaborate nationally to build resilience by anticipating and planning countermeasures to address these concerns.
- **ANS 4.4:** Establish international enforceable agreements among all commercial trading partners using energy from hydrogen, hydrogen derivatives, and ammonia to continually examine and update relevant safety standards and regulations for transparent presentation to the public.
- **ANS 4.5:** Establish ongoing surveying of the affected population to continually update governmental and private sector understanding of public views concerning the safety and utility of energy from hydrogen-based sources.

AoC 5: Clarify the role of carbon capture, utilization, and storage (CCUS) in decarbonization

The high efficiency, durable reliability, and large-scale applicability of CCUS technologies and methodologies are essential components to strategies promoting the continued production of energy from fossil fuels and as a contribution to global decarbonization. The CCUS-fossil fuel linkage is viewed as a necessary pathway to reaching both climate change goals (e.g., United Nation's Conference of the Parties (COP) agreements) and facilitating economically viable transitions in existing and evolving (e.g., hydrogen, hydrogen-derivatives) energy sources. Accurate lifecycle evaluations of CCUS in practical applications are ongoing for hard-to-abate industries (e.g., steel, paper, chemical, cement) and for the overarching environmental sustainability needed to prevent carbon dioxide from entering the atmosphere. As energy from hydrogen and hydrogen derivatives is introduced globally, multilateral trade agreements, safety standards, and enforceable certification regulations governing the CCUS-fossil fuel linkage are required to balance economic prosperity with environmental sustainability. The transparency of these frameworks is essential for sustained public support and for incentivizing financial investments at local, regional, national, and international levels.

- **ANS 5.1:** Establish a regulatory framework for efficiently approving, managing, and monitoring CCUS sites and operations, including the after-project completion phase.
- **ANS 5.2:** Identify and assess the availability and functionality of CCUS sites, and the technologies they employ, for the cost-effective development and deployment of CCUS applications *writ large*.
- **ANS 5.3:** Facilitate the deployment of CCUS infrastructure by funding and implementing incentive mechanisms, including early investor guarantee options, to encourage wider adoption of CCUS technologies.
- **ANS 5.4:** Assess the societal and environmental implications of installing CCUS infrastructure projects within local communities with a focus on addressing public resistance and potential risks to environmental sustainability.
- **ANS 5.5:** Initiate a communication platform for multi-stakeholder dialogues among governmental, private sector, and investor communities as well as civil society to develop strategies to optimize advantages and address real and/or perceived risks related to developing CCUS policies and projects.
- **ANS 5.6:** Develop clear and consistent standards for CCUS implementation to guide CCUS project developers, regulatory bodies, and advocacy groups on the adoption of CCUS based on transparency of communication, environmental effectiveness, and societal acceptance.

AoC 6: Develop internationally trusted, certifiable standards accurately quantifying carbon Intensities for hydrogen, hydrogen derivatives, and ammonia

Globally standardized and trusted methodologies that accurately quantify the carbon intensities associated with the PTSU of hydrogen and hydrogen derivatives needs to replace the popular, but imprecise color designations (i.e., blue and green). The resultant quantitative index, derived from evidence-based measurements, needs to provide an accurate evaluation of the contributions from specific PTSU of hydrogen to environmental sustainability based on strategic policies aimed at mitigating climate change impacts. An accurate understanding of these indexed contributions needs to be based on detailed analyses of measured carbon intensity data reflecting the entire lifecycle of all materials and processes utilized for the PTSU of hydrogen and hydrogen derivatives. Carbon intensity must be evaluated in three areas to obtain international consensus and support for specific energy production, logistical options, and end-use conversion. Imprecise metrics (e.g., color designations) for the carbon impact on atmospheric emissions convey incorrect information concerning specific PTSU of hydrogen and hydrogen derivatives. Determining a carbon threshold for the entire hydrogen energy supply chain balancing economic prosperity and environmental sustainability relies on an accurate carbon intensity index.

- **ANS 6.1:** Empower a neutral, globally respected certification group (e.g., International Organization for Standardization, British Standards Institute) to provide pathways towards globally standardized measurements of carbon intensities for hydrogen and hydrogen derivative production in a fashion that garners broad public trust.
- **ANS 6.2:** Enact legislation on national and international levels to codify the needs of stakeholders and consumers in the energy sector.
- **ANS 6.3:** Engage the private sector in endorsing this transition towards low- or net-zero carbon emissions.

AoC 7: Establish practical justification for hydrogen and hydrogen derivatives within global energy systems

It is essential that evidence-based analyses of the advantages, challenges, and potential risks of adopting hydrogen energy, and/or hydrogen derivatives (e.g., ammonia, e-fuels), be critically evaluated against alternative options provided by other low-carbon energy sources. Analyses need to consider factors reflecting the (i) economic and timing viabilities of transitions from fossil fuels, (ii) practicality of specific technology applications, (iii) impacts on local, regional, national, and global environmental sustainability, and (iv) acceptance by the public *writ large*. Adoption of hydrogen energy depends on detailed cost-benefit analyses justifying early-stage public and private sector investments viewed as advancing both economic prosperity and environmental (e.g., decarbonization) goals. Strategies in individual communities concerning how energy is respectively employed in production, transportation, storage, and applications can be anticipated to emerge from their respective economic, environmental, and cultural priorities.

- **ANS 7.1:** Expand financial programs, from governmental and private sector sources, in concert with policy incentives, for evidence-based research and analyses focused on accurately identifying the benefits, limitations, and foreseeable risks associated with incorporating energy from hydrogen and hydrogen-derivatives.

- **ANS 7.2:** Ensure cost-benefit analyses of energy production sources consider the potentially significant opportunity losses of neglecting or minimizing the contributions to power generation from renewable hydrogen and hydrogen derivatives generated from low-carbon intensity hydrogen sources.
- **ANS 7.3:** Establish internationally-endorsed, evidence-based standards to accurately determine the economic, environmental, and societal values of energy from hydrogen and its derivatives in formats amenable to the critical evaluations pertaining to specific geographical, political, and cultural applications required to garner broad, sustainable public endorsements.
- **ANS 7.4:** Ensure analyses on the overarching benefits, limitations, and risks for hydrogen energy introduction prioritizing parameters realistically characterizing the human consequences of energy transitions on (i) societal stability, (ii) equity in governance, (iii) economic viability, (iv) technological reliability, (v) employment options, (vi) environmental sustainability, and (vii) cultural diversity.
- **ANS 7.5:** Use evidence-based carbon intensity indices to evaluate all potential energy production, transportation, and end-use options considered in the global energy transition away from fossil fuels.

AoC 8: Ensure an internationally endorsed maximum carbon intensity threshold correlates with environmental sustainability goals

All communities, local, regional, national, and international, have significant responsibilities to maintain viable economic prosperity and environmental sustainability, and to future next generations who will need to address the societal consequences of failures. These responsibilities include the prioritized investments in decarbonizing their respective energy systems as effectively, efficiently, and as quickly as possible. While ensuring that the global air and water temperatures remain below specific threshold values are critical targets to be collectively met, it is critical to recognize each target represents only a degree of success or failure. Carbon intensities and temperature thresholds, derived from scientific consensus and evidence-based data, are associated with specific actions (e.g., energy production) as a guide to policies that transcend geographical, pollical, and cultural boundaries and require mutually beneficial actions.

- **ANS 8.1:** Establish internationally endorsed standards for measurements of carbon intensities from specific methods in the production, transportation, storage, and usage of hydrogen and hydrogen derivatives that incorporate life-cycle assessments.
- **ANS 8.2:** Ensure the results from studies by Green Hydrogen Organisation

(GHO), International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), International Organization for Standardization (ISO), Ammonia Energy Association (AEA), and others are considered in the establishment and harmonization of metrics evaluating the characteristics and properties of hydrogen energy PTSU.

- **ANS 8.3:** Identify a coalition or platform of actors (e.g., the G7) to lead the standardization of carbon intensity threshold exercise.
- **ANS 8.4:** Establish local, regional, national, and international certification schemes to support hydrogen and hydrogen derivative market growth while adhering to carbon decarbonization goals.

AoC 9: Establish cooperative international regulatory frameworks for hydrogen and hydrogen derivatives

Establishing evidence-based, global regulatory frameworks governing the production, transport, storage, and utilization of hydrogen and hydrogen derivatives is critical to advancing the introduction of these energy sources as important components in transitions currently underway in global energy systems. The integral contributions of ammonia to the energy production, transportation, storage, and usage of hydrogen and hydrogen derivatives emphasizes the importance of ensuring regulatory frameworks include ammonia. International protocols monitoring compliance with regulatory benchmarks require cooperative agreements among governmental, private sector, and public advocacy stakeholders recognizing practical economic limitations and challenges of environmental sustainability, especially recognizing differentiating impact based on carbon intensity data and decarbonization benchmarks. Strategic roadmaps for regulatory compliance need to optimize societal benefits and minimize individual risks across the entire value chain in any given energy sector (e.g., transport, industry, maritime, aviation).

- **ANS 9.1:** Coordinate infrastructure investments worldwide to optimize opportunities for mutually beneficial economic outcomes in different countries and regions while remaining compliant with regulatory roadmaps and strategies developed by respected multilateral agencies (e.g., International Hydrogen Organization (IHO)).
- **ANS 9.2:** Encourage the development of evidence-based standards and certification protocols governing the qualities (e.g., carbon intensity index) and metrics required for commercially trading hydrogen, hydrogen derivatives, and where appropriate, ammonia.
- **ANS 9.3:** Accelerate the development and impact of collaborative research and manufacturing agreements facilitating international sharing of technological

advances by re-examining licensing and patents procedures pertaining to the introduction of hydrogen energy.

- **ANS 9.4:** Examine within an international forum (e.g., the G20) changes in the financing guidelines operating within key global economies required to improve the efficiency of commercial commitments for the funding of low carbon intensity projects worldwide.
- **ANS 9.5**: Prioritize the responsibilities of governmental departments, agencies, and commissions to develop comprehensive strategic roadmaps designed to identify and critique the potential contributions of energy from hydrogen, hydrogen derivatives, and where appropriate, ammonia, that can realistically contribute to existing and foreseeable energy needs.

AoC 10: Develop equitable and economically viable supply chains for hydrogen, hydrogen derivatives, and ammonia

The geographic diversity in the demand for low-carbon hydrogen provides a degree of international energy security that benefits from the differences in the technology value chains and the trading of commodities related to hydrogen, hydrogen derivatives, and ammonia. Increased efficiencies in supply chains for hydrogen and hydrogen derivatives are needed in (i) efficiencies of storage mechanisms, (ii) access to low-carbon energy corridors for shipping, and (iii) relaxing regional regulatory barriers. As with historical developments of other advanced energy sources, the early-stage introduction of energy from hydrogen, hydrogen derivatives, and ammonia encompasses specific geopolitical challenges (e.g., integration into the existing fossil fuel system, access to critical minerals). Public and private sector investments supporting early stage funding decisions and expanding personnel training with advanced skills are recognized as priorities to address these challenges.

- **ANS 10.1**: Establish hydrogen supply chain and storage networks to increase the hydrogen demand and improve supply chain efficiencies (e.g., construct cross border pipelines, adopt specialized trading policies and regulations, expand port infrastructure).
- **ANS 10.2**: Expand national and international funding mechanisms (e.g., Asia Transition Finance) to support the development of enabling infrastructure and personnel training required for the full adaptation of hydrogen and ammonia energy.
- **ANS 10.3**: Develop coordinated roadmaps across national boundaries to advance the inactivated design and efficient construction of facilities in diverse locations within countries providing financial and workforce subsidies.

- **ANS 10.4**: Create economic platforms that incentivize and/or subsidize the private sector to invest in energy from hydrogen, hydrogen derivatives, and ammonia needed to lower future energy costs.
- **ANS 10.5**: Assess collaboratively the potential risks and impacts of disruptions from non-resilient supply chains for hydrogen, hydrogen derivatives, and ammonia as well as interruptions in technology supplies.
- **ANS 10.6**: Expand research needed to remove bottlenecks within supply chains that are identified as restriction to the use of hydrogen energy (e.g., lower electrolyzer cost with increased efficiencies, ammonia leak detection).
- **ANS 10.7**: Encourage the public distribution of accurate information on technological advancements and the benefits of international collaboration for the introduction of hydrogen and ammonia energy.

AoC 11: Ensure global transitions toward low-carbon energy sources contribute to the advancement of decarbonization goals

Scaling the production of hydrogen, hydrogen derivatives, and ammonia from fossil fuels, in conjunction with techniques for carbon capture, utilization, and storage (CCUS), can be rapidly increased to commercially viable levels based on the existence of a comparatively mature fossil fuel supply chain. The absence of similarly advanced supply systems limits the scalability of hydrogen, hydrogen derivatives, and ammonia produced by renewable sources (e.g., wind, solar). While the current priorities for lower-cost energy for immediate use favor fossil fuel generated sources, the increasing awareness of the instabilities fossil fuel usage imposes on global environmental sustainability signals the need to eliminate these negative externalities to energy production. Realistic evaluations of the actual cost of fossil fuel-produced energy needs to include the overall negative consequences for economic, environmental, and public health outcomes. These factors demonstrate the need for strategic policies and improved infrastructures diminishing fossil fuel use while expanding sustainable methods (e.g., wind, solar) in the production of hydrogen, hydrogen derivatives, and ammonia. Incentivizing governments, the private sector, and public *writ large* to transition from fossil fuels while maintaining energy security requires decisions derived from accurate, realistic evaluations of the full range of economic, societal, public health, and environmental challenges now being encountered.

- **ANS 11.1**: Establish strategic roadmaps, with enforceable provisions, representing the range of local, regional, national, and global priorities and capabilities to facilitate the transition from fossil fuel usage in energy production, transportation, and storage.
- **ANS 11.2:** Mandate government/private sector commercial agreements

and contracts maintain energy security and incorporate restrictive provisions that recognize the criticality of transitioning from fossil fuel-based on times scale consistent with meeting environmentally sustainability outcomes.

- **ANS 11.3:** Develop protocols and guidelines for using fossil fuel-based energy to address emergency circumstances related to ensuring energy security and/or immediate crisis management.

Institute on Science for Global Policy (ISGP)

program on

Global Pathways to Hydrogen Energy Futures - Japan (GPHEF — Japan)

3.5-Day Hybrid Conference

(invitation-only)

Conference Dates: April 6 — April 9, 2023
Conference Agenda and Structure

ISGP GPHEF — Japan Conference is convened primarily at the **Pacifico Yokohama Conference Center (1 Chome-1-1 Minatomirai, Nishi Ward, Yokohama, Kanagawa 220-0012, Japan)**.

Conference Overview

- Three (3) days
- Six (6) Topics
- Nine (9) 90-minute Position Paper Debates
- Three (3) 3.5-hour Small-Group Caucus Sessions

Conference Events: April 6-9, 2023

April 6:	Day Zero	Registration, Reception, Panel Discussion, Dinner
April 7:	Day One	Three (3) Debates, Small-group Caucuses
April 8:	Day Two	Three (3) Debates, Small-group Caucuses
April 9:	Day Three	Three (3) Debates, Small-group Caucuses, Adjournment

Day Zero: April 6th, 2023

1400 -1530 **Participant Registration**

1555 - 1600 **Introductory Remarks**
Dr. George Atkinson, Founder, and Executive Director, ISGP

1600 - 1630 **Panelist One Presentation/Discussion**
Moderated by Euphemia Anderson, ISGP Senior Fellow, Program Manage under Chatham House Rule (not-for-attribution)
Panelist: **Dr. Kazunari Sasaki,** Distinguished Professor, Hydrogen Utilization Engineering, Kyushu University

1630 - 1700 **Panelist Two Presentation/Discussion**
Moderated by Euphemia Anderson, ISGP Senior Fellow, Program Manager under Chatham House Rule (not-for-attribution)
Panelist: **Dr. Keigo Akimoto,** Chief Researcher, Research Institute of Innovative Technology for the Earth (RITE)

1700 - 1730 **Panelist Three Presentation/Discussion:**
Moderated by Euphemia Anderson, ISGP Senior Fellow, Program Manager under Chatham House Rule (not-for-attribution)
Panelist: **Mr. Shigeru Muraki,** Representative Director, President, Clean Fuel Ammonia Association

1730 - 1800 **Panel Discussion Summary**
Moderated by ISGP Ciaran Fitzpatrick, ISGP Senior Fellow, Program Manager under Chatham House Rule (not-for-attribution)

1800 - 1900 **Reception**

1900 - 2030 **Dinner**

All times provided in Japan Standard Time

Day One: April 7th, 2023

Topic 1: Hydrogen/Ammonia Demand and Cost Projections for the Realistic Transition from a Fossil Fuel-Dominated Economy

3, 90-minute debates (moderated by ISGP staff) and small-group caucuses (moderated and scribed by ISGP staff). All debates and caucuses held under Chatham House Rule (not-for-attribution)

0630 - 0800 **Participant Registration**
Breakfast - on your own

0800 - 0815 **Conference Room**
Please be seated behind your placard

0815 - 0830 **Introductory Remarks**
Dr. George Atkinson, Founder, and Executive Director, ISGP

Program Overview and Small-group Caucus Assignments
Conference attendees receive instructions and small-group caucus groups from ISGP staff.

0830 - 1000 **Debate/Position Paper One: Competitive Costs and Market Issues Related to Hydrogen Energy**
Moderated by Euphemia Anderson, ISGP Senior Fellow, Program Manager under Chatham House Rule (not-for-attribution)
<u>**Position Paper One Author**</u>: **Mr. Masakazu Toyoda**, Chairman, and CEO, Japan Economic Foundation (JEF); former Chairman and Chief Executive Officer, the Institute of Energy Economics, Japan (IEEJ)

1000 - 1015 **Break**

Topic 2: Hydrogen/Ammonia Production Methods

1015 - 1145 **Debate/Position Paper Two: Scalability and Practicality of Local Production vs. Importation**
Moderated by Camelia Bou, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

All times provided in Japan Standard Time

	Position Paper Two Author: **Mr. Koji Hosono**, General Manager, New Power Generation Fuels Business Department, Next-Generation Fuels & Petroleum Business Div., Mitsubishi Corporation
1145 - 1200	**Break**
1200 - 1330	**Debate/Position Paper Three: Comparative Analysis of Hydrogen/Ammonia Production Methods (i.e., Blue, Green, and Pink Hydrogen) in Terms of Cost, Supply Amount, Life Cycle, and Carbon Footprint, and Environmental Compatibility** *Moderated by Ciaran Fitzpatrick, ISGP Senior Fellow, Program Manager* *under Chatham House Rule (not-for-attribution)* **Position Paper Three Author: Dr. Yuki Ishimoto**, Senior Researcher, Vice Director, Hydrogen Program, Research and Development Division, The Institute of Applied Energy
1330 - 1400	**Lunch** *Located in small-group caucus rooms*
1400 - 1530	**Small-group Caucuses** Moderated and scribed by ISGP staff *under Chatham House Rule (not-for-attribution)*
1530 - 1540	**Break**
1540 - 1700	**Small-group Caucuses** Moderated and scribed by ISGP staff *under Chatham House Rule (not-for-attribution)*
1700 - 1705	**Day One Adjournment**

All times provided in Japan Standard Time

Day Two: April 8th, 2023

Topic 3: Hydrogen/Ammonia Supply Chain

3, 90-minute debates (moderated by ISGP staff) and small-group caucuses (moderated and scribed by ISGP staff). All debates and caucuses are held under Chatham House Rule (not-for-attribution).

0630 - 0800 *Breakfast - on your own*

0800 - 0830 **Conference Room**
Please be seated behind your placard

0830 - 1000 **Debate/Position Paper Four: Supply Chain Logistics of Hydrogen/Ammonia Production, Storage, and Distribution**
Moderated by Daniela Baeza Breinbauer, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)
Position Paper Four Author: **Mr. Kenji Takahashi,** General Manager, Decarbonization Promotion section, Planning division, JERA Co. Inc.

1000 - 1015 **Break**

Topic 4: Utilization of Hydrogen/Ammonia for the Decarbonization of Power and Maritime Sectors

1015 - 1145 **Debate/Position Paper Five: Zero-emission Power Generation by Hydrogen/Ammonia**
Moderated by Kat Wheeler, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)
Position Paper Five Author: **Mr. Radhanon Diewvilai, M.Eng.,** Researcher, Energy Research Institute, Chulalongkorn University

1145 - 1200 **Break**

1200 - 1330 **Debate/Position Paper Six: Decarbonizing Ocean and Coastal Maritime Shipping Utilizing Hydrogen, Ammonia**
Moderated by Ian Shotts, ISGP Fellow under Chatham House Rule (not-for-attribution)

All times provided in Japan Standard Time

	<u>Position Paper Six Author:</u> Mr. James Laybourn, Regional Sales Director, Asia Pacific, DNV; Director, The Society of Offshore Marine Warranty Surveyors (SOMWS)
1330 - 1400	**Lunch** *Located in small-group caucus rooms*
1400 - 1530	**Small-group Caucuses** Moderated and scribed by ISGP staff *under Chatham House Rule (not-for-attribution)*
1530 - 1540	**Break**
1540 - 1700	**Small-group Caucuses** Moderated and scribed by ISGP staff *under Chatham House Rule (not-for-attribution)*
1700 - 1705	**Day Two Adjournment**

Day Three: April 9th, 2023
Topic 5: Utilization of Carbon Capture, Storage, and Utilization (CCUS)
3, 90-minute debates (moderated by ISGP staff) and small-group caucuses (moderated and scribed by ISGP staff). All debates and caucuses are held under Chatham House Rule (not-for-attribution).

0630 - 0800	*Breakfast - on your own*
0800 - 0830	**Conference Room** *Please be seated behind your placard*
0830 - 1000	**Debate/Position Paper Seven: Carbon Capture, Storage, and Utilization (CCUS) for Hydrogen/Ammonia Production and beyond** *Moderated by Tory Brewster, ISGP Fellow* *under Chatham House Rule (not-for-attribution)* **<u>Position Paper Seven Author:</u> Mr. Matthew Loughrey,** Principal Consultant Carbon Capture Technologies, Global CCS Institute

All times provided in Japan Standard Time

1000 - 1015 **Break**

Topic 6: Policy Recommendations and Geopolitical Implications

1015 - 1145 **Debate/Position Paper Eight: Policy Recommendations Toward the Adoption of Hydrogen/Ammonia Energy**
Moderated by Mattia Anfosso Lembo, ISGP Fellow
under Chatham House Rule (not-for-attribution)
Position Paper Eight Author: Mr. Shigeru Kimura, Special Advisor to the President on Energy Affairs, Economic Research Institute for ASEAN and East Asia

1145 - 1200 **Break**

1200 - 1330 **Debate/Position Paper Nine: Geopolitical Implications of Hydrogen/Ammonia Energy Adoption**
Moderated by Ciaran Fitzpatrick
under Chatham House Rule (not-for-attribution)
Position Paper Nine Author: Ms. Jane Nakano, Senior Fellow, Energy Security and Climate Change Program, Center for Strategic and International Studies

1330 - 1400 **Lunch**
Located in small-group caucus rooms

1400 - 1530 **Small-group Caucuses**
Moderated and scribed by ISGP staff
under Chatham House Rule (not-for-attribution)

1530 - 1540 **Break**

1540 - 1700 **Small-group Caucuses**
Moderated and scribed by ISGP staff
under Chatham House Rule (not-for-attribution)

1700 - 1705 **Conference Adjournment**

All times provided in Japan Standard Time

Panel Discussion: Position Paper One
Toward Social Implementation of Hydrogen and Ammonia: A Japanese Perspective**

Kazunari Sasaki, Ph.D.
Senior Vice President and Director, International Research Center for Hydrogen Energy, Kyushu University, Japan

Current realities

Hydrogen is attracting great attention worldwide as a promising decarbonized fuel. In addition, ammonia is increasingly recognized as a promising hydrogen carrier, which is already widely traded and used extensively in agriculture. Stationary fuel cell systems have been commercialized across the globe for residential and industrial applications such as co-generation and backup power. The use of hydrogen fuel has already begun in the mobility sector for passenger cars, public transport, and commercial vehicles. There is also potential for much larger amounts of hydrogen and ammonia to be used in power generation. It is expected that hydrogen will be supplied to natural gas-based power plants, and ammonia will be supplied to coal-based power plants to reduce their overall CO_2 emissions. Hydrogen and ammonia can also contribute to the decarbonization of major industries, including steel manufacturing and chemical industries. Japan aims to generate 1% of electric power using hydrogen or ammonia in power plants by 2030. Hydrogen usage in the mobility sector will become increasingly common, especially for commercial and heavy-duty applications.

Actionable next steps (ANS)

Achieving these targets will not be easy. The current price of both hydrogen and ammonia is still too high for general use. Commercial players are traditionally reluctant to invest in infrastructure if the price is high. To tackle this so-called "chicken-and-egg" problem, Japan has taken a step-by-step approach, leveraging the continuous efforts in research and development for over a half-century. Japan's approach is outlined in the National Hydrogen Strategy issued and revised in 2017. First, close to 2 trillion Japanese yen (around $15 billion USD) has been made available in the Green Innovation Fund for supporting technological development toward social implementation of hydrogen and ammonia. Second, the Japanese government is currently preparing financial support for constructing large-scale supply chains of hydrogen and ammonia. Meanwhile, in one or two years, the "first movers" (i.e., companies initiating hydrogen business) of hydrogen and ammonia supplies will be partly or fully subsidized for the next 15 years, in principle, similar to the Contract for Difference scheme in the United Kingdom. Third, several large-scale and medium-scale hubs for hydrogen and ammonia will be established in Japan in the next decade. A large amount of hydrogen and ammonia will be imported from overseas, but domestic hydrogen production will also be encouraged from the viewpoint of energy security.

Of course, the use of hydrogen and ammonia must ultimately contribute to achieving net-zero, or carbon neutrality. Whilst the different colors of hydrogen (i.e., brown, gray, blue, and green) are coming into common parlance, the carbon intensity of hydrogen production methods gives a more quantitative measure, in kilograms of CO_2 emitted per kilogram of hydrogen produced. The above-mentioned financial support targets "clean" hydrogen and ammonia based on carbon intensity for hydrogen comparable to the international criteria, including EU targets and those of other countries. On the other hand, carbon intensity levels need to be utilized to establish stable, affordable hydrogen and ammonia global supply chains. The harmonization of international standards and regulations is essential for the establishment of a carbon-neutral society based on the international trade of hydrogen and ammonia fuels as commodities.

***** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Position Paper One
Panel Discussion Summary

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is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the discussion.

The unique geographical, social, and economic characteristics of Japan were a focal point of the panel discussion. It was highlighted that Japan is the world's fifth-largest energy consumer and has the third-largest GDP, with Tokyo being the second-largest single metropolitan area internationally. Currently, Japan imports nearly 90% of its energy supply, most of which is imported fossil fuel sources (e.g., oil, natural gas). It was noted that in the Japan Strategic Energy Plan, hydrogen and ammonia is expected to make up 1% of the primary energy and electricity supply mix by 2030, and 10% of the energy mix by 2050. The achievability of these goals was questioned, and it was posited that although reaching these goals will be challenging, these goals provide an actionable framework that the governmental and private sectors can utilize to make progress toward country-wide decarbonization through investment of capital, labor force, and innovation. The extent to which renewable energy production from wind and solar was included in the Strategic Energy Plan was also questioned, and although no specifics relating to the plan were given, it was stated that in Kyushu, Japan (the third largest of Japan's main islands), approximately 60% of electricity is already carbon neutral, with 35% of the electricity produced by nuclear energy, and 25% produced by wind and solar. However, it was stated that recent energy policy in Japan is focused on Tokyo, Kansai, and Nara.

Discussions regarding hydrogen hub systems focused on the comparison of the developing Japan-based hub systems, as well as the hub systems currently evolving in the United States. It was recognized that The United States Department of Energy had enacted the Regional Clean Hydrogen Hubs program (H2Hubs) with plans to establish 6 to 10 clean hydrogen hubs across the country. It was emphasized that these hydrogen hubs will have specific enforced conditions and must exhibit diversity in feedstock production methods and variety in end-use applications. It was questioned what conditions may be enacted to implement a Japan-based hub system, to which it was stated that hydrogen hubs in Japan would differ largely from those being developed in the United States since most of the hydrogen and hydrogen-derivatives to be used in Japan are expected to be imported. It was emphasized that since hydrogen demand would differ largely in each region and respective city, the hub specifications (e.g., location, size, projected end-use) will depend directly on these factors throughout Japan.

It was noted that a major focus in Japan (from both government and private sector initiatives) had been placed on hydrogen and ammonia utilization (i.e., end-use applications). Several stakeholders asked what specific technological advancements will be needed to accelerate economically viable hydrogen and ammonia-based energy production in Japan. Multiple participants agreed that it will become increasingly important to focus government and private sector funding and personnel on the development of production-specific technology.

Another major focus during the discussion was the challenges associated with transporting hydrogen by sea, which is specifically relevant to Japan, based on its continued reliance on imported hydrogen and ammonia. The urgency to mitigate the rapidly advancing impacts of climate change was separately asserted as a critical factor in addressing the underdeveloped state of maritime transportation supply chains of hydrogen in general, and the specific decarbonization goals currently set by the Japanese government. It was contended that to reach decarbonization goals, nuclear energy would need to serve as a carbon-neutral hydrogen production method, while increasing energy security (i.e., decreasing Japan's reliance on energy imports). It was stated that although nuclear power is an effective and efficient method of producing hydrogen, especially when utilized in high temperature process heat applications (e.g., using a steam electrolyzer), hesitation following the Fukushima disaster of 2011 remains a prominent concern of stakeholders and the public *writ large*.

Panel Discussion: Position Paper Two Economic Views for Achieving Carbon Neutrality Considering Different Conditions of Energy Systems across Regions/Countries: the Role of Hydrogen-based Energy Sources**

Keigo Akimoto, Ph.D., Prof.
Chief Researcher, Research Institute of Innovative Technology for the Earth (RITE), Japan

Current realities

The world is seeking a significant reduction in greenhouse gas emissions to reach net-zero by the middle of this century to meet the +1.5°C goal. To achieve net-zero emissions, renewable energy, nuclear power, and fossil fuels with carbon capture, utilization, and storage (CCUS), including CO_2 removal (CDR) technologies are required as primary energy sources, as well as energy savings and electrification. Meanwhile, several specific sectors are considered difficult to electrify, and these decarbonized energy sources have several limitations in many countries and regions: (i) limited resources in terms of location, with renewable energy and CO_2 geological storage potentials vary across countries and (ii) limitations in matching the different timings of electricity supply and demand for variable renewable energy with even greater difficulty in matching them for, small-scale power grid countries, particularly. In order to overcome these limitations, hydrogen and hydrogen-based energy sources (e.g., ammonia, e-methane, e-fuels), play an important role in supporting the achievement of carbon neutrality (CN).

Currently, blue hydrogen and blue ammonia (i.e., produced while utilizing) are cheaper than green hydrogen (i.e., produced using renewable energy). However, green hydrogen and hydrogen-based energy sources are expected to be competitive with blue hydrogen in the future. The cost-effective deployments of hydrogen to meet emission reduction pathways toward CN need to be considered, and both blue and green hydrogen will be important from an economic perspective. Additionally, hydrogen and hydrogen-based energy sources can contribute to the achievement of CN in all sectors, including the power, industry, building, and transport sectors. Most notably, in the countries that have no interconnections of power grid and smaller capacities of CO_2 geological storage (e.g., Japan), the importance of hydrogen and hydrogen-based energy will be significant **(Figure 1)**. In addition, cost-efficient power systems also include hydrogen and ammonia power generation.

Actionable next steps (ANS)

In order to assuredly achieve net-zero emissions with a successful transition, all possible options need to be employed, including green hydrogen and green hydrogen-based energy sources as well as blue hydrogen because both will play a key role in reaching this achievement. In addition to blue hydrogen, blue ammonia will contribute to emissions reductions relatively early. Meanwhile, cost reductions in hydrogen production, for both green and blue hydrogen, will be necessary to avoid mounting costs of emissions reduction. For cost reductions, increases in hydrogen-based energy demands and developments of hydrogen supply chains at global levels will be required. In the U.S., the Inflation Reduction Act of 2022 (IRA) was introduced, which includes a subsidy for clean hydrogen energy that will encourage broader deployment. The Government of Japan is also considering a subsidy for clean hydrogen and ammonia. These subsidies for clean hydrogen and hydrogen-based energy will not only help increase demand, but reduce costs as well.

*** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.*

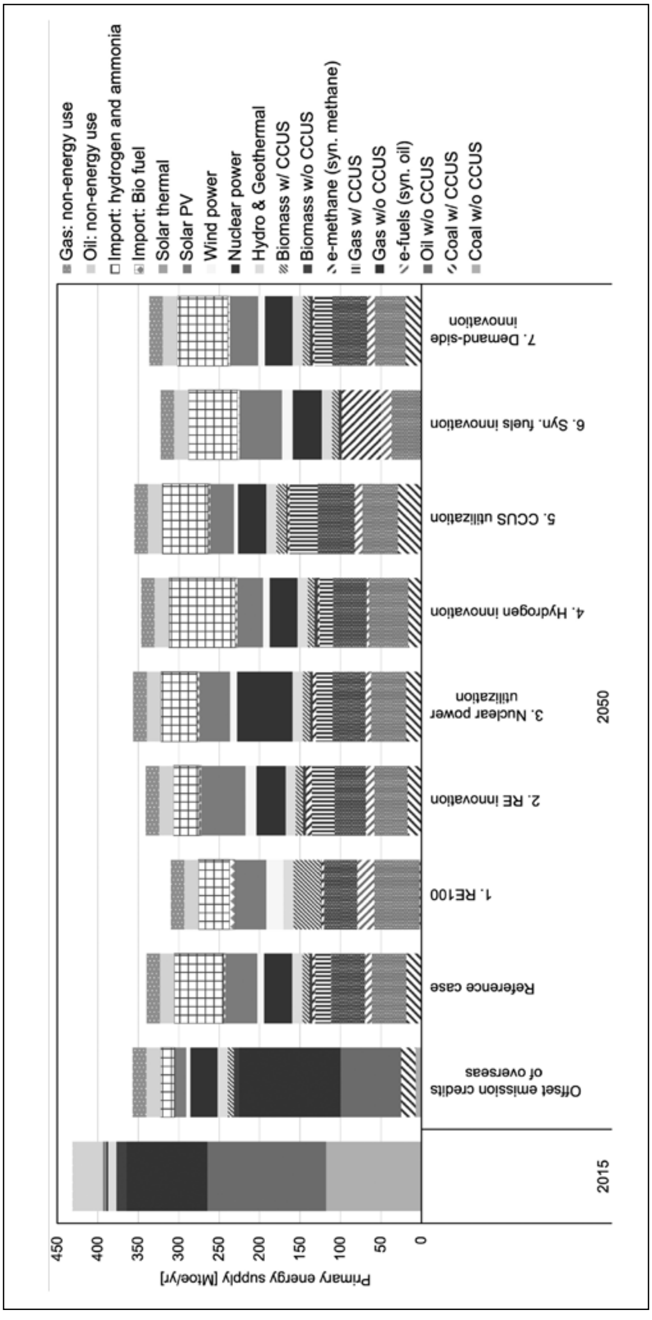

Figure 1: The cost-efficient primary energy supply for achieving net-zero emissions in 2050 in Japan

Position Paper Two
Panel Discussion Summary

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The impact of introducing hydrogen and hydrogen derivatives into Japan's energy mix on the basis of GDP considerations was the focus of these discussions in which it was noted that economic growth is a determining factor concerning increased development and investment into the hydrogen and ammonia sectors. It was asserted that the potential for negative economic impacts from increased hydrogen deployment is dependent on international competitiveness for decarbonization. It was stated that if all countries reduced CO_2 emissions with equal carbon prices and marginal abatement cost, the international competitiveness deficits (i.e., the ability of a country's producers to compete successfully in world markets) could remain staggering but have reduced impacts in specific economic arenas. It was also stated that while investment into the energy sector in Japan would increase GDP, the increases in energy prices (e.g., paying a premium for hydrogen and ammonia energy due to higher production or import costs) may subsequently decrease GDP. Due to several Japan-specific characteristics (e.g., lack of renewable energy potential and suitable geological storage sites for captured CO_2), it was suggested that the estimated carbon prices for Japan in 2050 will be approximately USD $400 per tonne of CO_2, which was expected to be double the estimated carbon prices for most other countries (i.e., USD $200 per tonne of CO_2).

There were questions regarding how energy consumers in Japan would ensure the cost efficiency of the country's hydrogen and ammonia supply in reaching carbon neutrality. In response, it was stated that due to limitations (e.g., lack of renewable energy and Carbon Capture and Storage technologies (CCS)), it is currently more cost-effective for energy consumers in Japan to import hydrogen and hydrogen derivatives (e.g., ammonia, e-methane, e-fuels) from countries with less expensive production potential (e.g., Australia, Saudi Arabia, and the United States) due to greater respective renewable energy production and suitable CO_2 geological storage sites in other countries. Because of these realities, it was posited that Japan would primarily import its hydrogen and hydrogen derivative supplies and would instead focus monetary and personnel investments on cost reduction (i.e., through technological improvements) of hydrogen and ammonia transportation.

The implications of the United States Inflation Reduction Act of 2022 (i.e., subsidizing the use of less greenhouse gas-intensive energy) in Japan were repeatedly mentioned. It was questioned if stakeholders in Japan were exploring possible investment opportunities into the hydrogen and hydrogen derivative industries that are currently evolving in the United States. Although no specific investment examples were given, it was recognized that stakeholders in Japan (both governmental and private sector) need to be encouraged by the recent developments in the U.S.-based hydrogen economy and foresee promising hydrogen and ammonia import opportunities from the U.S. by 2030 and 2050.

The projections of a cost-efficient primary energy supply for achieving net-zero emissions by 2050 in Japan were explored during the discussion, including specific percentages of: (i) oil with Carbon Capture, Utilization, and Storage (CCUS), (ii) gas with CCUS, (iii) ammonia and biofuel, (iv) renewable energy (i.e., solar, wind, hydroelectric, and geothermal), (v) biomass with CCUS (vi) synthetic methane, (vii) synthetic oil, and, (viii) coal with CCUS. Estimates of oil, gas, and coal without CCUS were also listed and were projected to be offset by Carbon Dioxide Removal (CDR) technologies. It was stated that within these estimates, hydrogen and hydrogen derivatives will make up 20% of the final energy supply in 2050 and will be a critical component towards Japan achieving carbon neutrality.

Panel Discussion: Position Paper Three
Role of Hydrogen Carriers for Global Decarbonization**

Shigeru Muraki
President, Clean Fuel Ammonia Association, Japan

Current realities

For the enhancement of maximum utilization of clean energy sources, it is crucial to develop efficient and feasible marine transportation methods for clean hydrogen. Currently, ammonia, liquefied hydrogen, methanol, and organic hydrides are considered potential hydrogen carriers.

Japanese industries are challenged to develop supply chains of ammonia, liquid hydrogen, and methylcyclohexane (MCH) with government support. Technology developments on supply chains of liquid hydrogen and MCH are underway, and developments of utilization technologies of hydrogen and direct combustion of ammonia are underway and well advanced.

The International Energy Agency (IEA) indicated that ammonia is likely the cheapest mechanism to transport hydrogen from Australia to Japan. A global, large-scale supply chain of ammonia has been developed in the fertilizer and chemical industries. In addition, ammonia can be directly used in various energy systems without CO_2 emissions, which has the cost advantage of eliminating dehydrogenation units. Therefore, ammonia is the most pragmatic and practical hydrogen carrier.

Clean hydrogen can be produced from various sources such as renewable energies, fossil fuels with carbon capture and storage (CCS), and nuclear energy. Currently, potential supplies of blue hydrogen and ammonia (i.e., produced from fossil fuels coupled with CCS) and green hydrogen and ammonia (i.e., produced using renewables) have been discussed and planned in various countries, and clean ammonia supplies will start during the 2020s.

Actionable next steps (ANS)

In the case of clean ammonia, the current estimated costs of blue ammonia production (natural gas Steam Methane Reformation (SMR) process with CCS and 60% CO_2 reductions) are \$300-\$400/ton which is equivalent to \$1.7-2.3/kg H2. The costs of green ammonia are \$600-800/ton, which is equivalent to \$3.4-\$4.6/kg H2. Shipping costs to Japan are \$30-\$60/ton depending on supply sites which is equivalent to \$0.17-\$0.34/kgH2. The scenario of the Hydrogen Strategy in Japan targets \$3/kg H2 in 2030, and \$2/kg H2 through 2050 as imported clean hydrogen. Blue ammonia costs will fluctuate with natural gas prices, however, ammonia may reach a target, economically viable price by 2030 in the U.S. and Middle East. Carbon intensity will be improved with minimum costs by technological advancement. Costs of green ammonia are currently high, but will gradually reduce through cost reductions in renewable energies and electrolyzers, potentially dropping as low as \$400/ton during the 2030s. In the early stages, green ammonia supply will start from small projects due to high capital costs, and the scale of supplies will be gradually expanded according to cost reductions.

Feasibility of a clean ammonia supply is essential for market development and steady transition toward carbon neutrality. Therefore, during early stages, blue ammonia will take a crucial role in reducing CO_2 emissions effectively and economically. Of course, green ammonia will play an important role together with lower carbon-intensified blue ammonia. Some potential sites of blue ammonia production will have the capability of introducing green hydrogen and eventually green ammonia, which is a practical solution to develop cost-effective green ammonia supply.

***** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Position Paper Three
Panel Discussion Summary

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and priorities, both in support and opposition, to points expressed by all those participating in the discussion.

Several stakeholders questioned the investment priority of hydrogen and ammonia-based energy, specifically the investment priority of ammonia produced via renewable energy sources (i.e., green ammonia) compared with ammonia produced via non-renewable sources with CCS (i.e., blue ammonia). In response, it was argued that due to the existing maturity of ammonia utilization (i.e., infrastructure, market, and transportation capabilities), investment into ammonia first, with plans to invest in hydrogen later, needs to be prioritized as ammonia has greater immediate potential to both increase GDP and lower CO_2 emissions in Japan. Regarding specific investment opportunities in green or blue ammonia, it was posited that investment in blue ammonia is a critical first step in the pathway to production and utilization of green ammonia, as it will enable the production of an ammonia fuel market, which will subsequently reduce the current high cost of green ammonia production in the long term.

Concerns were raised regarding the temporal implications of the transition from blue ammonia and hydrogen to green ammonia and hydrogen. It was asserted that to allow both hydrogen and ammonia to become economically viable options in the energy market, USD $54 billion is planned to be allocated to the development of hydrogen and ammonia supply chains over approximately 15 years. It is anticipated that USD $38 billion is planned to be allocated to supply chain development subsidies to close the gap between existing hydrogen and ammonia production (i.e., blue hydrogen and ammonia) and future green hydrogen and ammonia production.

Infrastructure development and logistical transportation costs were repeatedly mentioned as concerns in relation to increasing the scale of the ammonia market in Japan. It was mentioned that there are multiple pathways being explored in Japan to overcome infrastructure-related challenges, including industry-led plans to convert existing Liquefied Petroleum Gas (LPG) tanks to ammonia tanks, a conversion that would (i) allow the importation of ammonia into existing LPG terminals and (ii) support the development of a hub shipping terminal equipped to dispatch and receive large gas carriers (i.e., carrying more than 80,000 tonnes of ammonia). Both would subsequently lower the cost of importing ammonia from producing countries (e.g., United States, Australia, etc.).

Maritime transportation was considered an appropriate end-use application for ammonia fuel, but several other zero-emission fuels were also noted as options for the maritime fuel market, including methanol (i.e., bio-methanol or e-methanol to be considered a zero-emission fuel) and hydrogen itself. It was noted that when comparing the efficiency of maritime fuels, ammonia and methanol have lower energy content per cubic meter than existing bunker fuels. Hydrogen has an even lower energy density, requiring more than double the fuel volume to maintain consistent energy content. However, to advance decarbonization in the maritime sector, it was noted that the International Energy Agency (IEA) is exploring the potential of all zero-emission fuels and the respective sectors for which fuels could be both economically viable and efficient. It was stated that there is a basic consensus among the shipping industry that in the short term, bio-methanol and e-methanol will be best suited for cross-ocean, long-haul shipping (i.e., by way of bulk carriers and containers). In the long term, however, ammonia provides significant advantages as a fuel for maritime transport. It was stated that hydrogen would be best suited for small coastal shipping traveling short distances (i.e., powered by hydrogen fuel cell motors).

A common theme that arose from the discussion was the critical importance of the identification of specific methodologies for accurately quantifying the carbon intensity of various hydrogen and ammonia production methods. It was repeatedly expressed that carbon intensity of production methods must be viewed, evaluated, and interpreted based on an evidence-based scale. The use of the popular, but imprecise, color designations (e.g., green, blue, pink, etc.) currently given to different hydrogen and ammonia production methods needs to be replaced by a carbon intensity index.

It was also questioned whether life cycle analysis needs to be applied to future carbon intensity designations for hydrogen and ammonia production methods, specifically including upstream fugitive methane emissions. In response, it was noted that although Japan is collaborating with the U.S. on this challenge, there is no conclusive answer for methodologies that could be used to quantify all greenhouse gas emissions from the entire hydrogen and ammonia supply chain.

The globalized aspects of hydrogen and hydrogen derivative production, transportation, and trading were repeatedly discussed, with a focus on the critical need for the global harmonization of standards and certification schemes regarding the methodology of measuring the carbon intensity of hydrogen and ammonia production methods. It was argued that although harmonization of standards across a global landscape is important, the creation of hydrogen and ammonia supply chains and markets need to be given immediate priority. In the short term, it was suggested that the first steps in harmonizing standards among countries need to be accomplished through bilateral agreements, (e.g., Japan and the U.S. and Japan and Australia).

The development of an internationally standardized carbon intensity index accurately characterizing hydrogen and ammonia production, transportation, and usage methods was discussed. It was noted that the International Partnership for Hydrogen Fuel Cells and the Economy (IPHE) is developing methodologies to calculate the carbon intensity of hydrogen and ammonia throughout supply chains, including the development of carbon intensity calculation methodologies for hydrogen carriers.

The importance of safety precautions, specifically regarding ammonia, was emphasized throughout the discussion. It was mentioned that there are several health and safety risks associated with (i) carrying ammonia onboard a vessel (e.g., gas leak potential, high toxicity, high-pressure storage specifications) and (ii) combustion of ammonia fuel (e.g., novelty, lack of space in combustion engine rooms). All these factors were viewed as currently under review by shipping companies and international organizations (e.g., the International Maritime Organization).

The environmental risks of potential nitrogen oxide (NOx) emissions as a product of ammonia combustion were also stated as a concern. In response, it was stated that while ammonia combustion does produce NOx emissions, several Japanese corporations (i.e., IHI Corporation and Mitsubishi Heavy Industries) are developing technologies that can control NOx emission by the fuel-to-air ratio and two-stage combustion (i.e., improving ignitibility in fuel flame areas).

Plenary Panel Discussion Summary

This not-for-attribution summary was prepared by the ISGP staff from an audio recording and its transcription of the plenary discussion following the three 30-minute panelist sessions. This Plenary Panel Discussion Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by the three Panelists: Dr. Kazunari Sasaki, Dr. Keigo Akimoto, and Mr. Shigeru Muraki. Given the not-for-attribution format of the Plenary Discussion, the views comprising this summary do not necessarily represent the views of the panelists, as evidenced by their respective position papers. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the discussion.

Three topics were identified as essential to the transition to hydrogen and hydrogen derivative utilization: (i) fostering international coordination and harmonizing regulations, (ii) the identification and development of international standards for safety, carbon intensity, and trading specifications, and (iii) financing at the local, regional, national, and international levels for hydrogen energy infrastructure.

Several stakeholders emphasized the importance of the creation of a standardized carbon intensity methodology to encourage (i) carbon metric interpretability among countries, (ii) certification, accountability, and transparency in carbon reporting, and (iii) evidenced-based prioritization of investments in various hydrogen and hydrogen derivative production methods to aid in global decarbonization. A participant provided an example of the varying timelines needed to create standards at the local (i.e., approximately two years), regional (i.e., approximately four years), and international level (i.e., a minimum of eight years), and warned that conclusive scientific evidence to substantiate standards is needed to launch the development of these standards. In response, it was posited that the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) developed a classification system for hydrogen that would determine the greenhouse gas emissions associated with the production of hydrogen, however, the entity responsible for guaranteeing this classification needs to be identified.

Regarding the development of an international trading mechanism, it was suggested that the initial signing of bilateral trade agreements (e.g., hydrogen and ammonia trade agreement between Australia and Japan) would allow for the subsequent signing of multilateral trade agreements and would ultimately facilitate a global trading market for hydrogen and ammonia.

The creation of safety standards was also posited as a critical step in removing barriers to the adoption of hydrogen and hydrogen derivatives into the global energy mix *writ large*. It was further stated that while carbon intensity standards should be developed on an international scale (i.e., to allow for and encourage international trade), safety standards must remain locally dependent due to the vast differences between countries and regions (e.g., population density, building codes, energy consumption, natural disaster frequencies). It was acknowledged that while safety standards for the transportation, utilization, and storage of ammonia have been developed and continually revised (i.e., due to the use of ammonia in fertilizer and petrochemical industries for more than 100 years), hydrogen safety and overall usage standards remain largely underdeveloped.

Multiple stakeholders argued that energy transition financing and investment incentivization is a critical aspect in global energy transitions and overall decarbonization. Concerning the role of different sectors in investment schemes (e.g., government, private sector, and banks), it was expressed that investments need to be case specific to allow ongoing and attractive investment opportunities for low-carbon technologies, energy sources, and fuels. It was stated that most of the hydrogen and ammonia technology projects are unprofitable, which renders banks unable to finance these projects until their net revenue is positive. It was suggested that the public sector must incentivize hydrogen and ammonia-based projects by implementing subsidies (e.g., for technological development) to encourage additional investment from private sector financial sources. It was posited that to reduce the risk of stifling investment, carbon intensity certifications must be solely based on scientific evidence to ensure hydrogen and ammonia classifications do not become politicized.

The importance of monetizing carbon intensity and the emissivity of emerging and existing energy sources was emphasized repeatedly. It was stated that if the market places a premium on carbon-intensive energy sources and subsidizes low-carbon energy sources, the result will be an increase of clean fuels in global markets.

Position Paper One
Competitive Costs and Market Issues Related to Hydrogen Energy**

Masakazu Toyoda
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Summary
No energy is perfect, and renewable energy is not an exception. Clean hydrogen will have to play an important role and will be produced by multiple methods, such as utilizing renewable energy, fossil fuels, and nuclear energy. Each method has advantages and disadvantages in terms of cost, supply volume, and supply stability. It is the responsibility of the current generation to diversify decarbonization options.

Current realities

While global concern about climate change grows, atmospheric greenhouse gasses continue to increase due to the eruption of the Russo-Ukrainian war and increased use of coal to make up for the lost supply of Russian natural gas.

It is evident that the mainstay of decarbonizing energy systems is the production and utilization of renewable energy. However, it is difficult to realize carbon neutrality at a sufficient scale and speed with renewable energy alone. First, most of the energy generated by renewable energy sources is in the form of electricity, which accounts for only a small fraction of final energy consumption. This share was about 20% of the global average in 2020. This percentage will grow in the future, but stands at approximately 50% even as of 2050 in the Net Zero Scenario (NZS) by the International Energy Agency (IEA). Second, like fossil fuel resources, the distribution of renewable energy resources is geographically uneven (**Figure 1**). Large differences in cost burdens will occur by region if decarbonization is pursued only with renewable energy. Third, even if a region has abundant renewable energy resources, other factors, such as the cost of grid integration, public acceptance (e.g., opposition from local residents), and availability of critical minerals may hinder their introduction.

It will be difficult to decarbonize in the future using renewable energy alone, and clean hydrogen produced from a variety of decarbonized production methods (e.g., fossil fuel with carbon capture, utilization and storage (CCUS), renewable energy, nuclear energy) will have to play an important role in complementing the limitation of renewable energy.

Scientifically and technologically credible approaches and challenges

Since hydrogen gas rarely exists as an available natural resource, it must be synthesized to be utilized as an energy source. There are multiple methods for its production (e.g., extracting hydrogen from fossil fuels with CCUS, electrolyzing water with renewable energy and nuclear energy). Each method has its own advantages and disadvantages (**Table 1**). It is desirable for each country and region to optimally combine various types of hydrogen production according to the size, location, and sector of hydrogen demand as well as resource availability for hydrogen production.

It is not appropriate to exclude fossil fuel-based hydrogen from supply options solely because it is made from fossil fuels. First, the biggest challenge to expanding the use of hydrogen is to create a supply chain encompassing production, transportation, and utilization. To solve the "chicken and egg" problem over infrastructure development and physical supply the "quantity" of hydrogen should first be secured at the lowest possible cost. Considering the uncertainty of technological developments and public acceptance, fossil fuel-based hydrogen, which has low technological and economic risks and can be produced at scale, needs to be utilized to facilitate investments in hydrogen supply infrastructure. Second, the problem of CO_2 emissions associated with producing hydrogen from fossil fuels can be solved. Although existing fossil fuel-based hydrogen production captures only about 60% of CO_2 produced, advanced production technologies (e.g., auto-thermal recovery) have been projected to enable 95% CO_2 recovery. The remaining few percent of emissions can be offset through a combination of negative emissions (e.g., afforestation, direct carbon capture from air). Third, the current high price of fossil fuels will not last forever. The current price hike was caused by a series of unusual events, including sudden post-pandemic economic recovery and the Russia-Ukraine war. One potential outlook suggests that despite the ongoing climate actions and the recent price hike, oil and natural gas will remain the main source of primary energy in 2050.

Evidence-based options (EBO) and actionable next steps (ANS)

The key to energy policy is to balance safety, energy security, environment, and economic competitiveness (S+3E), and the principle for hydrogen supply is to build a safe, stable, sustainable, and affordable supply system. Actionable steps to achieve this objective include:

- Allow a variety of hydrogen supply options based on a scientific and objective approach. At this stage, it is impractical to rely only on hydrogen produced using renewable energy sources, which remains somewhat uncertain in terms of cost, supply volume, and supply stability. In consideration of future generations, it is the responsibility of the current generation to diversify decarbonization options, including decarbonized uses of fossil fuels and nuclear power.
- Determine the “eligibility” of hydrogen as a decarbonizing fuel based on its carbon intensity instead of its production method. There are various types of potentially eligible fossil fuel-based hydrogen supply projects, depending on their carbon footprint.
- Develop and implement government policies and support mechanisms based on the carbon intensity of individual private sector projects to motivate businesses to supply cleaner hydrogen.
- Provided governmental policy support based on market mechanisms. In the upstream side of the supply chain (i.e., production and transportation), public financial support may be needed to supplement and de-risk initial investments, which are comparatively large. On the procurement side, the government can guarantee long-term supply contracts through a bidding process (e.g., similar to Germany’s H2Global system). On the end-user side, while regulatory arrangements may be an option because of their relatively low administrative cost, market-based types of policy frameworks (e.g., contract for difference and feed-in-premium) are preferable as they can be flexibly adjusted in accordance with the developments of the market.

References

Mackintosh J. “German wind power cable sparks protests,” DW. April 22, 2019. https://www.dw.com/en/germany-protesters-oppose-suedlink-wind-energy-cable/a-48437451. Accessed on February 11, 2023; Akita N, Ohe Y, Araki S, Yokohari M, Terada T, Bolthouse J. Managing Conflicts with Local Communities over the Introduction of Renewable Energy: The Solar-Rush Experience in Japan. Land. 2020; 9(9):290. https://doi.org/10.3390/land9090290.

Pettersen, J, Steeneveldt, R, Grainger, D, Scott, T, Holst, L-M, Hamborg, ES. Blue hydrogen must be done properly. Energy Sci Eng. 2022; 10: 3220- 3236. http://doi:10.1002/ese3.1232

ExxonMobil, “Energy Demand: Three Drivers.” October 22, 2023. https://corporate.exxonmobil.com/energy-and-innovation/outlook-for-energy/energy-demand. Accessed on February 18, 2023.

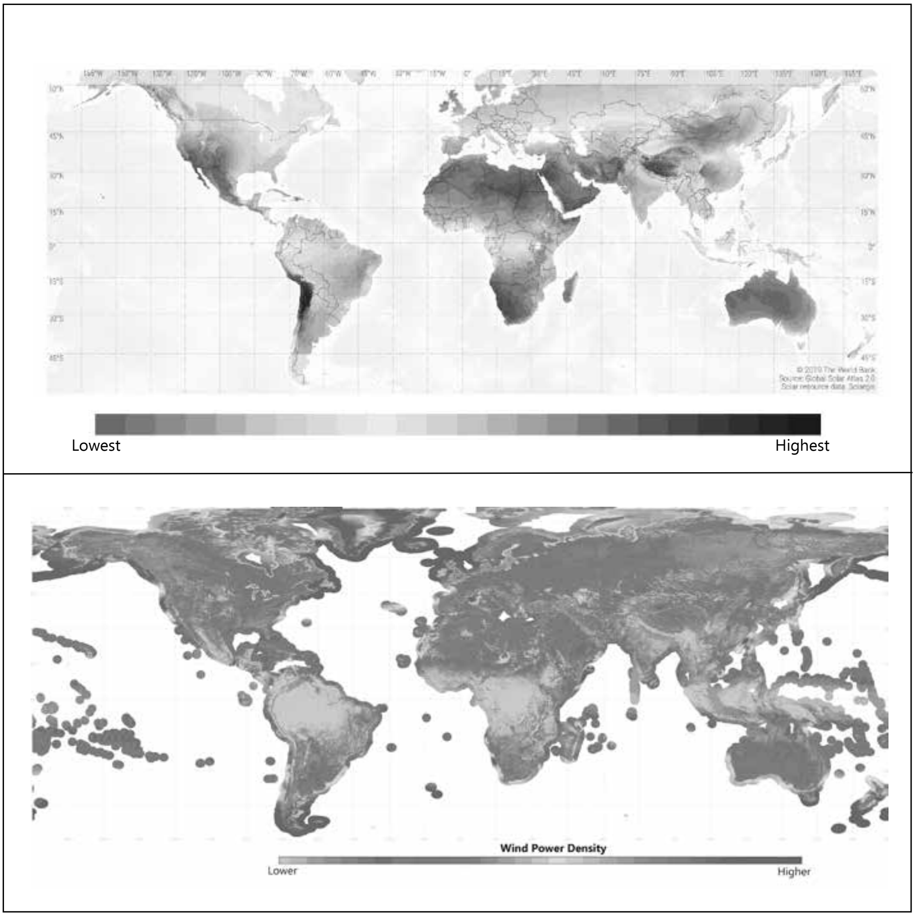
***** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Table 1. Hydrogen production methods and their pros and cons

Feedstock	Pros	Cons	Cost as of 2020	Estimated cost as of 2050
Fossil fuel	Technologically matured; Cost competitive (Figure 2); Stable and large-scale production at a single site **Abundant feedstock**	A few percentages of CO_2 emissions even after CCS **Limited room for cost reduction** compared to electrolysis	$3.0/kg (SMR with CCS)	$2.0+/kg (SMR with CCS)
Renewable energy (Wind and solar)	No CO_2 emissions **Cost reduction potential** (Figure 3) Excess electricity can be utilized.	Current cost is high. Public acceptance issues such as opposition from the local community **Small production volume per site** and requires **additional cost for aggregation**.	$5.0/kg (Electrolysis)	$2.0/kg (Electrolysis)
Nuclear	No CO_2 emissions **Stable production**	**Cost is likely to be high as of 2050** Technological limitations (in case of high-temperature reactor) Public acceptance	$5.0/kg (Electrolysis)	$3.0+/kg (Electrolysis)

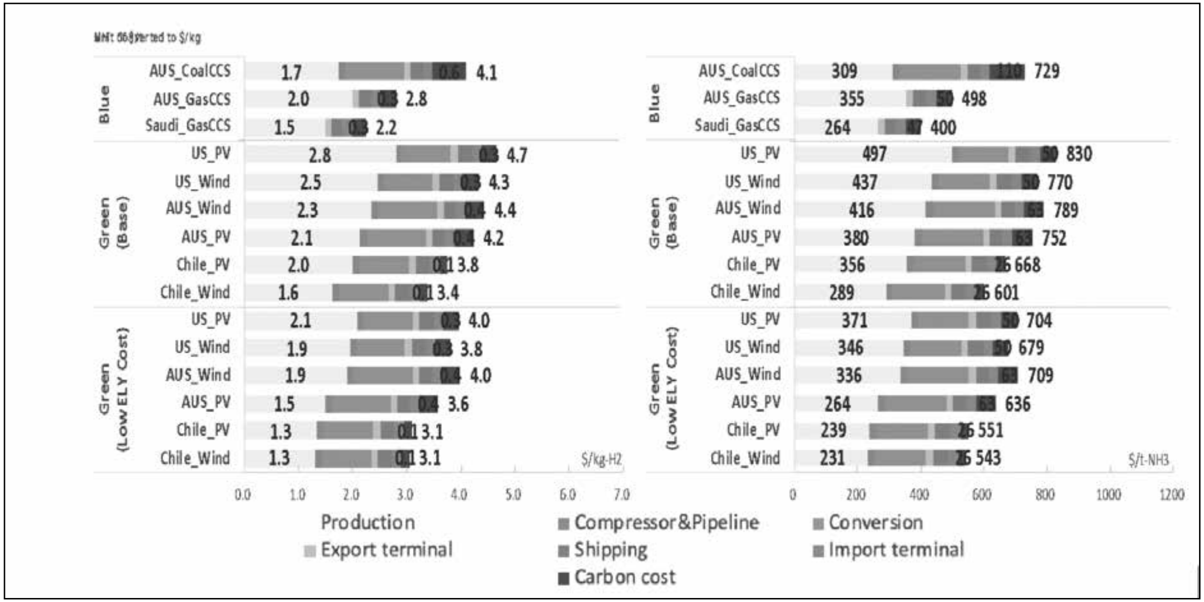
SMR: Steam methane reforming process; CCS: Carbon capture and storage
Source: DNV, *Hydrogen Forecast to 2050*. June 2022 for cost figures.

Figure 1. Geographical distributions of renewable energy resources Solar top; bottom wind.



Source: Global Solar Atlas (https:globalsolaratlasinfomap?c=11.005904,10.195313,2); Global Wind Atlas (https://globalwindatlas.info/en)

Figure 2. Hydrogen supply cost to Japan as of 2030 - considering C.Price ($100/t-CO2)

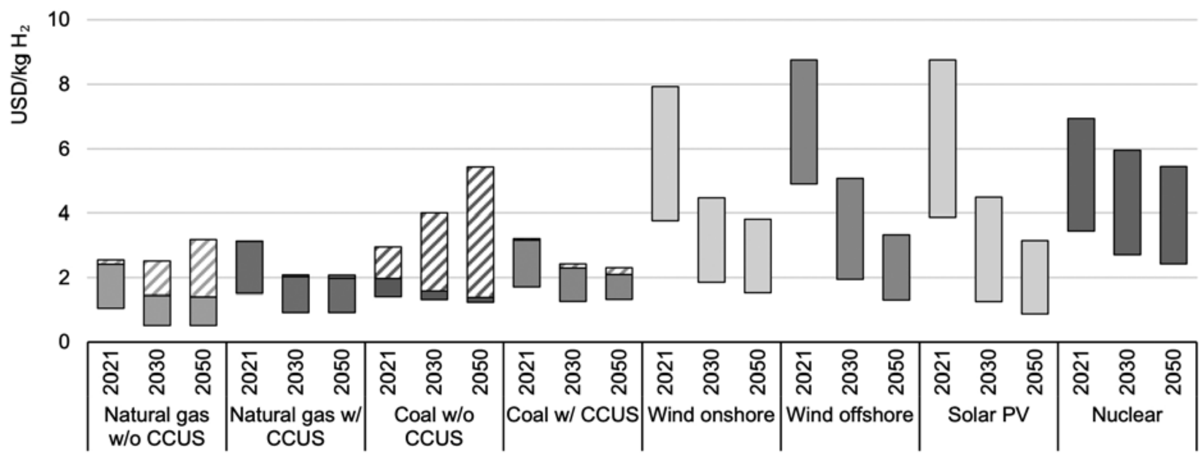


Source: Institute of Energy Economics, Japan. "Study on the Economics of the Hydrogen"

Figure 3. Hydrogen production cost by different sources and methods

Opportunities for cost reductions to produce low-emission hydrogen

Levelised cost of hydrogen production by technology in 2021 and in the Net Zero Emissions by 2050 Scenario, 2030 and 2050



Notes: Ranges of production cost estimates reflect regional variations in costs and renewable resource conditions. The dashed areas reflect the CO_2 price impact, based on CO_2 prices ranging from USD 15/tonne CO_2 to USD 140/tonne CO_2 between regions in 2030 and USD 55/ tonne CO_2 to USD 250/ tonne CO_2 in 2050.

Sources: Based on data from McKinsey & Company and the Hydrogen Council; Council; IRENA (2020); IEA GHG (2014); IEA GHG (2017); E4Tech (2015); Kawasaki Heavy Industries; Element Energy (2018).

Source: International Energy Agency. *Global Hydrogen Review 2022*.

Debate One Summary

TOPIC: Competitive costs and market issues related to hydrogen energy

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Masakazu Toyoda (see position paper above and author biographical information in the Appendix). Mr. Toyoda initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Masakazu Toyoda and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Toyoda, as evidenced by his position paper. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

The debate focused largely on the economic aspects of the developing hydrogen economy and how the economic viability of low-carbon energy sources can be improved through market mechanisms, investments, and targeted government support. It was stated that, to accelerate the wide-scale adoption of hydrogen and hydrogen derivatives, there needs to be targeted support on the upstream (i.e., hydrogen production, Carbon Capture, Utilization, and Storage (CCUS)), midstream (i.e., transportation), and downstream (i.e., end-use application, demand, market creation) aspects of how hydrogen energy is introduced into the global energy system.

It was specifically suggested that governments need to subsidize hydrogen and hydrogen derivative production to improve the economic viability of demand and consumption. Additionally, the German H2Global initiative of 2021 (i.e., a model aimed at compensating the difference between supply prices and demand prices with grant funding from the German government) was referenced as a “matchmaking mechanism” (i.e., a system that aggregates producers and consumers). It was questioned how the initiative may be applicable to Japan considering (i) temporal scales, (ii) organization structures unique to Japan, and (iii) the stakeholder profile that might interact with the mechanism. In response, it was stated that the Japanese economic model differs from those in other countries due to its strong reliance on imported energy (i.e., nearly 90% of current energy consumption). It was posited that several groups of stakeholders will likely interact with these types of mechanisms, including oil and gas companies and renewable energy producers, but will most notably attract power generation companies in Japan due to the hydrogen and ammonia energy targets set within the Strategic Energy Plan created by the Japanese Government.

The challenges of implementing market-based policies for low-carbon hydrogen within the Association of Southeast Asian Nations (ASEAN) member countries (i.e., Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam) alongside potential for economic disadvantages was considered a concern, in addition to the potential rise in overall energy prices. In response, it was asserted that no definitive predictions for the future cost of any energy source can be made, and the importance of approaching energy transitions *writ large* on a technologically neutral basis was emphasized. Furthermore, the utilization of information-sharing platforms provided by various international organizations (e.g., International Energy Agency, International Renewable Energy Agency, etc.) was strongly asserted to be a critical component in encouraging global energy transitions away from fossil fuels.

Amongst discussions regarding technological neutrality and the viability/ methodology of "green" hydrogen production (i.e., produced using renewable sources) was vigorously debated. It was widely acknowledged that the focal barrier to the development of a global hydrogen market and wide-scale implementation and adoption of green hydrogen is cost. Green hydrogen production costs currently cannot compete economically with existing energy sources (e.g., fossil fuels) and fossil fuel-based hydrogen production methods. Based on the cost barrier of green hydrogen adoption, it was questioned what methods could accelerate the cost reduction of green hydrogen production. In response, it was stated that the utilization of hydrogen produced by fossil fuels coupled with CCUS (i.e., blue hydrogen) is a critical component to the eventual scale-up of green hydrogen production and will allow for investment into hydrogen-specific infrastructure and market creation. It was noted that increased investment and advancement of electrolyzer technology and production will be an important element in reducing green hydrogen production costs.

Several debaters raised questions about less common avenues of green hydrogen production, specifically, the utilization of hydroelectric power and biomass gasification methods. It was stated that hydroelectric power could be harnessed by electrolyzers to produce green hydrogen, and that some Asian regions (e.g., Laos and East Malaysia) are equipped with substantial hydropower resources. Hydrogen produced by biomass gasification was also discussed, however, it was contended that biomass gasification still produces carbon dioxide (CO_2) emissions and would therefore require CCUS in order to contribute to decarbonization efforts.

It was stated repeatedly that, to make decisive progress towards decarbonization, clear goals need to be set for hydrogen and ammonia production transitions from blue to green. It was warned that if the goal of the Japanese government is to reduce the worsening impacts of climate change through emission reductions, blue hydrogen and ammonia will likely add to emissions by both prolonging the use of fossil fuels and requiring the need for increases in energy production overall. This unfortunate consequence is due to the lower energy content of hydrogen compared to existing fuels (i.e., coal, gas, and oil.)

It was questioned whether policymakers need to prioritize investments into CCUS or invest in the advancement of renewable energy capabilities, thus influencing production capabilities of blue and green hydrogen, respectively. Throughout the debate, the capability and efficacy of CCUS were called into question, leaving little consensus on the fruitfulness of further CCUS investments. For CCUS to be effective, it is essential that carbon capture rates of 90%–95% be credibly demonstrated as practical under conditions where hydrogen is produced at scales commensurate with global energy requirements. In response, it was stated that a mixture of financial incentives for producing and importing green hydrogen in conjunction with the deployment of CCUS could foster an environment in which both green and blue hydrogen are utilized. Currently, there is a much larger supply of blue hydrogen, which is significantly less expensive than green hydrogen. According to comments posited by a debater, Germany is reconsidering its green hydrogen-focused endeavors due to limited supply in the European region. It was discussed that, considering hydrogen shortages and high prices, a greater supply of both green and blue hydrogen is needed prior to investing primarily in green hydrogen.

To continually address the climate crisis while employing blue hydrogen by reaching low carbon thresholds, it was suggested that CO_2 and methane emissions upstream need to be taxed. Taxing upstream emissions could eventually drive down greenhouse gasses emitted during production. However, the question regarding premiums on natural gas prices used for low-carbon hydrogen was repeatedly raised in response.

Despite suggestions that investments in blue hydrogen should continue due to its economic favorability in comparison to green hydrogen, it was repeatedly questioned whether the goals to reduce CO_2 emissions overall should be prioritized due to the substantial, destructive impact of climate change on communities around the world. The underperformance of carbon capture and equipment failures (i.e., CCUS plant breakdowns) underlies increasing concerns by stakeholders focused on the validity of carbon reduction efforts. Although carbon offsets (i.e., the removal of CO_2 in one production process to compensate for emissions elsewhere) and other techniques for reducing the climatic impacts of more carbon-intensive hydrogen production (e.g., direct air carbon capture) were mentioned, it was acknowledged that some of these efforts and technologies are not yet sufficiently developed to be both economically viable and effective.

Carbon capture in power plants was noted to have demonstrated capabilities that reach 97%–98% efficacy in certain reports. It was contended, however, that there is persisting concern regarding CO_2 storage or utilization methods after it has been captured, as only a few countries are purportedly currently able to sequester captured CO_2 underground. It was posited that countries lacking in sequestration capabilities (e.g., Japan) would benefit from cross-country collaborations with countries capable of carbon storage or utilization to which captured CO_2 could be exported. Without keeping the carbon from entering the atmosphere, carbon capture does not positively by itself control the negative impacts on the environment globally.

The role of policy regarding its impact on the cost-effectiveness of green and blue hydrogen was identified as an area of opportunity. Currently, the United States is an example of a country with a specific policy that reduces the price of green hydrogen by offering financial incentives "per kilogram of clean hydrogen," thus making it more economical than blue hydrogen and encouraging decarbonization efforts. It was suggested that other countries (e.g., Japan, China, European countries, Australia, etc.) could also adjust their economic policies to reduce the price of green hydrogen. It was further suggested that international collaboration could foster further technological and policy developments to reach climate goals.

It was noted that the inclusion of methane, upstream fugitive methane emissions, and other elements of a full lifecycle analysis are imperative issues to be included in any analysis used for accurate carbon pricing based on volume of emissions.

Participants questioned whether carbon risk in market mechanisms needs to be acknowledged, and which stakeholders are best placed to accept that risk. It was suggested that governments play a critical role in balancing carbon intensity and cost. Currently, there is no standard timeline for achieving carbon neutrality, although many countries are seeking to decarbonize by 2050, according to the Net Zero Coalition set out by the United Nations. Conversely, the balance between carbon intensity and cost is more difficult for emerging economies which may not be able to resource the high costs for lower carbon intensity within a limited timeframe. Finally, it was posited that balancing carbon intensity and cost largely depends on country-specific policies, although the absence of standardization could prove restrictive to the global effort toward decarbonization.

It was acknowledged that Japan still produces approximately 71% of its electricity from fossil fuels, most notably from coal and gas. Furthermore, 1 kilowatt-hour (kWh) of energy produced by wind or solar would displace 7 Million British Thermal Units (MMBtu) of natural gas. In comparison, when used for hydrogen, the same methods would displace only 2 MMBtu of natural gas. Considering Japan's position as a major importer of natural gas, it was questioned whether Japan needs to prioritize the decarbonization of the electricity grid rather than focus on hydrogen energy. Concerns were also raised regarding Japan's ability to both decarbonize its electricity grid and utilize blue hydrogen at the same time.

In response, it was recognized that Japan primarily prioritizes cheap energy, regardless of its carbon intensity. Currently, stakeholders (e.g., national governments, energy suppliers, etc.) are focusing on keeping a variety of energy options available for consumers. Nuclear-produced hydrogen (i.e., "pink hydrogen") is becoming an increasingly attractive option due to its low carbon intensity. However, it was noted that uncertain societal acceptance amongst the Japanese population needs to be considered, especially considering historically low approval for nuclear projects following the 2011 Fukushima Disaster. Japan can employ nuclear reactors domestically, decreasing its dependence on imported energy derived from fossil fuels. It was contended that using nuclear energy to produce hydrogen displaces less natural gas imports than using nuclear energy directly. However, recognition was given to hard-to-abate industries in which less carbon-intensive hydrogen would allow for decarbonization efforts. Given the current climate crisis, it was stated that there is a need for recognition that this is both a "cost and climate" issue, ultimately delegitimizing the claim that Japan should solely rely on the most cost-effective energy option.

It was repeatedly acknowledged that, as a "pioneering country" for hydrogen adoption, Japan is positioned to have ample opportunities for hydrogen technology deployment. Subsequently, it was suggested that diversifying hydrogen technology options could prove beneficial for Japan as uncertainty remains regarding global technology production competition and general regional stability. However, a lack of consensus on technology choice and development uncertainties regarding CCUS presents an area of contention in Japan, considering the foreseeable uptake of blue hydrogen in Japan and surrounding regions.

It was repeatedly mentioned that currently estimated timelines of 20–30 years to develop viable hydrogen infrastructure are not sufficient to meet recent Intergovernmental Panel on Climate Change (IPCC) reports that suggest that 60% of CO_2 emissions must be reduced to prevent the international 1.5°C degree rise target. Additionally, studies reporting the amount of CO_2 that must be reduced, and the time in which global emitters must do so, often shifts forward, creating accelerating timelines. It was stated that climate targets with hydrogen technology could be achieved by an international harmonization of regulation and permissible carbon-intensity standards. Furthermore, accurately priced carbon could promote market uptake, thus encouraging actions that could contribute to CO_2 emissions reduction.

It was questioned whether the risk of reducing investment in new fossil fuels is considered in the commitment to fossil fuel-produced hydrogen and hydrogen derivatives. In response, it was suggested that cost-effective blue hydrogen may help provide the necessary finances to eventually allow investment into green hydrogen, ultimately lowering its cost. Considering regional constraints (e.g., limited renewable infrastructure), initiating the transition with investments in blue hydrogen could potentially allow for a quicker transition. It was widely agreed upon that the goal of the energy transition is to reduce CO_2 emitted into the atmosphere.

Position Paper Two
Blue vs. Green Ammonia: A Path Toward Energy Resilience and Carbon Neutrality**

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Summary

Ammonia has an important role to play in reaching carbon neutrality, particularly for countries such as Japan that are dependent on imports for their energy needs and where the cost of renewable energy is high. Ammonia can be used not only as a hydrogen carrier, but also as a fuel. Currently, the production of ammonia using renewable energies (i.e., "green ammonia") is more expensive than the production of "blue ammonia," which entails coupling carbon capture and storage (CCS) technologies with processes for producing ammonia from non-renewable sources. From a cost perspective, it may be practical for countries dependent on energy imports to initially import blue ammonia and gradually switch to green ammonia importation in the long term as competitive renewable energy technologies develop. The key challenges for facilitating this transition will be: (i) producing cost-competitive blue ammonia, and (ii) securing sufficient quantities of ammonia to meet energy needs. In addressing these issues, it is important to consider the different benefits of potential ammonia production sites and to diversify ammonia production sources to reduce the risk of supply disruptions and increase energy resilience.

Current realities

Japan, South Korea, and Taiwan are large energy consumers that rely heavily on imports to meet their energy needs. In Japan, the self-sufficiency rate (i.e., the percentage of primary energy resources needed to accommodate public consumption and economic activities that can be produced or purchased domestically) was 12.1% in 2019, while South Korea's was 17.7% in the same year. Even if these countries meet their ambitious targets to become carbon-neutral by 2050, their import dependency is unlikely to change due to the limited installed renewable power plant.

Hydrocarbons, particularly natural gas, are more expensive in these countries compared with North America and the Middle East because of the import cost. This means that producing "blue" hydrogen and ammonia from natural gas combined with CCS technologies is comparatively more expensive in Japan, South Korea, and Taiwan. Renewable energy is also more expensive in these countries than in other parts of the world due to various factors including limited land areas, and limited natural capacity to produce wind, solar, and other renewable sources. As a result, "green" hydrogen/ammonia produced from renewable energy sources is also more expensive.

As these countries seek to increase their renewable energy capacities, securing backup energy to manage the intermittent nature of renewable power is critical. Currently, a natural gas power plant is used as a buffer in Japan to absorb fluctuations in the energy supply caused by the volatility of renewable energy sources; however, low-carbon fuels, such as ammonia and hydrogen, will need to gradually replace natural gas to reduce greenhouse gas emissions.

Under these circumstances, ammonia can serve as both an effective hydrogen carrier and a fuel in the region. The government of Japan has announced in its "Sixth Strategic Energy Plan" that 1% of the overall power energy portfolio will be constituted from hydrogen and ammonia by 2030, equivalent to 3 million tonnes of ammonia. South Korea has also stated in its "Tenth Basic Energy Plan," that it aims to consume 5 million tonnes of ammonia by the same year. However, there are challenges to overcome, including the consistent production of cost-competitive ammonia and the need to secure sufficient quantities of ammonia to meet the energy needs in these countries.

Scientifically and technologically credible approaches and challenges

According to the Fuel Ammonia Supply Chain Public-Private Task Force of the Ministry of Economy, Trade and Industry (METI) Japan, assuming a natural gas price of $3/Metric Million British Thermal Unit (MMBtu) in North America and a depreciation period of 15 years, the cost of ammonia exported from North America to Japan (CFR) is $410, $23.3/MMBtu (Lower Heating Value).

Green ammonia production is more expensive than blue ammonia production due to the high cost of renewable energy production, land requirements for renewable energy facilities, and lack of infrastructure for green ammonia production and transportation. When the electricity price is ¢3/kilowatt-hour (kWh), it is equivalent to $8.8/MMBtu, almost three times more expensive than the current feedstock price of blue ammonia. In addition to greater energy costs, renewable energy plants require much more land than fossil fuel plants.

Several regions and countries have favorable conditions for the scalable production of cost-competitive blue hydrogen that can contribute to meeting energy needs in areas that are less likely to establish large ammonia production industries (e.g., Japan, Korea, Taiwan). The Middle East benefits from (i) competitive and abundant gas supply, as well as (ii) the expectation of governmental support due to alignment between state governments and national oil companies. The United States has a high potential for CCS and enhanced oil recovery (EOR) for large-scale production of blue ammonia, and legal frameworks for implementing CCS/EOR have been established. According to the "GLOBAL STATUS OF CCS 2022," the U.S. has 13 CCS/EOR projects in operation, the highest number of CCS projects in a single country in the world, and their total capacity of CO_2 recovery was 19.82 million tonnes per year. At present, there are 66 CCS/EOR projects planned, and the total CO_2 capture capacity of these projects is more than 75.31 million tonnes per year. In addition to this CCS/EOR potential, the Inflation Reduction Act in the U.S., including Section 45Q (i.e., a scheme that provides tax credits based on the amount of CO_2 stored/used) and Section 45V (i.e., a scheme that provides tax credits based on the amount of hydrogen produced), is an advantage for reducing the cost of producing blue ammonia in the United States, Australia, as well as Asian countries (e.g., Indonesia) have more competitive freight rates to Japan, South Korea, and Taiwan due to proximity.

Given the challenges that Japan, South Korea, and Taiwan face in transitioning to a carbon-neutral society, it may be practical for these countries to import blue ammonia as a first step and gradually switch to green ammonia importation in the long term, as the latter option is currently more expensive due to the high cost of renewable energy sources and electrolysis. However, as the cost of renewable energy sources is expected to decrease in the future, green ammonia may eventually become more competitive with blue ammonia.

Evidence-based options (EBO) and actionable next steps (ANS)

- Analyze potential production sites with a focus on cost reduction benefits, with particular emphasis on researching the advantages that different regions offer for reducing the cost of blue ammonia production (e.g., low price of natural gas, government incentives, proximity to Japan).
- Conduct an economic cost/benefit analysis of producing blue ammonia in each region.
- Develop ammonia production projects at economically and geographically viable sites in several different regions (e.g., Middle East, United States, Australia, Asia) for reducing dependence on a single specific country/region and creating a resilient supply chain for blue ammonia at a competitive price.

- Adopt a comprehensive approach to energy security like Japan's energy policy of "Three Es, Plus S" (i.e., energy security, economic efficiency, environmental sustainability, and safety).
- Promote Research and Develop of ammonia technologies (e.g., ammonia cracking to hydrogen, ammonia combustion co-firing) to uncover and raise demand for blue ammonia in various kinds of industries.
- Prepare ammonia distribution infrastructure (e.g., pipelines, vessels for shipment, storage tank) for large-scale ammonia import.

References

Ministry of Economy, Trade and Industry, Japan. (2022, February). *JAPAN'S ENERGY*. Retrieved March 6, 2023, from https://www.enecho.meti.go.jp/en/category/brochures/pdf/ japan_energy_2021.pdf

Fuel ammonia supply chain public-private task force. (2022, September). *Fuel ammonia supply cost analysis (Interim report)*. Retrieved March 6, 2023, from https://www.enecho.meti.go.jp/en/ category/brochures/pdf/japan_energy_2021.pdf

GLOBAL CCS INSTITUTE. (2022, November). *GLOBAL STATUS OF CCS 2022*. Retrieved March 6, 2023, from https://status22.globalccsinstitute.com/wp-content/uploads/2022/11/Global- Status-of-CCS-2022_Download.pdf

***** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Debate Two Summary

TOPIC: Scalability and practicality of local production vs. importation

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Koji Hosono (see position paper above and author biographical information in the Appendix). Mr. Hosono initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Hosono and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not

necessarily represent the views of Mr. Hosono, as evidenced by his position paper. Rather, it is, and should be read as an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

The "color" of ammonia (i.e., blue, green, etc.) that could most suitably be utilized as a fuel carrier was a primary point of discussion throughout the debate, although no clear consensus emerged. Many debaters noted that the cost of blue, green, or other colors of ammonia would be the primary driver in which private sector stakeholders will need to consider before investing on energy projects. To reach these points of decision, accurate cost-benefit analyses are essential. A few debaters suggested that ammonia fuel pricing needs to be established as a separate market from the existing market of ammonia in the petrochemical and fertilizer industry in order for the transportation and utilization of ammonia to be cost-effective. Furthermore, it was asserted that pricing needs to be based on a cost-plus analysis (i.e., all fixed and variable costs including producing, transporting, and storing) to ensure stability in supply, demand, and pricing for consumers. It was also noted that the initial return on investment in the fuel ammonia market would be low and is estimated to have an internal rate of return of about 10%, as opposed to the ideal 20%-30%. It was countered by multiple participants that any cost-benefit analysis of blue versus green hydrogen and ammonia needs to include the societal benefits of a transition away from fossil fuels and reduction in greenhouse gas emissions (GHGs) that drive the current global climate crisis. While it was agreed that private sector funders would be primarily concerned with the financial cost and return on investments, the societal benefits of green hydrogen and ammonia warrant government subsidization to reduce the effects of energy production and usage on climate change.

It was widely agreed upon that the reduction of GHGs was a top priority and, therefore, a number of participants agreed that green hydrogen and ammonia were preferable to their blue alternatives due to the societal costs associated with emissions, and urgency of addressing climate change. Several participants shared their preference for blue hydrogen and ammonia but noted that it would act as an initial step towards an ultimate goal of a full transition to green hydrogen and ammonia production and utilization. A timeline for this transition from blue to green hydrogen and ammonia was estimated to be about 10 years to allow for technology advancements and cost reduction. A few participants expressed doubt that green hydrogen and ammonia production and technology will become more cost-effective over time if most current investments are providing financing and subsidies for blue ammonia. In response, it was posited that stakeholders need to invest in both blue and green hydrogen and ammonia in the early stages of the energy transition to establish a viable market for green hydrogen and ammonia.

It was repeatedly acknowledged by many participants that a scale of carbon intensity needs to be used in place of the current color system to accurately determine emissions associated with each hydrogen and ammonia production method. Much of the doubt cast on the color system was relating to the current lack of consideration for whole of life cycle emissions, (i.e., emission-intensity measured across the entire lifespan of an energy product including production, transportation, utilization). It was also posited that additional colors of hydrogen and ammonia (e.g., pink, white, yellow) persist in current discussions, although no further comments were made regarding the use of other colors of hydrogen and ammonia.

One proposal that emerged from the discussion was the use of carbon capture, utilization, and storage (CCUS) technology to mitigate the greenhouse gas emissions of blue hydrogen and ammonia. It was indicated that CCUS technology could be an attractive initial option for producers as the financial costs of transitioning directly to green hydrogen and ammonia is not economically competitive. Many participants expressed concern about the practicality and scalability of CCUS in terms of technological capability, storage capacity, and cost. Several debaters countered that utilizing CCUS to reduce the GHG emissions of blue hydrogen and ammonia is not currently feasible due to the limited physical capacity to store carbon, therefore increasing storage costs. Consequentially, the usage of blue hydrogen would be more expensive and subsequently encourages initial investments into green hydrogen and ammonia over blue. It was further argued that, due to the finite amount of carbon storage space globally, CCUS is not a sustainable option and is only useful in the short term. It was additionally contended that CCUS technology has not yet advanced to the point where it is accessible or practical on a large scale. Doubts surrounding the utilization of CCUS technologies to reduce GHG emissions of blue hydrogen and ammonia were countered as the United States has significant carbon storage capacity in several regions (e.g., Texas, Appalachian Mountains). It was expressed by many participants that the significant role of CCUS in the broader decarbonization discussion needs to be questioned, and further evaluation of the scalability of CCUS technology is needed.

Several debaters further questioned which stakeholder group needs to be held responsible for the utilization of CCUS to reduce greenhouse gas emissions, as well as the role of international policies in regard to the sequestration and storage of carbon from the atmosphere. It was suggested that the responsibility of CCUS falls on the governments of energy producing and exporting countries. Said governments would need to (i) enact safety standards to ensure the sustainability of carbon storage and prevent potential leakage, (ii) codify policies that place the responsibility of managing CCUS initially on private companies producing the energy, then transfer the long-term management of carbon storage to local governments for long-term sustainability, and (iii) subsidize and encourage the use of CCUS and similar technologies that reduce GHG emissions and mitigate the effects of climate change. It was also posited that the Inflation Reduction Act of 2022 in the United States (i.e., subsidizes the use of less greenhouse gas-intensive energy) encourages U.S. energy producers to lower the cost of less carbon-intensive energy exported to other countries.

The scalability of the hydrogen and ammonia market throughout Japan, and internationally, emerged as another concern for debaters, alongside the need for government incentives to transition away from fossil fuels in the energy sector was repeatedly stressed. It was further noted that blue ammonia is only one potential option, and the establishment of a sustainable and cost-effective energy market with reduced greenhouse gas emissions is essential. Innovation in ammonia production solely utilizing renewable energy is not expected to be viable until around 2030, and production methods of hydrogen and/or ammonia will require a higher energy input than fossil fuels. A major challenge of the energy transition identified by debaters is the committed costs of existing fossil fuel infrastructures along with the cost of establishing infrastructure for the importation, distribution, and use of hydrogen and ammonia as fuel. It was expressed that the responsibility falls on governments to subsidize initial investments, with private sector stakeholders bearing most of the financial burden.

It was questioned whether existing fossil fuel infrastructure could be converted to support the use of hydrogen and hydrogen derivatives in the production of energy. Concerns were raised whether the promotion of using blue hydrogen and ammonia is being utilized to simply prolong the use of coal and fossil fuels, but it was indicated that utilizing existing power plants is an important step towards increasing demand and creating a viable market for hydrogen and ammonia. It was recommended by one participant that the best course of action is to process and supply ammonia through existing power plants before allocating major investment into the development of new structures, which stakeholders may be hesitant to establish due to large overhead and capital costs. Utilizing ammonia within current fossil fuel infrastructure was posited as an essential step in reaching net-zero emissions goals using boilers, steam, and/or turbines and 100% ammonia and hydrogen fuel.

It was questioned whether ammonia's utilization as a fuel in the power sector, rather than other sectors, is a priority due to existing alternatives that are poised to reduce GHG emissions. It was asserted that ammonia's most effective use would be hard-to-abate industries (e.g., steel, cement, etc.). Concerns regarding end cost to consumers in energy transitions were raised by multiple participants. It was countered that if there is a need to reduce energy costs for the public, consumers could install solar panels in their homes, a technology that is currently available to the public. In response, it was expressed by several participants that residential solar panels are an underutilized area of power generation.

Debaters made a comparison regarding the efficiency of ammonia as a hydrogen carrier in relative to liquid hydrogen. In response, it was explained that high efficiency is largely dependent on end use. It was mentioned that liquid hydrogen is an ideal hydrogen carrier when the final use requires high purity of hydrogen (e.g., fuel cell vehicles), however, it is difficult to transport liquid hydrogen as its storage requires cryogenic temperatures (i.e., -259 degrees Celsius). It was contended that ammonia is easier to transport and can also be used as a carbon-free fuel. Concern was expressed on the efficiency and economic feasibility of the ammonia cracking process because (i) the ammonia cracking process requires high temperatures (i.e., anywhere from 650 degrees to 1,000 degrees Celsius), significantly increasing the demand for energy as an input and the cost, and (ii) there is a significant loss of hydrogen during the process, making it less efficient than other hydrogen transportation methods (e.g., pipeline). The reliance on importation of energy for small, and particularly island countries (e.g., Japan, Singapore), was stressed several times throughout the debate.

It was posited that co-firing ammonia (e.g., 20% ammonia) in coal plants will not be productive in reducing emissions and would prolong the use of fossil fuels in the energy system. Multiple participants argued that the introduction of ammonia in coal-fired power plants is a government strategy to incentivize the use of ammonia while employing existing infrastructure. Although ammonia combustion is carbon-free, there was debate on the concerns of nitrogen oxide (NOx) emissions, with some participants positing that current levels of emissions are permissible, but it was instead argued that, with the increase of ammonia co-firing, there would be a continuous linear increase of NOx emissions.

Multiple participants asserted that bunkering would serve a major role in developing fuel ammonia supply chains and is, therefore, essential to the transition from fossil fuels. It was stated that the fuel ammonia bunkering market needs to be independent from the market for ammonia as a fertilizer as (i) the market for ammonia bunkering is currently very limited, and (ii) bunkering ammonia was estimated to double the price of bunkering crude oil. Therefore, the price of ammonia bunkering will drastically increase the cost to end users. Another debater expressed concern that the increased cost of ammonia bunkering will raise the cost of the fuel downstream and will further alienate stakeholders concerned about the cost of energy transition away from fossil fuels. It was further noted that the infrastructure to allow for ammonia bunkering is not currently sufficient for widespread use, and it was suggested that ammonia be injected into diesel fuel engines since the only new fuel infrastructure that would be required for this strategy would be ammonia tanks and discharge ports.

Position Paper Three
Review of the Economic, and Environmental Characteristics of Hydrogen Production Technologies from Asian and Japanese Aspects**

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Summary
In order to reduce carbon dioxide (CO_2) emissions from hydrogen production primarily caused by the use of fossil fuels, low-carbon hydrogen should be used (e.g., blue or green hydrogen). The application of carbon capture and storage (CCS) technologies is required for blue hydrogen. To reduce the cost of green hydrogen, electricity and electrolyzer costs must first be reduced through upscaling, the learning effects of mass production, and improve utilization factors. In Asian countries, including Japan, the amount of available renewable energy is insufficient for the population and energy demand. Since each country has different resources and future energy demand, hydrogen production technologies should be selected based on the characteristics of the energy demand structure in each respective country.

Current realities

Most hydrogen and ammonia are currently produced using fossil fuels without the application of CCS technologies in the industry sector, which means their production costs are dependent on the cost of fossil fuels. In the conventional hydrogen and ammonia production processes, CO_2 is captured to improve the purity of the product and subsequently sold as a byproduct. A urea production plant is often located next to an ammonia production plant to use ammonia and captured CO_2, where the excess CO_2 is emitted into the atmosphere. Therefore, the color of current hydrogen and ammonia is so-called gray. In this paper, hydrogen from fossil fuel with CCS is defined as blue, and hydrogen from renewable energy (i.e., mainly using water electrolysis) is defined as green, regardless of the CO_2 emissions.

In Japan, most of the hydrogen is currently produced from oil products (e.g., naphtha) and natural gas, and it is also obtained as a byproduct of industrial processes (e.g., caustic soda production). Due to Japan's importation of most of its primary energy resources (e.g., oil, coal, natural gas), the hydrogen production industry also has a history of seeking less expensive feedstocks, (i.e., waste plastics for ammonia production). In general, when the natural gas price is \$3.3 USD/Metric Million British Thermal Unit (MMBtu), hydrogen production using natural gas steam reforming (SMR) technologies without CCS is approximately \$1 USD/kg-H_2, and its CO_2 emissions are 9 kg-CO_2/kg-H_2. Regarding hydrogen production via water electrolysis with renewable electricity, assuming electricity costs of 6 cents/kWh and the operation of 4,000 hours per year, the hydrogen production cost is about \$3 USD/kg-H_2.

Scientifically credible approaches and challenges

Ammonia is conventionally synthesized from hydrogen and nitrogen gases by the Haber-Bosch process, which is a commercial technology with CO_2 emissions mainly a result of hydrogen production. In addition, the selection of hydrogen or ammonia as an end-product is dependent on the end-use technologies. Therefore, SMR (as a representative of fossil fuel reforming technologies) and water electrolysis are discussed as the two major hydrogen production and supply technologies for ammonia production in the following sections.

Economic aspects of hydrogen production technologies: The major challenge of SMR is the high dependency of production cost on feedstock costs, and the additional cost of CO_2 capture. The feedstock cost is highly affected by external conditions. Utilization of alternative resources and technologies (e.g., brown coal gasification) is one option against volatile natural gas prices. The second major challenge is that CO_2 capture requires additional equipment, fuel, and power, which increases costs (i.e., higher capture rates lead to higher hydrogen costs).

The main cost drivers of hydrogen production by water electrolysis are electricity and equipment. Both the alkaline and PEM type electrolyzers require about 5 kWh of electricity (AC) to produce 1 Nm^3 of hydrogen, and the conversion efficiency is about 70% compared to the enthalpy of hydrogen. Therefore, the main measures to reduce hydrogen costs are to reduce electricity and equipment costs. The so-called surplus electricity (i.e., renewable electricity that exceeds the demand) is expected to be inexpensive when a large amount of renewable energy is integrated into the grid system. If it is not generated frequently, the utilization factor of the electrolyzers decreases. Since the fixed costs are inversely proportional to the utilization factor, the impact will be significant when the utilization factor is less than about 30%. Therefore, it could be a solution to improve the utilization factor by combining multiple power sources (e.g., renewable energy sources and grid power) to power electrolyzers. In addition, as renewable energy increases, integration costs are required.

Although the current price of natural gas is soaring, the natural gas prices in 2030 and 2050 are projected to fall in the range of \$2-\$4USD/MMBtu in the Announced Pledges and NZE Scenarios of World Energy Outlook 2022. Considering the cost ranges of hydrogen production (**Figure 1**), blue hydrogen is expected to be competitive, especially in the medium term. The regions with abundant fossil fuel resources have experience exporting energy, and also have ambitions to export hydrogen. It would therefore be a plausible solution to build the first hydrogen supply chain using blue hydrogen in the medium term, and then introduce green hydrogen while observing its costs. Hydrogen production and carrier conversion plants typically will be located adjacent to the loading terminal for export to reduce hydrogen transport costs, which are greater than the costs of transporting feedstock (e.g., natural gas, electricity) to hydrogen production plants. Lignite is not fit to transport due to its low energy weight density and the flammability of dried lignite. Lignite gasification plants will be located near the mining sites.

Hydrogen specifications (e.g., pressure, purity) also affect the economics of hydrogen. The purification and compression processes required to achieve specific specifications consume energy and some hydrogen, thus increasing prices and reducing potential supply. Hydrogen specifications also need to account for the method of hydrogen transportation that will be used in later stages of the supply chain. While pipelines are generally the least expensive form of intracontinental transportation, the cost rapidly increases with distance, compared with the ship transport costs. There is the breakeven point between the transportation costs by pipelines and ships around several thousand kilometers. Therefore, for intercontinental purposes, ship-based transportation can be utilized in some cases. While pipelines have fixed transportation between the connected points, ship-based transportation is more flexible as it is possible to transport between ports. Therefore, economic efficiency, flexibility, and security should be taken into account regarding hydrogen transportation.

Environmental Aspects of Hydrogen Production Technologies: Beyond climate change, other factors within energy systems affect environmental outcomes (e.g., regional air pollution, eutrophication of oceans and rivers). The trade-off between the CO_2 capture rate and its cost, requires that both factors be selected according to their respective CO_2 emissions per unit hydrogen. The emissions from production also vary with the indirect emissions (i.e., electricity, fuel consumption, methane leakage during mining during transportation, fuel for liquefaction regarding liquified natural gas (LNG), and construction of hydrogen production facilities).

There are many initiatives being undertaken in different countries by hydrogen-related organizations to quantify emissions and certify the amount of hydrogen production. U.K. and U.S. being among those countries developed guidelines for quantification. The European Commission legislated EU taxonomy and supports building the scheme for quantification and certification through the CertifHy Project. The threshold figure to determine what can be classified as "clean hydrogen" is set in these guidelines and documents. The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) published the methodology for quantification the boundaries of which include production, conditioning, and conversion, and will include the transport of hydrogen and hydrogen-derived carriers.

Introduction of Hydrogen in Various Countries: Asian countries have different advantages and constraints in energy demand-supply systems (e.g., available energy resources, energy demand densities, energy-related assets). In addition, available renewable energy resources may not be sufficient for energy demand due to the climate characteristics in these same countries. Therefore, their transition strategies toward carbon neutrality are different, including their plans for utilizing hydrogen production technologies. The portfolio of hydrogen production technologies must be made considering those specific characteristics.

Evidence-based options (EBO) and actionable next steps (ANS)

The economics of blue hydrogen are governed by feedstock prices, CO_2 capture rates, and CO_2 storage.

- Identify the CO_2 capture rate required for clean hydrogen production and determine the appropriate technology for optimized CO_2 capture.
- Capture low-density CO_2 in furnace exhaust gasses when using the conventional steam reforming process or utilize an autothermal reforming process if a high capture rate is required.
- Invest in the research and development of emerging technologies (e.g., membrane separation, chemical looping).

The economics of green hydrogen is affected by the cost of electricity, utilization factor, and electrolyzer costs.

- Combine multiple renewable energy types to improve the utilization factor of electrolyzers to reduce fixed costs.
- Facilitate large-scale deployment so as to reduce CAPEX by the learning effect.
- Strategize to sell both green and gray hydrogen using renewable and grid electricity mixture to increase the utilization factor. Green and gray hydrogen can be sold separately.

- Invest in emerging electrolysis technologies (e.g., anion exchange membrane electrolysis, solid oxide electrolysis). Since the PEM type uses PGM materials (e.g., iridium in electrodes), there are concerns about the supply amount of these resources in the mass diffusion phase.
- Foster, over the long-term, low TRL emerging technologies to economically improve current commercial hydrogen production from various sources (e.g., thermochemical water splitting using nuclear and renewable heat, photoelectrochemical water splitting, biomass gasification).

References

International Energy Agency (2019), The Future of Hydrogen.

Oni, A. O. et al., (2022), https://doi.org/10.1016/j.enconman.2022.115245

Reference Yuki Ishimoto, Analysis of economic efficiency on international hydrogen supply chains to Japan, Quad Hydrogen Workshop, 9th December 2022, Kyoto.

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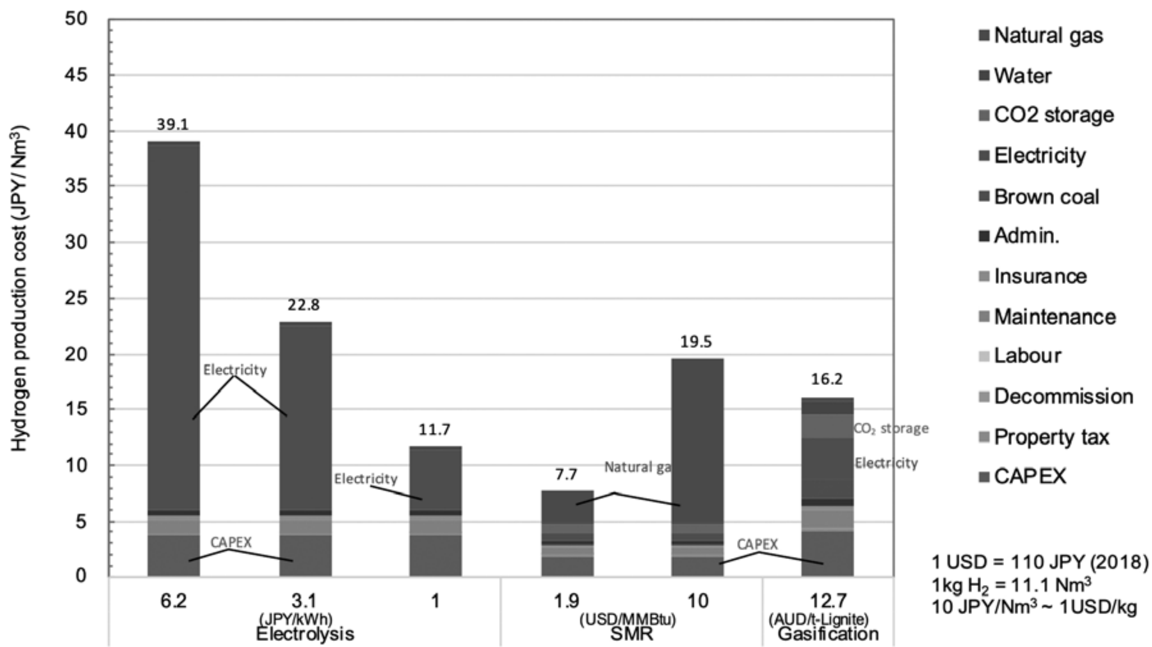
Figure 1. Hydrogen production costs using electrolysis, SMR, and lignite gasification technologies



<u>Assumptions for hydrogen production</u>
Electrolysis: Energy intensity 5.27 kWh/Nm3 (incl. compression), electricity (wind) 6.2JPY/kWh, Utilization factor 35%
SMR: Gas price 2 USD/MMBTU, CO_2 storage cost 15 AUD/t-CO2
Gasification: Brown coal price 12.7 USD/t-coal
Discount rate: 5%

Debate Three Summary

TOPIC: Comparative analysis of hydrogen/ammonia production methods (i.e., blue, green, and pink hydrogen) in terms of cost, supply, life cycle, carbon footprint, and environmental compatibility

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Throughout the debate, the increasing economic investment needed to advance carbon capture technology was identified as an important step for Japan to reach national carbon emissions reduction goals. Investing in carbon capture technology for current fossil fuel infrastructure would increase the carbon capture rates from flue gas (i.e., emissions from combustion plants) in addition to the 50% carbon captured on an existing energy production line. It was contended that utilizing autothermal reforming, rather than steam reforming, in ammonia production/processing procedures may enable greater carbon capture rates. However, it was argued that applying carbon capture technologies to reduce the amount of CO_2 in flue gas during the production process is a key target to reduce the amount of CO_2 overall.

It was posited that certain parts of East Asia (e.g., India, China) may have an advantage in producing renewable hydrogen at lower costs than countries with low land availability (e.g., Japan). However, there was disagreement surrounding the cost to produce hydrogen and utilization solutions to combine different power sources. It was initially suggested that green hydrogen could be produced at 6¢ USD/kWh and

4,000 operation hours per year, resulting in a hydrogen cost of $3 USD/kilo. It was claimed that green hydrogen could be effectively produced at 3¢ USD/kWh and $2 USD/kilo. While acknowledging that diversifying energy sources for electrolysis is beneficial, it was argued that multiple renewable energy sources (e.g., wind and solar) should be utilized instead of a singular renewable energy source with grid power.

Multiple participants noted that the production of both blue and green hydrogen requires large amounts of water and is utilized in multiple production stages, resulting in subsequent concerns regarding environmental challenges, particularly in water-scarce countries. It was asserted that developing technologies for utilizing seawater in hydrogen production would be beneficial to communities with limited access to other water resources. However, it was noted that demineralizing seawater for electrolysis produces waste-products (i.e., brine) that require appropriate disposal methods. Discarding brine into any marine environment would be detrimental to the local ecosystem. It was recognized by multiple participants that Japan has limited land availability to support infrastructure for producing geothermal energy. While it was contended that geothermal energy may not be a suitable option for hydrogen production in Japan, some participants suggested that nuclear or coal-fired plants could be converted to utilize geothermal power as an alternative heat source for hydrogen production.

It was broadly agreed that increasing the percentage of renewable energy in Japan's energy mix is critical for addressing climate change, and sufficient land availability was repeatedly raised as a key challenge for expanding renewable energy production. In small island communities, low land availability is a major challenge for developing solar and wind farms. Furthermore, the environmental aspects of producing and shipping ammonia and hydrogen need to be quantified and considered to ensure that hydrogen energy systems substantially contribute to emissions reduction goals. It was argued that diversifying energy sources (e.g., solar, wind, ammonia, fossil fuel) and suppliers (e.g., hydrogen exporters) allows for energy security and the production of hydrogen from multiple sources.

The viability of initially producing blue or brown hydrogen then gradually transitioning to the production of green hydrogen was a topic of frequent debate. It was acknowledged that utilizing brown coal gasification would exponentially increase costs, pose threats to the environment (e.g., higher carbon emissions rate), and be unsuitable for exportation. It was suggested that utilizing blue hydrogen first would allow for the supply chain to be established quickly to facilitate an efficient and economically effective transition to green hydrogen. Concerns were raised, based on a study in Australia, that developing hydrogen production via fossil fuels requires significantly different infrastructure than green hydrogen production, reducing the effectiveness of implementing blue hydrogen as an initial step prior to implementing full-scale renewable hydrogen production. Multiple participants regarded transitioning from blue to green hydrogen as a potentially ineffective long-term approach due to additional infrastructural and technological requirements. It was acknowledged that immediately prioritizing green hydrogen production involves economic challenges because of the large amount (several gigawatts) of solar and wind that would need to be installed to support a large-scale power generation facility. Another participant noted that green hydrogen production requires a large amount of electricity-generating infrastructure, which could be derived from geothermal sources, and often are more cost-effective. Similarly, a project in Australia developed large hydrogen hubs to focus on producing both blue and green hydrogen while repurposing existing infrastructure.

One debater noted the importance of the cost breakdown and structuring of potential hydrogen energy infrastructure and supply chains rather than financial forecasting of hydrogen energy pricing. It was acknowledged that funding allocation needs to be prioritized through cost-benefit analysis (i.e., on a case-by-case basis) to maximize its effectiveness and impact (e.g., building a new hydrogen storage facility or decarbonizing the power grid). This breakdown of best-case financial application was strongly supported by many participants. Numerous suggestions regarding targets and approaches for reducing the cost of green hydrogen were proposed, including (i) reducing of electricity and electrolyzer prices, (ii) rapid upscaling of mass production, (iii) improving the utilization factor of electrolyzers, and (iv) identification of the most cost-effective feedstocks. Brown coal gasification with CCS technology was proposed by one participant as another cost-reducing approach in the short-term. Several participants strongly disagreed with this proposal, as the process was considered prohibitively carbon-intensive. There was support from several participants for utilizing blue hydrogen as an intermediary solution between current fossil-fuel-dominated energy economies and renewable energy systems in the future.

It was suggested that it would be critical to account for the greenhouse emissions associated with blue hydrogen production in both hydrogen-producing and -consuming nations. The question of which type of nation (i.e., producer or consumer) would hold responsibility (e.g., financial) for expended greenhouse gasses was raised. Three current initiatives associated with the development of hydrogen energy systems and carbon financing were identified: (i) joint crediting mechanisms in Japan to provide support (e.g., financing, technology), allowing stakeholders to share in Japanese infrastructure and technology development whilst distributing savings in terms of carbon emissions, (ii) the Asian Energy Transition Initiative under which $10 billion USD is allocated for financing technologies (e.g., carbon capture, green hydrogen, blue hydrogen, clean fuels), and (iii) a ¥2 trillion JPY financing mechanism in Japan for supporting technology development, through which Japanese stakeholders can invest in reciprocating countries, helping support their energy transition.

It was emphasized that, even for effective and supportive schemes, energy security concerns in Japan may necessitate additional approaches. The domestic production of hydrogen was argued to be a future necessity to ensure energy security in import-dependent nations (e.g., Japan), however decarbonization of the electrical grid and reduction of electricity costs was acknowledged as a more immediate focus. It was suggested that this initial focus would also make domestic hydrogen production more feasible by creating infrastructure that could eventually make domestic hydrogen production more economical than hydrogen importation. It was acknowledged that blue hydrogen is currently cheaper than green hydrogen, but it was also contended that industrial partners using hydrogen will focus on the landed cost rather than the production cost. It was therefore argued that, while domestic hydrogen production in Japan may currently be uneconomical, reductions in production costs can become competitive with the landed cost of imported hydrogen.

Energy security needs and energy price volatility (e.g., impacts from global events) were posited as critical considerations associated with the importation of hydrogen and its usage in Japan. There was widespread agreement for the usage of blue hydrogen, but little agreement about the application and implementation of hydrogen utilization. It was noted that subsidies would be needed initially to support the transition to clean energy utilization, while the transportation and industry sectors would likely utilize imported hydrogen in the near term. It was acknowledged that there is currently limited demand for hydrogen in these sectors, and some projections for hydrogen demand by 2030 anticipate that demand will still be limited. Electricity and power generation sectors were posited to be important sources of demand for hydrogen in the future, with some hydrogen energy going to homes for electricity and heating.

The transportation of hydrogen was discussed as a key issue, which was also expanded further within other debates. There was disagreement regarding whether pipelines or maritime transport is the most effective method of transporting hydrogen (e.g., in terms of time, storage, capacity, and range). It was posited that the transportation cost of pipe lining hydrogen is almost proportional to the distance traveled due to the pipeline construction cost per unit of pipe remaining constant. In contrast, maritime transportation was described as requiring a larger initial investment, as it requires significant infrastructure (e.g., a loading terminal, receiving infrastructure, maintenance), regardless of the distance traveled. It was asserted that once the infrastructure is constructed for maritime transportation, the relationship between cost and distance traveled becomes more comparable to the cost of using pipelines, suggesting a break-even point between pipeline and ship transportation. It was stated that, based on analysis by one energy research center, this break-even point may be around 4,000 – 5,000 kilometers (km).

There was a strong focus on the technological requirements of hydrogen energy systems, including the need for future developments of hydrogen energy technologies. Concerns raised regarding the intermittency of conventional renewable energy sources (e.g., solar and wind) were met with enthusiastic support for supplementing this energy with next generation technologies (e.g., electrolysis, hydrogen, and hydrogen derivatives), which would facilitate the utilization of renewable energy. The optimization of these technologies would further market and real-world viability of renewable energy.

It was noted that "next generation" energy technologies are anticipated to have large manufacturing capacities, with global market competition. China was offered as an example of a country that controls large sectors of electrolyzer production and solar panel development. It was acknowledged that there may be energy security concerns if manufacturing of renewable technologies in Japan could not be completed domestically, and therefore Japan would need to continually rely on trade with other nations for energy. If Japan pursues the domestic production of electrolyzers, it was argued that directly connecting electrolyzers to electrical grids would be the most effective approach initially, providing the greatest utilization factor under current conditions until efficiencies and costs are improved for application to other technological areas. It was also acknowledged by many participants that low-carbon, non-renewable hydrogen production (e.g., blue hydrogen) could supplement the hydrogen supply to reduce initial costs. It was stated that the production and utilization of blue hydrogen would depend on the accurate certification and regulation of each energy source alongside local legislation. It was also noted that the availability and costs of mineral and critical material requirements need to be taken into consideration when developing new technologies to improve ease-of-access. The development of strong supply chain routes was resoundingly supported and was considered a top priority in the development of new and existing hydrogen energy technologies.

There was contention over the efficiency of CCS and CCUS, especially concerning the suggestion that 40% of greenhouse gas emissions could effectively be removed from flue gas. Concerns over the validity of these CCS and CCUS efficiencies were strongly challenged. However, it was recognized that many questions surrounding CCS and CCUS needed to be based on observational evidence including (i) efficiencies over long time scales, (ii) direct air capture efficacy, (iii) storage-related issues over time, and (iv) removing of CO_2 from the atmosphere to storage and not direct total removal.

Position Paper Four
Supply Chain Logistics of Hydrogen/Ammonia Production, Storage, and Distribution**

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Summary

The world is turning towards achieving a decarbonized future. This transition will have significant impacts across supply chains and companies have begun reconsidering their energy consumption trends, introducing new business models, and developing technologies to support this transition. A viable component of this process will be the utilization of renewable energy and adopting technologies that could reduce carbon emissions at thermal power plants. Hydrogen (H_2) has the potential to play a significant role in this transition, as it is formed by using renewable energy or low-carbon fuels. Moreover, ammonia (NH_3), well-known for use in fertilizers, can be an effective "carrier" for hydrogen, but direct use applications for ammonia are broadening its scope of utilization (e.g., marine, industry, and power generation's fuel). Hydrogen and ammonia have the potential to become more meaningful parts of the zero-emissions energy mix. Even though supply chains exist for ammonia, substantial infrastructure development (e.g., storage, transportation, ports) to handle the new demands is needed.

Hydrogen and ammonia usage as fuel is in the early stages, and there are many hurdles (i.e., fuel supply, infrastructure, safety, regulations, and public perception) to overcome. However, through collaboration across multiple stakeholders and a shared vision for a decarbonized future, hydrogen and ammonia can become more meaningful parts of the zero-emissions energy mix. The recent government policies of major energy consumers (e.g., Inflation Reduction Act (IRA), Green Transformation (GX), Temporary Crisis and Transition Framework (TCTF)) are helping to create more certainty in decarbonization pathways. These policies will help major projects move from the planning phase to the implementation phase. However, there is a need for a global regulatory structure and collaboration to lead towards a smooth and just transition.

Current realities

Climate change is driving an urgency in the transformation of the energy sector, with private and public sectors working towards the goal of, not only decarbonization, but sustainable growth and energy security. Considering the fast pace of economic developments and the limited potential of renewable energy resources in Asia, achieving decarbonization targets and transitioning to clean energy is not viable solely through renewable energy sources utilization. In addition to optimizing the renewable energy potential, there is a need for some innovative and viable approaches to offset carbon footprints and cleaner energy production in the existing relatively young thermal power plants.

Hydrogen has the potential to be a lower greenhouse gas (GHG) fuel and a means of storing renewable energy. To achieve the International Energy Agency's (IEA) Net Zero Emissions by 2050 Scenario (NZE), hydrogen and carbon capture, use, and storage (CCUS) technologies play key roles. Today, hydrogen is predominantly produced using natural gas or coal/lignite using a process called steam reforming. Steam reforming remains more economical for hydrogen production as compared to other technologies today and is a convenient hydrogen source with a high hydrogen-to-carbon ratio. However, the process is CO_2 intensive, especially in the case of coal/lignite.

Hydrogen demand reached 94 million metric tons (Mt) in 2021, most of which being locally produced and consumed. By 2030, the NZE requires a demand of 200 million Mt of hydrogen, and 12 million Mt of hydrogen to be exported yearly based on export-oriented projects. Ammonia is the hydrogen carrier of choice for the majority of these projects. By cooling hydrogen to -252.9°C, it can be transported and stored in its liquid form without further reactions or purification required. However, significant energy is needed to maintain this temperature throughout the supply chain.

Ammonia is produced through the ammonia synthesis process by reacting hydrogen with nitrogen. As ammonia can be stored in refrigerated tanks at -33 °C or at ambient temperatures under a pressure of 8-10 bar, storage and transportation are relatively manageable and affordable. Ammonia can be used as a hydrogen carrier and "cracked" back to hydrogen. But there are also options for direct use of ammonia as fuel. Due to toxicity, storage and transportation will require sufficient precautions from potential leaks. The key advantage ammonia has over liquified hydrogen is its higher volumetric energy density and liquefaction temperature, making it easier to transport and store.

In 2020, 185 million Mt of ammonia was produced, and around 20 million Mt was traded globally. According to NZE by IEA, ammonia demand will grow to over

500 million Mt per year. The expected demand for ammonia in Japan is 3 million Mt in 2030, 30 million Mt in 2050, and 100 million Mt for the global supply chain by Japanese companies in 2050.

Liquid Organic Hydrogen Carriers (LOHC) absorb hydrogen through a hydrogenation process. They can be handled at ambient temperature and pressure, are non-explosive, and do not have storage losses over time. The challenge is to scale the use of LOHC, considering the energy required for hydrogenation and dehydrogenation and the emissions created during the transformation processes.

Scientifically credible approaches and challenges

Regarding production, while producing blue hydrogen, the carbon sequestration is a major challenge. CCUS technology is in its infancy and requires intensive studies and investments. Moreover, lack of relevant and necessary policies and regulations in the producing countries for CCUS would further delay the process of decarbonizing blue hydrogen. However, there are some promising steps encouraging and supporting CCUS technologies and investments.

Regarding transportation and storage, liquefied ammonia has higher temperatures than liquified natural gas (LNG), therefore repurposing an existing LNG/LPG terminal to accommodate ammonia is cheaper and is technically less challenging. Ammonia, as a hydrogen carrier, offers more credible options for storing, transportation, and usage of hydrogen in the near term. In addition to being easier to handle, the ammonia supply chain already exists due to fertilizers and industrial applications. This usage is not limited to the power industry, as even shipping companies are looking at the options for using ammonia directly as marine fuel.

Lastly, regarding consumption, while ammonia doesn't release CO_2 when combusted, it does produce Nitrogen Oxides (NOx), which are potent GHGs. Several key learnings have emerged from studies considering NOx reduction. If ammonia is injected into the flame of coal, NOx generation is suppressed. NOx generation behavior is quite similar to normal 100% coal-fired power generation, and thus if the 20% ammonia is mixed evenly with the coal it is easier to manage the NOx emissions.

Currently, JERA is leading in the usage of hydrogen and ammonia in power generation, with several projects underway around the world demonstrating either co-firing or 100% combustion. At the Hekinan Thermal Power Station, Aichi Prefecture of Japan, the company is proceeding with a demonstration for co-firing 20% ammonia with coal at the 1GW Unit 4 in early 2024. Once operational, the 20% co-firing will use approximately 500,000 Mt of ammonia per year.

Evidence-based options (EBO) and actionable next steps (ANS)

Utilization of ammonia and hydrogen presents several challenges, but there are approaches that can overcome them.

Emissions and Energy Intensity: Currently, hydrogen production requires a significant amount of energy and has high emissions due to the use of fossil fuels as feedstock.

- Increase renewable energy generation capacity to support production of sufficient hydrogen and nitrogen to produce green ammonia.
- Utilize and commercialize CCUS methods to reduce CO_2 emissions in the production process of natural gas-based hydrogen – creating low-carbon ammonia.

Feedstock: As traditional hydrogen and ammonia production relies on the availability of fossil fuels as feedstock, these may be more limited resources in some regions.

- Explore local and affordable alternative feedstocks such as biomass and renewables.
- Develop large-scale blue/green projects to support ammonia production and export.

Cost**:** Supply chains for hydrogen and ammonia remain costly for power generation.

- Continue and expand developing technologies and evaluate production methods across areas, including ammonia cracking, carbon capture, and direct combustion, to improve efficiency.
- Provide necessary government support and subsidies to enable feasibility studies, tariff setting, fuel supply, etc.

Safety Measures: It is critical to ensure proper safety protocols are in place to protect both workers and the environment.

- Provide necessary support to promote studies and development of industry standards to ensure proper usage of hydrogen and ammonia in power generation.

Policy and Regulatory: Clear policies and regulatory framework are necessary for supporting and achieving commercially viable ammonia and hydrogen utilization.

- Announce national targets for ammonia/hydrogen utilization to ensure economic viability.
- Certify and regulate low-emission energy sources to support the transition.
- De-risk investments in ammonia/hydrogen to encourage financiers and stakeholders to engage.

Gradual transition: To balance decarbonization, energy security, and sustainable economic development, it is necessary to embrace a gradual transition from black to green.

- Initiate a transition with blue ammonia and hydrogen to make it commercially viable. Initial transition would create and develop the supply chain, market, and infrastructure.
- The secondary transition would be from blue to green. The technology, supply chain, and infrastructure would already be ready to move from blue to green.

References:

IEA (2022), Global Hydrogen Review 2022, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2022

IEA (2021), Ammonia Technology Roadmap, Paris https://www.iea.org/reports/ammonia-technology-roadmap

*** **A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Debate Four Summary

TOPIC: Supply chain logistics of hydrogen/ammonia production, storage, and distribution

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Kenji Takahashi (see position paper above and author biographical information in the Appendix). Mr. Takahashi initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Takahashi and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Takahasi, as evidenced by his position paper. Rather, it is, and should be read as an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

During the debate, it was widely acknowledged that Japan set an ambitious national strategy aimed at significantly scaling up the use of hydrogen and ammonia-based energy by 2030, namely by replacing the most inefficient coal-fired power plants in Japan and achieving carbon neutrality by 2050. It was noted that these national energy ambitions have led Japan to explore competitive suppliers for hydrogen and ammonia (e.g., at the local, national, and international level). Furthermore, it was mentioned that Japan is promoting research by local private sector partners to design and improve technologies that can increase power generation efficiency in power plants. The debate session covered a range of topics related to these efforts, current technological progress and challenges, regulations and safety standards related to the production and transport of hydrogen and ammonia, and logistics and supply chain.

There was a strong emphasis on the importance of maintaining a holistic view of energy systems and recognizing that no single energy option alone will be sufficient for decarbonization. As a result, the question of whether to produce hydrogen locally or import it from abroad was raised. Participants noted that locally generated energy from renewable sources is less reliable due to seasonal variability (e.g., temperature changes, wind patterns, daylight hours, etc.), and therefore, import options need to be considered. Additionally, it was noted that the mode of transportation for energy might vary depending on production location. For example, while energy produced in Hokkaido, Japan, and other localities within the country may be transported via hydrogen pipeline, energy produced and imported from longer distances requires power transmission lines and/or maritime transportation requiring the capacity to store large quantities of hydrogen for extended periods of time and the delivery of hydrogen over long distances. Several debaters suggested that the practice of energy planning needs to account for such logistical challenges surrounding hydrogen and ammonia transport.

It was also discussed that the Japanese government has plans to establish a new supply chain that aims to increase the utilization of hydrogen and ammonia by 50% to a target of 3 million tons per year by 2030. It was also noted that pilot projects have been launched as part of this plan to achieve a 20% ammonia co-firing by 2025.

Regarding the "color" of hydrogen and ammonia production, several participants suggested that Japan needs to use a mix of blue (i.e., produced by non-renewable sources with Carbon Capture and Storage (CCS) technology) and green (i.e., produced by renewable sources) sources to achieve its decarbonization goals. Favorability was expressed for the temporary use of blue hydrogen and ammonia until green alternatives become cost-competitive, estimated around 2030-2035, with the transition to green options proposed to occur when they become economically viable. However, some stakeholders challenged the rationale for utilizing blue hydrogen and ammonia, asserting that the current cost of green hydrogen has decreased to the degree that the price is not an impediment to immediate transition. Moreover, a few participants suggested that the significant expansion of green hydrogen production and usage should be prioritized immediately rather than blue hydrogen and ammonia. It was argued that the volume of green hydrogen imported to Japan is currently limited due to logistical and supply challenges (i.e., restrictive transport requirements, low level production). Since long-distance transportation of hydrogen and ammonia depends on volume, maritime transportation of green hydrogen is not currently feasible. Due to this limitation, it was noted that only a few pilot projects had been launched to determine whether transporting hydrogen across oceans is technologically and economically feasible. Therefore, it was recognized that current circumstances require the use of blue hydrogen and ammonia until the production and market for green hydrogen develop to a capacity that can support energy import-dependent economies like Japan.

Multiple debaters noted that most available hydrogen and ammonia are currently produced from natural gas with little or no usage of CCS technology. Therefore, it was recommended that hydrogen be produced using non-renewable sources (e.g., oil, natural gas, coal) with CCS. As the Japanese government is considering a mix of hydrogen and ammonia to achieve its decarbonization goals, debaters indicated that companies in Japan are concentrating on deploying and expanding their renewable portfolios, as well as establishing supply chains for hydrogen production, transportation, and usage for power generation.

The cost-effectiveness of co-firing ammonia with coal compared to solar and nuclear energy was questioned. In response, it was claimed that the total cost of a co-firing power plant is the sum of the existing firing power cost and the added hydrogen/ammonia cost. It was acknowledged that while co-firing may increase the average power production cost, it requires no new construction, unlike transitioning to a full natural gas or ammonia-powered plant, reducing the capital expenditure (CAPEX) associated with building new power plants. For example, it was indicated that private sector power generation companies are aiming to co-fire ammonia at a rate of 20% in one of the production units at the Hekinan thermal power station in the financial year 2024-2025. This facility will be the first demonstration project in which a large amount of ammonia will be co-fired in a commercial coal-fired power plant. Debaters also indicated that the government of Japan is providing incentives for retrofitting existing plants to encourage the adoption of ammonia co-firing technology in power plants. It was also indicated that raising the carbon tax will incentivize a market for the development of this technology, allowing this method to become more economically viable. For example, it was noted that if pilot co-firing projects currently being launched are successful, there is a plan to scale these projects for use in coal-fired power plants.

Debaters also inquired about nitrogen oxide (NOx) emissions produced during co-firing ammonia in large commercial power plants and available technology developed to abate these emissions. Debaters indicated that the government of Japan provided a grant to implement a demonstration project at the Hekinan Thermal Power Station that aims to evaluate both boiler heat absorption and environmental impact characteristics, including exhaust gasses. Many tests have already been conducted, and methods are being refined to stabilize emissions while increasing the ratio of ammonia co-firing in power plants. However, some debaters emphasized that even though co-firing demonstration projects currently being conducted are technically sound, they cannot be properly scaled up due to high development costs, a result that disincentivizes investors from funding projects. It was acknowledged that retrofitting coal plants is expensive, especially for power plants with high ammonia co-firing ratios. To overcome this challenge, debaters suggested that specific policies and rules are required to encourage investors to adopt cleaner (i.e., less-carbon intensive) technologies and deploy these technologies at project locations.

The potential of nuclear power as a CO_2-free energy source to produce green hydrogen was discussed by a few participants, but current government and private sector engagement in demonstration projects is limited in scale and high in cost. Public concerns over the use of nuclear energy was also noted as a serious barrier currently.

The issue of storage for ammonia and hydrogen, particularly for consumers located outside port areas was discussed. Debaters indicated that most energy is produced and utilized around ports. However, ports also play a role in storing and distributing hydrogen to multiple end-users inland who depend on hydrogen. One potential solution that was discussed by few debaters as a means of storing hydrogen for inland use is the utilization of metal hydrides as a solid storage option. It was indicated that this option would be more cost-effective than liquid storage and could be used at moderate temperatures without the need for additional cooling or heating. However, it was indicated that progress within Japan concerning this option has not been extensively explored.

Decentralized ammonia cracking (i.e., smaller-scale cracking units installed at multiple locations) versus centralized ammonia cracking (i.e., ammonia cracking at specific larger-scale facilities at central locations) was another topic of discussion during the debate. It was explained that centralized production of ammonia involves large-scale onsite cracking at industrial sites located near ports, which means that utilization will be concentrated in coastal areas. Therefore, it was argued that less inland transportation is needed. Contrarily, it was posited that in a decentralized approach, ammonia is distributed in smaller volumes through pipeline or vehicle transport for cracking at urban locations and filling stations. Several debaters urged that there are risks associated with the decentralized approach, such as fire and leakage during ammonia transportation and use in small industries and/or households. Debaters recommended the development of safety measures and guidelines to address safety concerns. It was indicated that private sector stakeholders in Japan are planning to develop safety guidelines for hydrogen transportation, and systems for cracking ammonia centrally, which will be ready to use by 2027.

Another critical issue discussed during the debate was the need for international regulatory frameworks to support hydrogen and ammonia utilization to achieve carbon neutrality. Many participants emphasized that global standards for carbon intensity certification are needed to encourage industries to install co-firing technologies. Undertaking Measurement, Research, and Verification (MRV) in production sites and CCUS areas for the certification of the carbon intensity was also recommended by debaters. Governmental support through finance and policy frameworks was highly recommended by debaters to realize the potential of these solutions. Debaters also emphasized the importance of collaboration between countries (e.g., the U.S., Australia, Middle East and North Africa (MENA) Countries) to support the production and transportation of hydrogen and ammonia. It was noted that the estimated global production rate of hydrogen and ammonia would not be enough to meet anticipated demands in Japan. Consequently, several participants recommended addressing the supply gap by forming partnerships with producers in the U.S., Australia, and the MENA region.

Participants discussed an ongoing demonstration test for hydrogen and ammonia co-firing and the need to establish a supply chain for hydrogen and ammonia. It was indicated that pilot projects are currently experimenting with a 20% hydrogen co-firing ratio in coal-fired power plants to cut carbon dioxide (CO_2) emissions using cleaner fuels. A 20% hydrogen ratio was selected to be used based on current limitations in the supply of hydrogen and ammonia. It was also noted that while the development of a single-fired power plant was expected to happen in the 2030s, the construction of such a plant would not begin until 2040. Debaters also discussed the need to engage with communities through dedicated programs to promote public acceptance of ammonia as a fuel for power generation. It was recognized that some power generation companies interact with community members to inform them about ammonia-based energy and technology being used in their projects.

Current efforts being made to develop the connection between ammonia production and transportation, as well as port refitting, were discussed by debaters. It was noted that Japanese companies were discussing hydrogen and ammonia production with local subsidiaries in the U.S., Australia, and countries in the MENA region and Asia and were collaborating with major Japanese shipping companies (e.g., NYK Line) to establish a maritime-based ammonia supply chain. Additionally, these companies are working with power utility companies in Taiwan, Thailand, Singapore, Indonesia, and Vietnam to establish a roadmap for ammonia and hydrogen utilization.

Regarding the future of innovation within Japan on energy technology and the hydrogen economy, the potential for new energy carriers (e.g., Liquid Organic Hydrogen Carriers (LOHC) and green ammonia) to replace traditional fossil fuels in the shipping and power sectors was discussed. It was contended that LOHC can absorb hydrogen, store it (with minimal loss), and release it again when needed. Since little or no pressure is required during this process, normal containers or tanks can be used. One debater indicated that while the development of LOCH is still ongoing, new partnerships and investment agreements are being established (e.g., JERA and Hydrogenious LOHC) to explore technology options.

Debaters also discussed the issue of market monopoly by a few dominant players affecting the supply of ammonia, as well as the energy-producing firms associated with decarbonization plans in Japan. If blue ammonia continues to dominate the market, its price will be driven by natural gas prices, potentially leading to a concentration of production among a small group of entities. The need to differentiate between ammonia demand for fertilizer production and ammonia demand for fuel production was also emphasized. It was mentioned that ammonia for fertilizer production holds a significant portion of the contract landscape currently, while ammonia utilized for energy production is expected to increase in demand and potentially become the dominant contract type in the long term. It was expressed that this development will likely be driven by an increase in new power plant installations that require ammonia as a feedstock, making ammonia production for power plants an attractive investment and potentially prioritized over ammonia utilization for fertilizer.

Some debaters raised a concern regarding the strategy of co-firing ammonia in coal-fired power plants currently being piloted by power-generating companies. In response, it was stated that while introducing ammonia may reduce the carbon intensity of the power plant, producing blue ammonia may use more methane or natural gas than firing it directly in a Combined Cycle Gas Turbine (CCGT). However, it was contended that as the volume of blue hydrogen increases, the cost of power generation would decrease. Fuel diversity in power plants is still needed to achieve a stable energy supply and energy security.

Overall, the discussion highlighted the complex nature of energy transitions and the need for careful consideration of different fuel and fuel carrier options and their potential impacts on energy security. Another main point of the debate session was that developing clean energy options using hydrogen and ammonia requires a deeper analysis of supply chains, reliability of technology, and infrastructure development.

Position Paper Five
Net-Zero Power Generation by Hydrogen**

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Summary

To achieve "Net-Zero" power generation, transitioning from fossil fuels to other alternative energy sources is necessary. Hydrogen is a low-carbon alternative fuel for electricity generation because zero greenhouse gasses are emitted by its combustion. Hydrogen can be used in two ways for power generation: (i) co-combustion, and (ii) fuel cells. For co-combustion, it can be blended with fossil fuels used in some conventional machinery (e.g., boiler, gas turbine, gas engine). Co-combustion also allows the use of conventional machines to maintain the reliability and stability of the current power system. Hydrogen can additionally be used with oxygen in fuel cells to produce electricity directly. Thus, a hydrogen fuel cell can be used with an electrolyzer, supplied by intermittent renewable energy sources such as solar Photovoltaic (PV) cells or wind turbines, as an energy storage system (e.g., PV + Hydrogen Energy Storage System (HESS), and wind+HESS). Considering the cost of using hydrogen in power generation for Thailand, co-combustion by blending hydrogen into natural gas is the main priority.

To ensure that "Net-Zero" emission power generation can be achieved by 2050, several generation expansion plans with options for new technologies having low emissions (e.g., solar PV with battery and different levels of hydrogen blending in natural gas) are proposed and discussed. Given that the Levelized Cost of Electricity (LCOE) of solar PV+Battery Energy Storage System (BESS) is higher than that of Combined Cycle Gas Turbine (CCGT) using blended gas, it is found that Thailand can achieve the net-zero emission target by promoting more use of renewable energy altogether. The trade-offs for this approach are the need for land for PV installation, and the amount of hydrogen blended with natural gas.

Current realities

The production and use of hydrogen for power generation are still in the early stages of widespread adoption, primarily due to limited infrastructure and high costs of hydrogen. Studies of hydrogen blending into the natural gas network have recently become popular. Moreover, investments in hydrogen-tolerant infrastructure, accommodating up to 100% hydrogen, are planned in many countries (e.g., the United States, Japan, the United Kingdom). However, the blending of hydrogen into natural gas networks also causes a reduction in the heating value of the mixed gases and a change in combustion behavior. Currently, efficient and safe operation can be achieved with up to 20% hydrogen blended by volume. This ratio can be increased if machines and infrastructure are upgraded.

It is stated in Thailand's Hydrogen Roadmap that since the LCOE of the PV+HESS system is still much higher than that of solar PV+BESS, Thailand will focus on co-combustion by blending hydrogen into natural gas. This method can reduce greenhouse gas emissions, not only in the power generation sector, but also in the industrial and transportation sector that use natural gas as fuel. Co-combustion with low-emission fuel also allows for the operation of non-intermittent conventional rotating generators, that provide more reliability and stability to the power system. According to Thailand's hydrogen roadmap, it is expected that hydrogen blending into natural gas will be started at 10%–20% by 2031. This ratio could be increased up to 75% by 2050.

There is currently no specific plan for implementing hydrogen fuel cells in Thailand. However, there exists a 300-kW test site for the wind+HESS system in Nakhon Ratchasima, owned by the Electricity Generating Authority of Thailand (EGAT). This facility supplies electricity to one of the EGAT learning centers and is the first building supplied by hydrogen fuel cells in Southeast Asia. There are also plans to produce green hydrogen from excess solar and wind energy to be blended into natural gas. However, since the natural gas network only exists in the central region of Thailand, this plan does not have much potential to benefit from the excess solar and wind energy generated in the northern and northeastern regions of Thailand. As a consequence, this approach is not economically practical, due to the additional cost of transporting hydrogen to natural gas networks.

Scientifically credible approaches and challenges

To emphasize the possibility of achieving "Net-Zero" emissions power generation with hydrogen in Thailand, generation expansion plans with three scenarios of hydrogen blending with natural gas (25%, 50%, and 75% by volume) are developed to create a generation system with the lowest cost of electricity generation with updated data and assumptions. These plans are developed with the same reliability criteria (e.g., Loss of Load Expectation (LOLE) at less than 0.7 days per year). Other planning constraints ensure varying generation plans are comparable. The percentage of hydrogen blended into natural gas can be found in **Table 1**. Since the target of this planning is to achieve "Net-Zero" emissions, options for generation expansion planning are limited to only two types of new power plants: (i) combined cycle gas turbines (CCGT) using blended gas and (ii) PV+ 3-hours BESS. The 3-hours BESS is selected since it is expected that demand during nighttime will be increased due to the load of Electric Vehicles (EV) while PV can supply power during daytime with expected energy generated (plant factor) is only 16%–18% of equivalent to 4 fully-operated hours. Thus, most of the energy generated from PV needs to be stored during daytime and discharged during nighttime. Additionally, it is assumed that the LCOE of PV+3-hours BESS is higher than that of CCGT using blended gas throughout the planning horizon. This assumes that the cost of hydrogen needs to compete with the cost of electricity generated from renewable energy using an energy storage system.

From these three plans, a summary of additional capacity for each scenario is shown in **Table 2.** This additional capacity does not include committed generation capacity, which remains consistent for every scenario. Since the amount of carbon dioxide that can be released from the generation system is limited, the lower the percentage of hydrogen, the more PV+BESS capacity is needed in that respective scenario. By comparing CCGT additional capacity of the 25% and 50% blending scenarios, 50% blending does not have significant differences from 25% blending. This is due to the heating value of hydrogen being quite low (325 BTU/scf) compared to that of natural gas (1,000 BTU/scf), so the emission factor of mixed gas is slightly reduced from 0.0503 $kgCO_2/MJ$ (25% blending) to 0.0421 $kgCO_2/MJ$ (50% blending). However, with 75% blending of hydrogen, additional CCGT capacity can be increased by 50% compared to the 50% blending scenario. This effect is in accordance with the reduction of the emission factor of mixed gas from 0.0421 $kgCO_2/MJ$ to 0.0283 $kgCO_2/MJ$ (75% blending). In addition, since the plant factor of PV is only 16%-18%, and it can supply only during daytime, unlike CCGT units (which can supply power all day long), more PV+BESS units are required to supply the same amount of energy. Thus, it can be concluded that low-ratio blending has only a slight effect on the emission factor of mixed gas and the additional capacity of PV+BESS that can be reduced compared to high-ratio blending.

The installed capacity of solar and land use for PV installation by 2050 is shown in **Table 3**. Given that, 1 MW of installed PV capacity requires 12,800 square meters of land. Approximately 19%–30% of unused land is required for additional PV capacity. From the result provided in **Table 2** and **Table 3**, it is found that Thailand can achieve "Net-Zero" emission power generation with 25% to 75% hydrogen blending in natural gas by volume. However, high-ratio blending is preferable since the effect of hydrogen on the emission factor is much higher. High-ratio blending also helps limit the amount of land required for PV+BESS installation. Lastly, with more non-intermittent conventional rotating generators, the generation system of the 75% blending scenario is less likely to be affected by the intermittency of solar PV generation. Thus, the system is more reliable with more inertia to stabilize the power system compared to other scenarios.

The amount of hydrogen consumed by the generation system in each scenario is shown in **Figure 1**. Given that the density of hydrogen is equal to 0.0024 kg/scf., it is clear that the peak consumption of the 75% blending scenario is around 4 million tons per year (i.e., much higher than those of the 25% and 50% blending scenarios). It is also shown that hydrogen consumption of the 25% and 50% blending scenario will decline around the end of the planning horizon. This is caused by the reduction of the carbon dioxide emission quota that limits the amount of mixed gas that the generation system can be used.

Evidence-based options (EBO) and actionable next steps (ANS)

Since "Net-Zero" Emission power generation can be achieved by hydrogen blending in natural gas from 25%–75% by volume, options can be made based on the actual cost of hydrogen and other renewable energy in the future. However, blending hydrogen in natural gas also allows the use of conventional rotating generators rather than depending on intermittent renewable energy. Thus, to ensure that "Net-Zero" power generation by hydrogen is achievable, Actionable Next Steps are as follows:

- Motivate the use of hydrogen in the power generation sector. The main benefit of using hydrogen in power generation is that the "Net-Zero" target can be achieved without heavily depending on intermittent renewable energy. HESS supplied by intermittent renewable energy can also be used as a grid-scale energy storage system.
- Develop standards and regulations for hydrogen fuel, hydrogen-tolerant equipment, and hydrogen-related activities such as storage, transportation, and distribution.
- Promote and support the development and investment in hydrogen-tolerant equipment of natural gas users, since retrofitting of natural gas network for high-ratio blending is required.
- Support the development of hydrogen production technologies to provide a reliable and affordable supply of hydrogen that can compete with intermittent renewable energy with energy storage since The LCOE of CCGT using blended gas must not be higher than that of PV+BESS. For example, carbon capture, utilization, and storage (CCUS) technologies need to be matured to produce more affordable Blue Hydrogen from natural gas. The efficiency

of electrolysers also needs to be increased to produce more affordable green hydrogen.

References

Diewvilai R., and Audomvongseree K. (2021). Generation Expansion Planning with Energy Storage Systems Considering Renewable Energy Generation Profiles and Full-Year Hourly Power Balance Constraints. *Energies*. 14, 5733.

Diewvilai R., and Audomvongseree K. (2022). Possible Pathways toward Carbon Neutrality in Thailand's Electricity Sector by 2050 through the Introduction of H_2 Blending in Natural Gas and Solar PV with BESS. *Energies*. 15, 3979.

*** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.*

Table 1: Percentage of hydrogen blended into natural gas by each year

Scenario	Percentage of hydrogen blended into natural gas (by volume)					
	Before 2030	2030 – 2034	2035 – 2039	2040 – 2044	2045 - 2047	2048 - 2050
25% Hydrogen	0%	20%	25%	25%	25%	25%
50% Hydrogen	0%	20%	30%	40%	45%	50%
75% Hydrogen	0%	20%	35%	50%	65%	75%

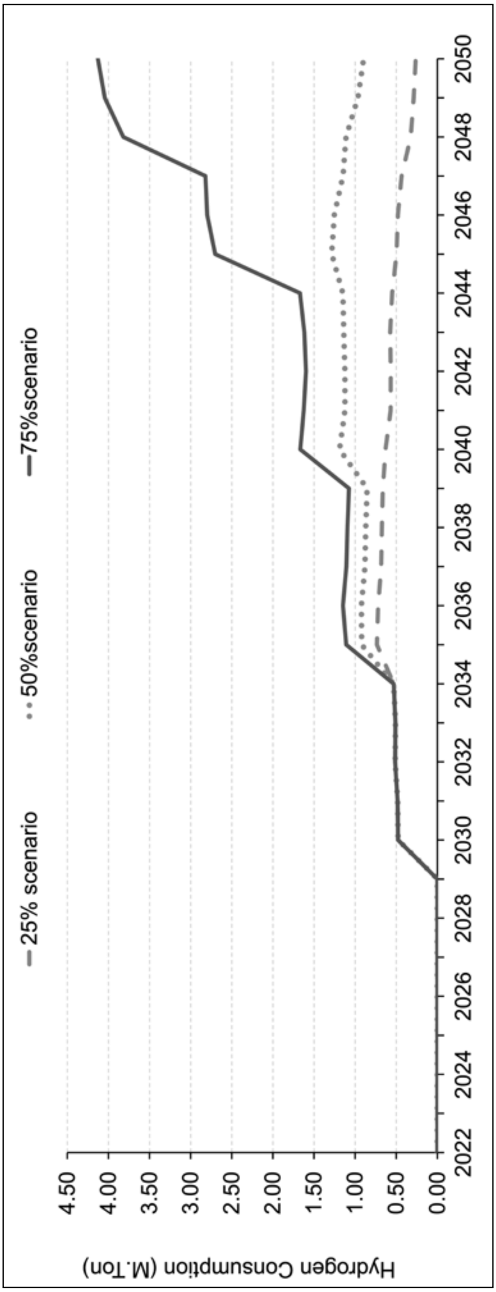
Table 2: Summary of additional capacity

Scenario	Additional capacity throughout the plan			
	CCGT (MW)	PV (MW)	Total Capacity (MW)	BESS (MWh)
25% Hydrogen	21,600	291,150	312,750	873,450
50% Hydrogen	24,000	269,550	293,550	805,650
75% Hydrogen	36,000	181,800	217,800	545,400

Table 3: Installed Capacity of PV+BESS and Land use for PV installation by 2050

Scenario	Installed Capacity by 2050		Area usage (sq.km.)	% Unused Land in Thailand (12,351 sq.km.)
	PV capacity (MW)	BESS capacity (MWh)		
25% Hydrogen	291,150	873,450	3,727	30.2%
50% Hydrogen	269,550	805,650	3,450	27.9%
75% Hydrogen	181,800	545,400	2,327	18.8%

Figure 1: Hydrogen Consumption per year of each scenario



Debate Five Summary

TOPIC: Zero-emission power generation by hydrogen/ammonia

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Radhanon Diewvilai (see position paper above and author biographical information in the Appendix). Mr. Diewvilai initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Radhanon Diewvilai and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Radhanon Diewvilai, as evidenced by his position paper. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

Hydrogen blending was heavily discussed in relation to its ability to contribute to net-zero emission goals serving the increasing energy demand. It was noted that the utilization of solar power generation may be less effective than the utilization of natural gas blended with hydrogen, as natural gas would be produced quickly and is considered economically viable. However, several participants disagreed with this notion claiming that the utilization of natural gas blended with hydrogen would pose many technical challenges (e.g., Singapore and Australia demonstrated a maximum limit of 10% hydrogen blending to reduce embrittlement challenges to existing pipelines). It was stated that the percentage of hydrogen blended would depend on varying technology and infrastructure. It was mentioned that every percentage increase of hydrogen blended by volume would contribute to the overall carbon emissions being lowered. A few participants expressed preference toward the utilization of other carbon-free hydrogen sources over the use of solar photovoltaics (PV) and batteries to achieve the carbon neutrality target, as many countries have implemented this strategy due to its economic advantage.

It was mentioned that current technology exists to utilize ammonia directly in the power sector, in addition to maritime transportation and gas turbines, without the need to crack hydrogen. This option allows for a quicker transition for usage. Additionally, it was noted that existing infrastructure (e.g., power plants) can largely support the production of ammonia, and much of the incompatible infrastructure can be easily converted to support ammonia production. It was stated by multiple participants that the safety of ammonia production and usage is a major concern if not stored and handled properly (e.g., toxic to humans, animals, and the environment). These concerns are currently being evaluated and new technologies are emerging focused on addressing these concerns (e.g., technology currently in development to detect ammonia leakages by an infrared camera).

It was acknowledged that technology for blue hydrogen and carbon capture and storage (CCS) is not widely available. It was also noted that while there are many demonstration projects for these technologies, concerns were raised regarding the evidence-based effectiveness of CCS technology. Given the diverse needs and resources available in various countries that are developing similar technologies, it was recognized that arriving at a decision regarding a global energy network would be challenging. An example was given that in Australia where hydrogen is often produced from coal and paired with carbon capture and storage (CCS), new technologies have yet to demonstrate an ability to store a significant amount of carbon dioxide during production. One renewable alternative posited in the discussion was offshore wind, which was identified as a lucrative source of power production with newer, larger turbines being developed. It was stated that multiple exports of blue hydrogen have already been made from Saudi Arabia and the United Arab Emirates to Japan, Germany, and South Korea. It was also noted that the carbon dioxide associated with ammonia production was captured and utilized to produce methanol and in Enhanced Oil Recovery (EOR) operations.

It was suggested that there may be challenges with pipeline infrastructure that need improvements or changes. Additionally, the decrease in gas turbine durability due to high-temperature combustion from gas blending and pipeline embrittlement represents serious challenges. However, one participant expressed support for a system in Europe that is currently testing the use of pipelines to accommodate pure hydrogen rather than a natural gas and hydrogen blend. It was suggested that one of the primary issues with operating a pipeline for hydrogen alone is monitoring pressure within the pipeline. There would need to be a considerable amount of hydrogen in the pipeline to maintain the required pressure (i.e., maintain capacity), which could lead to more issues of operation. It was countered that the issue of embrittlement could be solved by following proper regulatory standards and maintaining pipe operations at lower pressures.

As hydrogen energy storage systems are still under development and not yet commercially viable, it was questioned whether they would be more efficient than current battery electric storage (BES) or PV. There were concerns expressed over the introduction of hydrogen energy storage based on the extended time periods required to develop the technology and test its safety. An example was raised regarding the

Netherlands addition of hydrogen to the national gas grid to support more efficient storage technology. Another major concern raised by debaters was the issue of safe and efficient hydrogen storage associated with solar and wind energy production, especially during high demand periods in the winter. Few debaters stressed that high usage times (i.e., in the winter) do not coincide with when the energy is primarily generated and therefore, it was indicated that a sufficient supply of hydrogen needs to be stored appropriately, as the quality of the gas would deteriorate overtime, requiring changes in infrastructure.

Another major focus was on the opportunity for power plants to promote reduced carbon dioxide emissions using solar energy in combination with battery storage and gas turbines with hydrogen blending. It was recognized that there is a tradeoff between the percentage of hydrogen mixed with natural gas and the use of solar. Additionally, the amount of combined cycle gas turbines needed to be installed increases when hydrogen and natural gas blends are increased, while PV and battery usages are decreased. It was noted that an increase in PV installations would require more land than is currently available. It was remarked that existing machines and infrastructure would need to be decommissioned to install new infrastructure to accommodate hydrogen blending with natural gas and potentially ammonia.

Position Paper Six
Decarbonising Ocean and Coastal Maritime Shipping Utilizing Hydrogen and Ammonia**

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Summary

The shipping industry is currently a major emitter of carbon dioxide (CO_2), but is facing increased pressure from international regulators, investors, and cargo owners to reduce the sector's carbon intensity. Hydrogen and ammonia are two promising fuel options to support the decarbonization of ocean and coastal maritime shipping. However, the technologies are not yet commercially available. Ammonia as a marine fuel is currently restricted by immature converter technologies but is expected to be available in 3–8 years. Both 2-stroke and 4-stroke engine technologies are developing on parallel paths, enabling uptake in both deep-sea and regional short-sea shipping. Hydrogen is less energy-dense, and its use is therefore expected to be focused on coastal shipping, with development focused on fuel cells and 4-stroke engines. The use of new fuels and fuel technologies will require increased focus on safety. The toxicity of ammonia and the extreme flammability of hydrogen bring new safety challenges, and safety regulations are not yet in place to support the widespread roll-out of these technologies. The lower energy-density, safety challenges, and dependence on renewable power or carbon sequestration mean that the introduction of hydrogen or ammonia as a marine fuel will necessitate significant additional investment in supply chains to support dedicated production, transportation, and storage facilities, resulting in higher fuel costs relative to traditional fuels. Actionable next steps must focus on fuel availability and infrastructure development. Clear policies (e.g., carbon tax, defined harmonized carbon intensity goals) will provide producers with confidence on future supply investment. Additionally, green energy corridors could support fuel availability and infrastructure development by pairing commitments on fuel supply and demand, and reducing first-mover risk.

Current Realities

The current bunker market is mature with fully developed infrastructure. The total bunker volume sold to ships in international trade was approximately 217 million tonnes (Mt) in 2019, with about 75% of the total reported fuel usage consumed by just three ship types: (i) tankers, (ii) bulk carriers, and (iii) container ships. In addition, domestic shipping sales amount to a further 57 Mt. Approximately 99.95% of bunker fuels consumed in 2019 were fossil fuel derivatives. Shipping currently accounts for approximately 2% of global energy-related CO_2 emissions, and increasing pressure to consider decarbonization pathways is leading to the exploration of alternative low-carbon fuels such as hydrogen and ammonia, amongst others. Low-carbon hydrogen and ammonia can either be produced from renewable energy sources via electrolysis (i.e., electrofuels) or from traditional hydrocarbon sources coupled with carbon capture and storage (i.e., "blue" fuels). Low-carbon ammonia presents an alternative fuel option for both short-sea and deep-sea shipping. Currently, neither 2-stroke nor 4-stroke engines using ammonia are commercially available, and the current Technology Readiness Level (TRL) of ammonia engines is estimated to be TRL 5-6. Key challenges to safe application in a marine context include ammonia's combustion properties, nitrous oxide (N_2O) emissions, toxicity, and potential ammonia slip. Engine technologies of appropriate size to serve the core markets may be available within the next 2–5 years. Solid oxide fuel cell (SOFC) engines present an alternate development route due to their ability to use ammonia fuel at potentially higher energy efficiency compared with diesel engines. A demonstration project for a 2 MW ammonia-driven SOFC system is planned for 2024, which will retrofit an existing supply vessel: the Viking Energy. The current TRL is estimated to be 5–6 but with a longer projected maturation than for internal combustion engines.

Given its low energy density, and corresponding space demands, hydrogen as a fuel is expected to be limited to the short-sea segment. Hydrogen 4-stroke engines are being projected with an estimated current TRL of 6–7. The world's first hydrogen-powered cargo ship, "With Orca," and the first hydrogen-powered tug, "Hydrotug," which use 4-stroke engines, are scheduled to be put into operation within the next couple of years. The proton-exchange membrane fuel cell (PEMFC) technology is an alternative application for hydrogen fuel cells that uses hydrogen to produce electricity and is relatively mature with an estimated current TRL of 8. Ballard Power Systems recently delivered two fuel cell modules having a total capacity of 400 kW to Norwegian ferry operator Norled for installation on the MF Hydra.

The current reality of bunkering is tied to the global oil market, with crude oil prices determining most of the cost of energy delivered to a ship. As a result, the bunkering market tends to favor markets with a mature petrochemical industry, and a price advantage delivering fuels to market. An estimated 55% of total bunker volumes for international navigation are sold in the 10 major bunkering hubs.

Several new regulations addressing emissions from international shipping took effect in January 2023, impacting ship design and operations. New CO_2 regulations from the International Maritime Organization (IMO) applicable to existing ships include the (i) energy efficiency index for existing ships (EEXI) addressing the technical efficiency of ships, (ii) the carbon intensity indicator (CII) rating scheme addressing ships' operational efficiency, and (iii) the enhanced Ship Energy Efficiency Management Plan (SEEMP) Part III, addressing the management system. At the Marine Environment Protection Committee 78th session (MEPC 78) in June 2022, the final guidelines supporting these regulations were adopted, including correction factors for the CII calculations and guidelines for the development of the SEEMP Part III. From a regulatory point of view, methanol gained an advantage over ammonia and hydrogen in December 2020 when the IMO approved the interim guidelines for the "Safety of Ships Using Methyl/Ethyl Alcohols as Fuel". If agreed upon, these guidelines can be used in lieu of the risk-based alternative design process for methanol-fueled ships. While no such international standard is currently in place for ammonia or hydrogen, the development of guidelines for these fuels is included in the IMO's work plan related to alternative fuels.

Scientifically credible approaches and challenges

A key challenge for electrofuels is the availability of renewable electricity, which currently accounts for more than 50% of electrofuel production costs. This results in limited production capacity and higher costs (i.e., between 3 to 5 times the price of non-decarbonized equivalents). This cost gap is forecasted to reduce over the coming decades due to a falling cost of renewable electricity and scaling of electrolyzer technology. Hydrogen and ammonia are also impacted by large energy losses associated with their production, distribution, and conversion onboard maritime vessels. This leads to low "well-to-wake" energy efficiency (e.g., only approximately 20% of the input electrical energy consumed on land reaches the propeller), adding significantly to the required production capacity. Production of low-carbon hydrogen or ammonia will therefore require substantial investment, which is compounded by the fact that associated infrastructure will also be required to support the decarbonization of other sectors (e.g., power sector) which will provide a greater decarbonization impact.

The lower energy-density of hydrogen and ammonia will make long distance-transport more expensive per unit of energy (i.e., based on transport cost per GJ of fuel) compared to traditional fossil fuels. For example, on a volumetric basis, the energy density of liquid hydrogen is 40% that of liquified natural gas (LNG), and when losses of 30%–40% from liquefaction and boil-off are included, this translates to hydrogen transport via ships being four times the cost of LNG per unit of energy.

This will lead to significant variation in bunkering approaches across ship types. As significantly increasing fuel storage capacity onboard ships presents commercial challenges, vessel operators may choose to increase bunkering frequency instead. This is not expected to impact the bunkering pattern of larger container liners, which bunker at either end of the roundtrip, but will likely impact other ship types (e.g., bulk carriers, feeder container liners). More regional bunkering hubs will be needed to support increased bunkering frequency and more direct shipping routes. As the cost of electrofuels is tied to renewable electricity cost, there will also be a commercial advantage to being located in geographies with access to lower cost renewables, or at major transshipment hubs. The role of bunker hubs is not likely to change, but the number and location of these hubs could.

Safety regulations for the use of hydrogen or ammonia as a marine fuel are currently not in place. The maritime industry has experience transporting ammonia cargo in gas carriers and using ammonia as a refrigerant, but the introduction of such fuels creates new challenges related to safe bunkering, storage, supply, and onboard consumption for different ship types. The full lifecycle carbon intensity of hydrogen and ammonia as fuel also requires specific attention as the production and transport of both electrofuels and blue fuels still retains some level of carbon intensity, with costs expected to increase as intensity decreases. This results in two key challenges: (i) determining what level of carbon intensity is acceptable and (ii) proving that a fuel consignment meets that level.

Evidence-based options (EBO) and actionable next steps (ANS)

The maritime industry is facing increased pressure from international regulators, investors, and cargo owners to reduce the carbon intensity of the sector. The uptake of carbon-neutral fuel needs to accelerate in the mid-2030s, reaching 40% of the fuel mix in 2050 under the current IMO ambitions, and 100% to decarbonize shipping fully. This will require time, investment, and combined efforts from all stakeholders in the maritime supply chain. Actionable next steps must focus on fuel availability and developing infrastructure to support the shift to carbon-neutral fuels:

- Establish integrated low-carbon fuel terminal(s) accommodating infrastructure for import, storage, distribution, and bunkering. Integrated terminal(s) will support increased cooperation between industrial sectors, reduce infrastructure investment risk, and ensure security of supply.
- Provide clear policy actions to coastal shipping companies to increase demand and provide confidence to producers. These policies need to offset the higher price of low-carbon fuels in the form of higher carbon prices or carbon credits.

- Develop green energy corridors to support the transition to alternative fuels on bulk freight routes. These routes normally have limited carriers and operate port-to-port, ensuring predictable demand, limited parties, and minimized upfront infrastructure investment. The corridors reduce first-mover risk by pairing commitments on fuel supply and demand in connected regions.
- Provide clear guidance on lifecycle carbon intensity requirements for maritime supply chains to reduce the risk to importers and enable optimization of the value chain. Assurance methods to track the veracity of the fuels will also be required.
- Establish frameworks to support large-scale piloting of low-carbon fuel technology and develop safety regulations to support bunkering and operation in local coastal regimes. This will enable more rapid technology development and enable demonstration of the safe application of new fuels for broader international adoption.

*** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Debate Six Summary

TOPIC: Decarbonizing ocean and coastal maritime shipping utilizing hydrogen, ammonia

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording, and its transcription, of the debate of the position paper prepared by Mr. James Laybourn (see position paper above and author biographical information in the Appendix). Mr. Laybourn initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Laybourn and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Laybourn, as evidenced by his position paper. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

Throughout the debate, it was stated that there are two potential pathways for catalyzing the decarbonization of the maritime sector: (i) introduction of technical requirements and carbon intensity thresholds for ships (set by the International Maritime Organization (IMO), that gradually become more stringent until the year 2050), and (ii) utilization of a carbon intensity trading scheme in the market in which those who surpass carbon thresholds are penalized, while those that stay under carbon thresholds receive rebates.

Accelerating the decarbonization of coastal shipping was asserted to largely be the responsibility of national governments. Debaters suggested that imposing carbon taxes on ships is one potential strategy that national governments could employ to incentivize decarbonization. Regarding deep water/international shipping, it was asserted that it is more challenging to standardize international carbon taxes, as this responsibility would largely fall upon the responsibilities of the IMO. Despite these propositions, infrastructure needs to incentivize and assist shipowners to implement decarbonization measures (e.g., bunkering ports, green corridors, etc.).

Throughout the debate, it was acknowledged that there are benefits to incorporating a number of different sectors (e.g., heavy industry, concrete, steel) into national hydrogen strategies for individual countries. Additionally, individual hydrogen strategies between countries will vary, considering that some have specialized industries and sectors that are hard-to-abate. One potential challenge that was raised regarding a government-mandated transition to decarbonized hydrogen and hydrogen-derivatives in some sectors is that decarbonized hydrogen is more expensive than more carbon intensive hydrogen. It was strongly argued that this would render other countries' more carbon-intensive fuels cheaper and more attractive to potential buyers.

It was repeatedly stated that as stakeholders transition toward carbon zero, the decarbonization endeavor becomes more expensive. It was therefore suggested that widely endorsed international standards for decarbonization need to be based on common methodologies emerging from full life-cycle analyses. This standardized system needs to accurately measure respective carbon emission intensities that are the foundation for increased practical understanding of how carbon-intensity measurements directly influence real-world decisions on the introduction of hydrogen energy.

Regarding the cost-effect reduction in fugitive emissions, a participant suggested that leading stakeholders looking to decarbonize often seek the easiest, quickest, and most cost-effective ways to start reducing emissions while still meeting government-set targets. It was repeatedly noted that as entities move forward in decarbonizing upstream emissions, there are concerns over (i) obtaining accurate measurements of emissions, (ii) establishing realistic baselines and benchmarks, and (iii) enforcing the applications of benchmarks in real-world applications. Ultimately, incentivizing companies to decarbonize by ensuring financial benefits and economic viability was viewed as imperative.

Numerous risks, as well as steps to minimize their impacts (i.e., risk mitigation) – especially for first movers (early-stage investors – were repeatedly identified throughout the debate as a major point of concern. It was identified that there is a growing need for policies that explicitly incentivize and compensate first-movers in order to facilitate and encourage the energy transition away from fossil fuels. Currently, there is pressure on many cargo ship owners to establish goals with sequential targeted deadlines for degrees of decarbonization. As some stakeholders have a significant influence on the shipping industry, it was posited that investment banks and funds could be prepared to meet minimum standards and potentially benefit first movers as an incentive to catalyze hydrogen and hydrogen-derivative adoption.

The role of the private sector and classification societies regarding hydrogen adoption was discussed. It was concluded that the private sector and classification societies need to be transparent in their communications and partnerships so that they can accurately disseminate research outcomes. One of the primary challenges identified for classification societies is taking a technology-agnostic public position as they aspire to support all potential customers, employing more than just one technology at a time as they set technology guidelines.

It was recognized in the discussion that an agreed-upon date for decarbonization in the maritime sector has not yet been established. It was suggested that future fuel choice and fuel mix for maritime sector decarbonization would depend largely on the price of the fuel itself in addition to competing fuels, regional availability, and the finalization of new fuel technologies. Eventually, a substantial supply, and subsequent security of supply, will encourage large-scale adoption by shipowners.

The concern of certain low-carbon fuels being produced and then kept for a nation's personal supply was identified. It was noted that a substantial increase of the supply of low-carbon fuels would be essential to ensuring that those fuels will be used in a diverse array of industries and subsequently exported to other countries. This reality of such a circumstance is mostly likely in countries with an excess capacity of renewables.

It was acknowledged that existing hurdles (e.g., lack of infrastructure) complicate the use of ammonia, and the related use of hydrogen, may require the imposition of regulations to overcome. While the timeline for these regulatory steps was suggested to be roughly five years, many observed that the process can be expected to be much longer since current maritime shipping infrastructure is not ready for the use of ammonia. There was some agreement regarding the need for regulations to be developed in parallel with technology and commercial models to incentivize consumer use and therefore, to establish a stable and reliable market.

It was largely agreed upon that safety and fuel leakage are of paramount public concern. Ammonia is toxic to humans, meaning current ship infrastructure models require that engine rooms, spare engine rooms, and key space areas within ships are unmanned. However, ammonia detectors could potentially manage small gas leakages onboard. Safety issues in the context of bunkering were a point of focus throughout the debate as onshore regulators have become increasingly sensitive and demanding in their safety regulations. It was suggested that mitigation measures (e.g., pilot programs) and more effective public communication methods need to be employed in regard to ammonia risk and safety to give greater confidence in the markets.

A number of different ammonia storage options were identified throughout the course of the debate, but repeated concerns arose regarding their cost benefits. It was suggested that cost limitations of current ammonia storage options would be difficult to overcome as consumers are more likely to invest in less expensive storage alternatives. Decisions by shipowners concerning ammonia storage options were recognized to be primarily driven by the available infrastructure to support these storage options.

The concept of retrofitting older vessels for new fuels was repeatedly mentioned. It was identified that, while alternative fuels can be utilized in existing engines without requiring major modifications, challenges arise when using hydrogen and ammonia as they require different infrastructure and engine technology. It was further asserted that numerous studies have been conducted on the cost-effectiveness of retrofitting ships for hydrogen and ammonia. Initial conclusions largely suggested that building a new vessel is a cheaper alternative to retrofitting.

Questions surrounding the location of existing ammonia terminals repeatedly arose during the debate. It was acknowledged that many ammonia hubs are currently positioned to better serve the fertilizer-based petrochemical industries, and are not in ideal locations to be utilized conveniently by the maritime sector. However, it was recognized that there is potential for change as some companies are exploring establishing better-located ammonia hubs for the shipping industry.

It was suggsted that low energy density from sources such as hydrogen means there is a need for greater storage capacity in ships to obtain the same amount of energy, presenting further need for more bunkering ports as many ship operators do not want to increase the capacity of their storage tanks. Likewise, green corridors utilized in maritime shipping have a lower energy density, which questions the current global infrastructure of bunkering hubs and the potential need for more. As a result, initial green corridors are being prioritized in places that have access to lower-cost renewables since it is more expensive to transport these fuels. It was suggested that many ship operators prefer frequent bunkering rather than significantly increasing the capacity of storage tanks. This led to the identification of potential advantages to bunkering (e.g., access to lower-cost fuels, therefore avoiding long-distance transport). Debaters discussed future expectations for an increase in bunkering ports. Today, bunkering ports are concentrated with 55% of the global supply of ammonia-based fuel, originating from only 10 total bunkering ports.

It was stated that the shipping industry needs to embrace technological advancements and innovative industrial changes to ensure compliance with current regulations. It was subsequently questioned how shipping manufacturers stay competitive in bunkering. In response, it was asserted that the shipping industry is extremely cost-sensitive as fueling a ship with non-economical fuel could be detrimental to a business where competitors would continue to fuel at a more economical rate. This highlighted the importance of trust that shipowners require in the market to be confident in their investment decisions.

Position Paper Seven
Carbon Capture, Storage, and Utilization (CCUS) for Hydrogen/Ammonia Production and Beyond**

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Summary

The role of clean hydrogen in the future energy landscape continues to gain momentum. With global hydrogen production of currently 95 million tonnes per annum and demand expected to exceed half a billion tonnes per annum by 2050, ramp-up of clean hydrogen production capacity is needed to meet both demand and climate targets. To progress at scale, we need to: (i) avoid focusing on one hydrogen production process over another (ii), identify the most suitable technologies for a given region, and (iii) provide funding and support mechanisms.

Current realities

Clean hydrogen can play a key role for emissions reduction in the power generation, transportation, and industrial sectors. Hydrogen can be used in turbines or fuel cells to generate electricity, in fuel cells to power electric vehicles, as a source of domestic and industrial heat, and as a feedstock for industrial processes to produce chemicals such as ammonia, methanol, and other synthetic fuels. Hydrogen may also be used to store excess energy generated by intermittent renewable electricity sources when supply exceeds demand, albeit with significant losses. The benefit of hydrogen is that it produces zero carbon emissions at the point of use.

Globally, approximately 95 million tonnes of hydrogen is produced annually (Mtpa). According to the International Energy Agency (IEA), only 1.4% comes from clean hydrogen production, 1% from fossil fuels with CCS, and less than 0.4% from renewable-powered electrolysis. Future hydrogen demand is expected to exceed half a billion tonnes by 2050, making up more than 20% of the final energy demand globally. If demand is met by clean hydrogen, this would result in avoiding annual emissions of nearly 7 gigatonnes of CO_2, equivalent to 20% of global emissions if we continue our current trajectory. This would require scaling up clean hydrogen production capacity from less than 2 Mtpa today, to over half a billion tonnes in less than 30 years. Rapid ramp-up of production capacity is a critical requisite for hydrogen to play a significant role in achieving ambitious climate targets.

The path to reaching this demand is still unclear, with several fossil fuel-based and renewable hydrogen production technologies that could be employed. The scale and technologies to meet this demand in a specific location will be dictated by several factors including (i) the emission intensity, (ii) cost of production, (iii) resources required (e.g., electricity, fuel, water land, CO_2 storage), and (iv) emissions-reduction potential for a given clean technology, or the abatement opportunity.

Scientifically and technologically credible approaches and challenges

Low-emission hydrogen production methods available today include steam methane reformation (SMR), autothermal reformation of methane (ATR), partial oxidation (POX), and coal gasification, each coupled with CCS, and electrolysis of water powered by near zero emissions electricity such as renewable generation or nuclear power.

While costs and available resources will play a critical role in the choice of technologies that are employed in a given region, ultimately, the market will demand hydrogen with very low life cycle emissions intensity to comply with climate-centric targets. The benchmark method for production of hydrogen is by SMR without CCS with an emission intensity near 9.0 kg of CO_2 per kg of hydrogen ($kgCO_2/kgH_2$). The current highest emitting production pathways are coal gasification without CCS, and electrolysis using grid power from fossil fueled generators. Both have an emission intensity near 22 $kgCO_2/kgH_2$.

Modern (i.e., next generation) SMRs are being engineered to optimize hydrogen production with a capture efficiency of 95% or greater with production emission intensities near 1.8 $kgCO_2/kgH_2$, considerably lower than the benchmark SMR without CCS. Other next generation hydrogen production technologies including ATR, POX, and coal gasification optimized with CCS offer similar emissions intensities. Life cycle emissions (e.g., fugitive emissions from coal or gas production) are not included, and will increase the emissions intensities, and will need to be carefully managed.

Hydrogen produced by electrolysis using renewables can produce similar emission intensities to hydrogen produced using next generation fossil fuel and CCS technologies. The challenge with renewables is the intermittency of electricity generation and consequent variable electrolyzer operation that can result in difficult control and operation and possible equipment damage or failure. To avoid excessive variable electrolyzer operation, either energy storage (e.g., batteries) or grid buffering is required. This can further add to the emission intensity for the hydrogen produced. If fossil fuel-based grid power is used to buffer renewable electricity supply, the carbon intensity can rapidly rise to beyond the benchmark SMR with no CCS. The production process does not automatically determine whether hydrogen is clean, and only the life cycle emission intensity of production can determine if hydrogen is clean. Clean hydrogen can be produced from both fossil fuels and CCS and electrolysis with renewables.

There is a range of costs for the production of clean hydrogen for both fossil fuels with CCS and renewable powered electrolysis. Key determining factors of cost include the price of coal or natural gas, and the quality of the renewable energy resource (which impacts electricity price and the capacity factor of the electrolyzers) for renewable hydrogen. Overall, hydrogen produced from coal or gas with CCS is the lowest cost clean hydrogen today and is expected to remain so until at least 2030 according to the IEA, and the consensus from most other techno-economic models.

Resource constraints (e.g., land, water, electricity, coal, gas, and available CO_2 storage) could also prevent scale up of hydrogen production in a given region. Hydrogen produced using fossil fuels with CCS and renewable powered electrolysis require similar amounts of water (around 6-9 kg of water per kg of hydrogen). The electricity required for hydrogen produced with fossil fuels with CCS ranges from 1.91-3.48 kWh/kgH_2, whereas electrolysis has an extremely high electricity demand at 55 kWh/kgH_2. To put this into context, using the Asian Renewable Energy Hub (AREH) project as a basis, for 1 million tonnes per year of hydrogen, the land required for wind and solar PV would be 3,270 km^2 (for a 48% capacity factor). For fossil fuels with CCS, the land required is between 14-17 km^2 (assumes 500 km of piping, injection, and storage infrastructure). Hydrogen produced using fossil fuels with CCS has a significant advantage over renewable power electrolysis with respect to the electricity required to produce it, and the land required to host dedicated renewable generation.

Hydrogen production with fossil fuels and CCS requires coal or gas; both which are relatively plentiful with mature industries and established supply chains. It also requires sufficient underground geological storage of CO_2. If all clean hydrogen produced in 2050 were produced by fossil fuels with CCS, annual storage capacity of around 8 billion tonnes of CO_2 would be required, compared to a global capacity of many thousands of billions of tonnes. Geological storage of CO_2 will not limit the hydrogen produced by fossil fuels with CCS; however, it will dictate the locations suitable for clean hydrogen production with fossil fuels and CCS.

Lastly, there is the question of whether hydrogen production by renewables is the most effective use of the significant electricity required. If grid power comes from natural gas combined cycle (NGCC) generation, renewable electricity delivers approximately three times more emission abatement than when used to produce hydrogen, which then displaces the combustion of natural gas. If grid power comes from coal-fired generation, this increases to approximately eight times more emission abatement. Renewable electricity needs to be used to displace unabated fossil fuel power generation, where possible, before the production of hydrogen which then displaces natural gas combustion.

Evidence-based options (EBO) and actionable next steps (ANS)

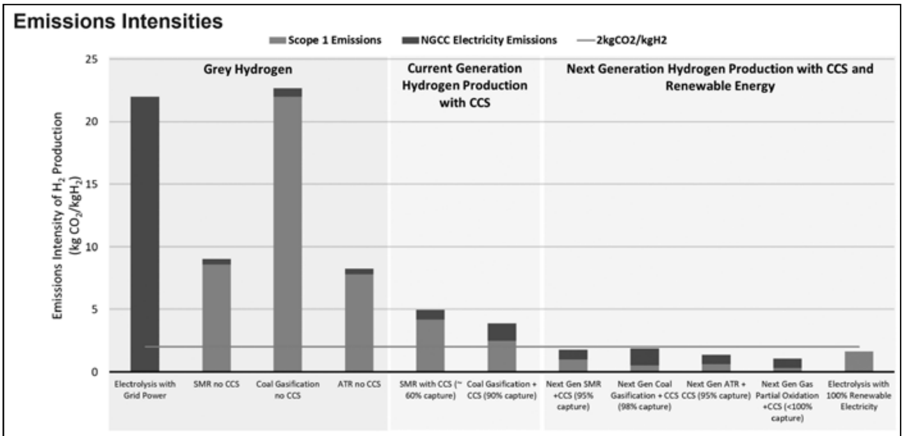
The most urgent need is to decarbonize in the quickest and most cost-effective way. If large-scale, low-cost hydrogen is required, the use of available low-emitting processes to produce this hydrogen and demonstrate through a full life-cycle analysis, for each project, a positive reduction in CO_2 emissions. Given the demand required, hydrogen produced by fossil fuels and CCS and electrolysis using renewables will be necessary. With clean hydrogen produced by fossil fuels and CCS a necessary part of the solution, the following actionable next steps will support large-scale deployment:

- Continue to invest public and private funds in research to develop and improve the production efficiency of clean hydrogen production technologies. Investment (particularly public) needs not discriminate between fossil fuel CCS, and renewable energy based technologies.
- Develop internationally recognized emission intensity standards for the certification of clean hydrogen, accompanied by audit and verification processes. This will be necessary to allow customers to efficiently and confidently purchase clean hydrogen, irrespective of the production process.
- With internationally recognized standards for the certification of clean hydrogen in place, countries need to develop internationally harmonized regulations based on those standards. This could include an emission intensity threshold for clean hydrogen production needed to qualify for policy benefits.
    - Regulations need to be robust yet workable, and not obstruct clean hydrogen production and uptake.
    - Internationally harmonized regulations can avoid countries with relaxed or no regulations skewing producers to cheaper, emission-intensive hydrogen production methods, leaving countries with tighter regulations with a constrained hydrogen supply.
- Use rigorous analysis to define the role of clean hydrogen from fossil fuels and CCS in meeting national emission reduction targets when developing hydrogen strategies and national decarbonization plans, and communicate this to industry and the public *writ large*.

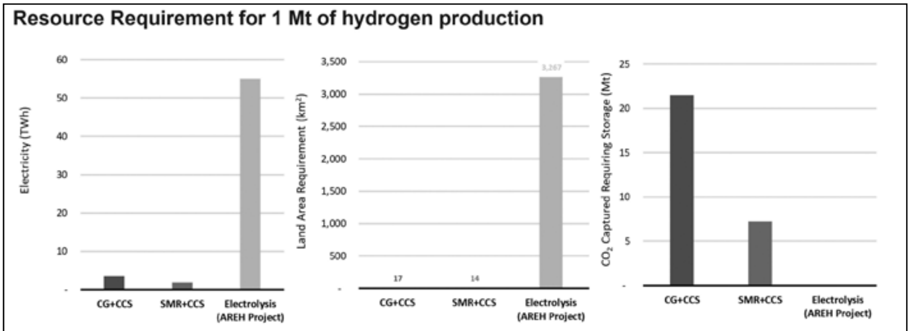
- Assessing the production of clean hydrogen using fossil fuels and CCS requires countries to identify and evaluate geological storage resources using existing data collected for hydrocarbon exploration.
- Create an assured long term high value on CO_2 storage.
- Identify opportunities for CCS hubs where hydrogen produced from fossil fuels and CCS can be produced and facilitate their establishment.
- Provide material capital grants to support clean hydrogen using fossil fuels and CCS projects/hubs to initiate private investment, where necessary.

*** A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Figure 1: Clean H_2 Production Cost, Intensity and Resources

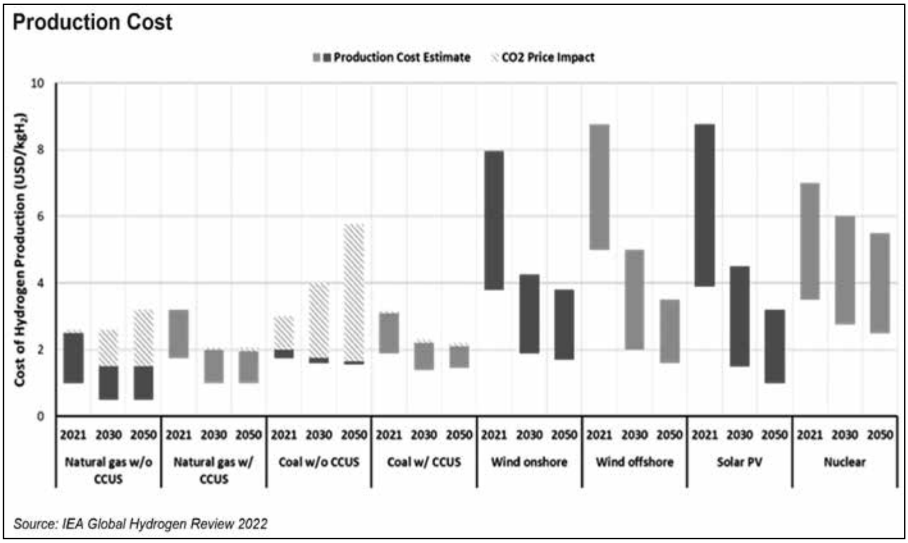


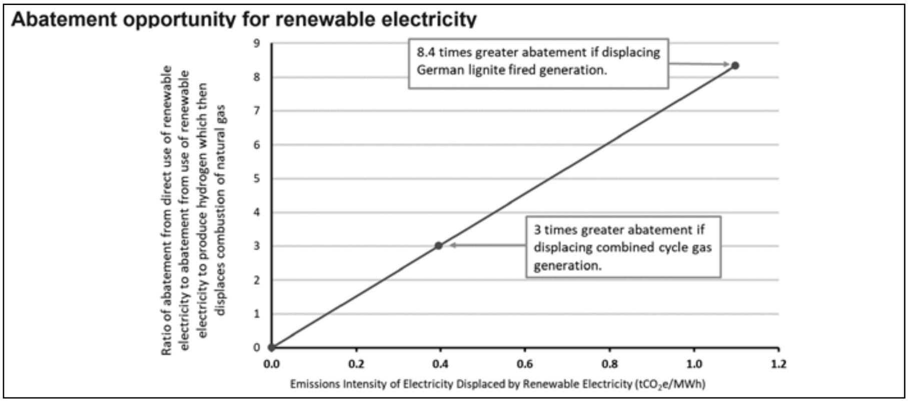
Assumes 400kgCO2/MWh grid electricity for CCS. Electricity for production of coal/gas is included. Assumes 55kWh/kgH$_2$ for electrolysis & 30kg CO$_2$/MWh renewable electricity. Other life cycle emissions such as from fugitives and electrolyser manufacture are additional.



Includes electricity for coal or gas production. Land for blue H$_2$ assumes 500km x 20m wide corridor for CO$_2$ pipeline plus production facility and injection wells. Land for green H$_2$ based on land required for AREH project – wind & solar PV. Power for electrolysis assumes 55kWh/kg of hydrogen. CO$_2$ captured requiring geological storage per kg of H$_2$ is 21.5kg for CG+CCS and 7.2kg for SMR+CCS

Figure 1 (Cont'd)





Clean hydrogen production costs, emissions intensities, and resource requirements.

Debate Seven Summary

TOPIC: Carbon capture, storage, and utilization (CCUS) for hydrogen/ ammonia production and beyond

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Matthew Loughrey (see position paper above and author biographical information in the Appendix). Mr. Loughrey initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Loughrey and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Loughrey, as evidenced by his position paper. Rather, it is, and should be read as an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

Global Carbon Capture and Storage (CCS) production and demand was a major topic of discussion throughout the debate. It was stated that the world produces 95 million tonnes per annum of hydrogen for various sources (e.g., chemical and fertilizer industries), of which only 1% of around 1 million tonnes per annum is clean. Debaters unanimously agreed that all types of hydrogen production, transportation, storage, and use, including blue and green options, can make differing degrees of contributions to producing energy under conditions that ensure environmental sustainability. These differences are significant and need to be seriously considered in all policy decisions concerning the major transitions underway in global energy systems. While critical goals encompass the establishment of energy systems that meet the myriad human demands in a rapidly increasing global population using rationale economic models, the environmental impacts of these decisions control the overarching consequences experienced across the global landscape.

Uncertainty was expressed regarding the future status of coal as a contributor to common fuel mixes, especially if carbon capture, utilization, and storage (CCUS) technology were demonstrated to be less effective than currently thought under commercially and economically viable conditions. It was recognized that if (i) the evidence-based effectiveness of CCUS was proven to be high, (ii) sustainable public confidence was established, and (ii) competitive economic systems installed, coal-fired power sources might be important alternatives for hydrogen production over the long-term.

It was claimed that the potential demand for hydrogen production by 2050 could reach approximately half a billion tonnes per annum. To meet this demand, there is a need to rapidly scale up new and emerging markets (i.e., power generation, building, heating, power, and transportation). There appeared to be uncertainty, however, regarding how to rapidly scale up new and emerging hydrogen markets to meet this demand. Debaters unanimously agreed that a global effort to develop adequate technology is required to support the rapid scale-up of hydrogen and ammonia energy demand, production, and utilization.

Several factors that influence decisions to expand hydrogen energy demand were acknowledged, including (i) redefining emission intensity of different methodologies for hydrogen production, (ii) reducing the cost of clean hydrogen production, (iii) expanding the availability of resources required to support hydrogen production, and (iv) improving abatement technology. It was asserted that to achieve large-scale hydrogen production there is a need to implement low greenhouse gas-emitting processes and technologies. It was repeatedly claimed that while all methods for hydrogen production would be necessary to meet a rapid increase in demand, each production method would need to demonstrate a positive reduction of CO_2 emissions (low carbon intensities).

It also was asserted that the identification and development of CCS hubs are essential factors for the large-scale implementation of hydrogen that minimizes environmental impact. It was stated that locating new hydrogen production facilities adjacent to existing industrial clusters provides several benefits, including the opportunity to supply hydrogen to adjacent industrial emitters, as well as to share CCS costs. It was suggested that the appropriate next steps to support the large-scale development of environmentally compatible hydrogen include continued investment from both the public and private sectors, as well as continual development and improvement of the production efficiency of environmentally compatible hydrogen production technologies. It was asserted that consideration of engineering economics and social license to operate is crucial, as the supply chain requires multilateral acceptance.

A highly debated topic was the prioritization of blue versus green hydrogen production methods. Factors pertaining to the comparison of blue versus green hydrogen (e.g., cost, storage, land use, power supply, fuel) were discussed. First, concern was raised that upstream fugitive emissions are not considered in the comparison of emissions intensities for blue and green energy production. A 2022 Stanford University study on fugitive emissions of both oil and gasses was discussed, in which 115 flights were flown over the New Mexican Permian Basin over 16 months. The study found that the fugitive emissions of methane, which is

28–36 times more potent than CO_2 in 100 years, was 9%, indicating that the official Environmental Protection Agency (EPA) figures are not up to date with current evaluations. Further, it was noted that there needs to be a definitive understanding regarding a regulatory timeline for the transition period from blue to green hydrogen to meet climate change goals. The expectation that the transition away from a fossil fuel-powered grid would offer a significant abatement if powered by renewable energy as opposed to hydrogen energy was questioned. Since there was uncertainty regarding the abatement opportunity for a renewable energy-powered grid versus a hydrogen-powered grid, the need for rigorous analysis to understand which energy source offers the greatest abatement opportunity was asserted.

It was repeatedly asserted that there is a need to account for upstream emissions, including expected methane emissions, when comparing potential greenhouse gas emissions of different hydrogen technologies. It was identified that the gas reservoirs have the potential to store CO_2 produced from power plants if the CO_2 is captured and transported to the site. A participant argued that blue and green hydrogen production methods would achieve a 95% CO_2 capture rate in the next generation, however, when including the current estimate of upstream methane emissions (i.e., next-generation steam methane reforming (SMR) processes), the percentage decreases five- or sixfold.

Concern was posited regarding the allocation of investment to renewable energy versus CCS-based projects. If the money allocated to CCS projects is higher than what is allocated for renewable-based projects, it was suggested that there is a risk that renewable-based projects will stall. Another participant stressed the importance of using CCS in hard-to-abate industries like steel and cement. Hydrogen can be a facilitator to meet demand and support the abatement of emissions from multiple industries. A participant suggested identifying environmental Social License to Operate (SLO) overlays to determine the realistic capacity of CCS. The importance of private organizations supporting knowledge development and acceptance of CCS/CCUS was asserted.

It was stated that blue hydrogen production will be cheaper than other production methods until 2030, and beyond 2030 there is a need for a cost comparison between hydrogen production methods. There was consensus that hydrogen projects need to proceed more quickly to meet expected demand to a sufficient degree. Concern regarding withholding investments to wait for technology to advance was assured by multiple participants. It was widely discussed that there were concerns regarding the prioritization of affordable hydrogen production methods above other concerns (e.g., environmental concerns). Conducting rigorous cost-benefit analyses was recommended by many debaters to understand the various pathways needed to decarbonize and understand the inherent impacts on a country's Gross Domestic Product (GDP). It was asserted that a country needs to prioritize minimizing the cost that will be transferred to the next generation of a given country and that energy modeling can be utilized to assess this cost. In response to the analyses of future energy costs, a participant referenced models from the Institute of Energy Economics Japan and the Institute of Applied Energy that could be utilized for an integrated assessment regarding the relationship between GDP and energy systems. It was claimed that hydrogen production is not likely to scale significantly until after 2030, so there is a risk of blue hydrogen production becoming uncompetitive against green hydrogen production from the next decade onwards, with an additional risk of stranded assets (i.e., disincentivizing early investments in hydrogen energy).

It was identified that the reduction in price combined with technological improvement in renewable energy has far outpaced that of blue hydrogen. While it is likely that this trend will continue, there remains a need to accurately predict hydrogen costs in the upcoming decades. It was noted that for blue hydrogen, there is a potential for incremental reductions in cost. It is unlikely, however, that there will be substantial reductions in cost unless there is a technological breakthrough. It was acknowledged that the profitability of blue hydrogen is not promising in the absence of carbon pricing, therefore regulations need to place a high value, long-term price for carbon to ensure that industries can decarbonize. Although, it was claimed that if investments in blue or green hydrogen were paused to allow technology to develop, there would be a risk of being unable to meet the demand going forward.

It was claimed that 7,000 million tonnes of CO_2 storage is available globally, and eight gigatons of storage is required for all hydrogen production. It was asserted that negative emissions are expected to play a crucial role in the future in mitigating global greenhouse gas emissions. The Global CCS Institute is actively examining and evaluating technologies designed to reduce emissions, including direct air capture, bioenergy, and CCS. These technologies remain in early stage development and therefore, it was suggested that the primary focus needs to be on improving and monitoring technologies for direct air capture and BioEnergy with Carbon Capture and Storage (BECCS).

It was asserted that blue hydrogen has a significant advantage compared to renewable energy paired with electrolysis regarding power supply and land. It was suggested that the amount of land available for renewable energy projects is not an issue due to the large areas of uninhabited desert sites with enormous renewable energy potential in many parts of the world. A participant argued that since available land resources vary, and some countries without available resources for renewable energy projects may have to offset grid power with a surplus of renewable energy from another country that can transport surplus energy.

Concerns were expressed regarding the utilization of blue hydrogen as justification for the exploitation and development of new oil and gas fields. It was suggested that there is a need to identify suitable locations for establishing hubs with the right regulatory frameworks and cleaner upstream emissions and determine the capacity for CO_2 capture. Another participant noted that financial institutions consider the return on investment as a determining factor regarding whether capturing and transporting CO_2 long distances are economically viable.

It was acknowledged that to utilize CCS technology from a platform, a few of the fundamental questions that need to be addressed include (i) the space required for a given facility and (ii) the power required to power the compression or liquefaction steps. A project in the Latrobe Valley was discussed to highlight technological carbon capture inefficiency wherein carbon was not captured in the production of liquified hydrogen at the target rate. Another participant identified that the next step for the Latrobe Valley project is to evaluate transportation options which include (i) transportation to the storage location and (ii) assessing a project currently in development through ExxonMobil (designed to store CO_2 once it comes up to the commercial pilot stage). It was argued that grid-connected green hydrogen, when combined with renewables and demand response, is an effective way to decarbonize grids and that there are established methodologies for auditing and managing the carbon emissions of the power used.

It was repeatedly posited that governments need to ensure the efficient development of hydrogen hubs by providing material grants for projects with evidence-based long-term benefits (e.g., decarbonization and energy security). There was uncertainty that carbon tax would fully address problems with investments not being allocated in areas with the greatest decarbonization interests. A participant responded that larger scale hubs could be useful for the biggest hydrogen production developments, potentially direct air capture down the line to decrease emissions in hard to abate sectors.

It was noted that China's hydrogen policy heavily favors green hydrogen, but blue hydrogen production was previously considered a part of China's future energy mix. It was identified that China is a net natural gas importer, making blue hydrogen a strategic risk due to the price volatility of fossil fuels. It was discussed that China is developing an extensive role in the renewable energy supply chain to control an entire internal supply chain for green hydrogen. Another participant commented that if China were to capture and store CO_2 from its expansion of coal-fired plants, it would be an exporting nation for CO_2, placing greater competition on those attractive storage locations.

It was widely asserted that there is a need for an independent international body to produce internationally recognized emission intensity standards (e.g., an International Organization for Standardization (ISO) standard) that would establish the evidenced-bases parameters for certifying the environmental impacts of hydrogen production, transportation, storage, and usage. Regulation and enforcement of a certification system requires government oversight. A participant identified a need for emission intensity standards to include an emission threshold that projects need to achieve to receive policy benefits. It was also asserted that there is a need for rigorous analysis to define the role of hydrogen, fossil fuels, renewables, and CCS in national hydrogen strategies and national decarbonization plans.

It was recognized that harmonized regulations would lead to an increased open market from which one can purchase hydrogen from multiple regions. For countries producing blue or green hydrogen below a certain threshold, consumers would have the flexibility to purchase hydrogen from multiple different markets as opposed to a country that might have more relaxed regulations in place and emission intensities that are higher.

Position Paper Eight
Policy Recommendations Toward the Adoption of Hydrogen/Ammonia Hydrogen: Combustible Fuel Without CO_2 Emissions**

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Summary

Since hydrogen is combusted like a fossil fuel but does not emit carbon dioxide (CO_2), it can contribute to decarbonization by phasing out fossil fuel consumption. In addition, if co-firing of hydrogen and ammonia is applied at thermal power plants currently powered by gas and coal, use of these existing plants can be continued while mitigating CO_2 emissions. For Asia and member countries of the Association of Southeast Asian Nations (ASEAN) to achieve higher economic growth by 2050, the production of an affordable and stable energy supply using existing power assets will be critical in the pursuit of becoming carbon-neutral by 2050, particularly considering the existence of many relatively new thermal power plants in the region. It may not be economically viable to produce hydrogen primarily from fossil fuels and through electrolysis, which costs more than producing hydrogen as the by-product of several manufacturing processes (e.g., iron, steel, caustic soda). Therefore, it is vital for the public and private sectors to establish a joint hydrogen supply network in Asia to increase hydrogen supply and demand. Three areas of technological development need to be pursued to achieve large-scale uptake of hydrogen: (i) production, (ii) transportation, and (iii) demand. As the private sector assumes the role of hydrogen technology development, the public sector (e.g., government) needs to play a supporting role by formulating appropriate policies and providing funding. It is critical to increase hydrogen demand and supply amounts gradually while continually working to reduce the cost of the hydrogen supply. Approaches such as gradually increasing the co-firing ratio of hydrogen and ammonia at thermal power plants can facilitate this goal.

Current realities

Hydrogen is expected to replace fossil fuels (e.g., coal, oil, natural gas) because it is combusted in the same way as fossil fuels. Hydrogen can potentially be used to power various sectors, including: (i) direct reduced iron in the iron steel sector (i.e., replacing coal), (ii) combustible fuels for boilers and furnaces in factories (i.e., replacing oil and natural gas), (iii) transport fuels for vehicles, trains, airplanes, and ships (i.e., replacing oil), (iv) combustible fuels for water and space heating in the residential and commercial sectors (i.e., replacing natural gas), and (v) power generation (i.e., replacing coal and natural gas). The greatest advantage of hydrogen is that it never emits CO_2 after its combustion. Consequently, hydrogen is expected to contribute to achieving a carbon-neutral region by 2050–2060 by phasing out fossil fuels.

ASEAN recorded high economic growth (i.e., 5.0% per year) during 1990–2019 and is projected to maintain average annual growth of 4.1% during 2019–2050, according to the East Asia Summit (EAS) Energy Outlook being updated by the Economic Research Institute for ASEAN and East Asia (ERIA). Thus, ASEAN will continue to need affordable energy, especially electricity, which is projected to have the highest growth amongst fuels at 4.0% per year during 2019–2050, using existing thermal power plants. In addition, ASEAN's thermal power plants are relatively young, so if ASEAN uses hydrogen and ammonia for co-firing at existing thermal power plants, these plants can be used continuously while mitigating CO_2 emissions.

Hydrogen produced either from fossil fuels through the application of reforming and gasification technologies coupled with carbon capture and storage (CCS), or through electrolysis using electricity produced with renewable energy, is currently much more expensive than the by-product hydrogen produced by several manufacturing processes (e.g., iron and steel, caustic soda, petroleum refinery). Currently, hydrogen energy is economically infeasible due to the high cost of hydrogen supply. An effective way to reduce the cost of the hydrogen supply is to increase the volume of hydrogen demand and supply and to promote innovative technology in both hydrogen production and transport. In this regard, public–private cooperation could establish an appropriate hydrogen supply system in Asia.

Since the private sector will implement technological developments to improve hydrogen production and supply, the government needs to play a complementary role by supporting the private sector through the establishment of appropriate hydrogen policy and financing mechanisms. The following three projects, supported by Japan's New Energy and Industrial Technology Development Organization, are examples of public–private cooperation: (i) Brunei project: based on gas by-product from liquefied natural gas production, hydrogen is produced through the application of reforming technology and transported to Kawasaki, Japan using methylcyclohexane (MCH) as a carrier molecule, (ii) Australia project: based on low-rank coal (e.g.

lignite, brown coal) in South Australia, hydrogen is produced by applying gasification technology and transported to Kobe, Japan using liquid hydrogen (LH2), and (iii) Fukushima project: hydrogen is produced by electrolysis technology using electricity from a solar photovoltaic system for consumption by vehicles, factories, and the residential and commercial sectors.

Scientifically and technologically credible approaches and challenges

The ERIA hydrogen potential study phase 1 (2017–2018) forecasts the hydrogen demand and production of each EAS country, except Russia and the United States, until 2040. The 16 EAS countries were classified into three groups: (i) hydrogen-exporting countries (e.g., Australia, Brunei Darussalam, Indonesia, New Zealand), (ii) countries in which hydrogen demand and production are almost balanced (e.g., intraregional), and (iii) hydrogen-importing countries (e.g., Japan, the Republic of Korea, Singapore). Hydrogen is expected to be traded amongst the exporting and importing countries throughout the years assessed in the study. This classification is dependent on the balance between hydrogen demand potential in the final energy consumption and power sectors compared to hydrogen production potential from coal, oil, gas, biomass, and renewable energies (e.g., solar, wind). Thus, the cost of hydrogen supply will be crucial to establish trade in hydrogen. Hydrogen cost is based on the following elements: (i) production, (ii) preparation for loading (e.g., hydrogenation in the case of MCH, liquefaction of LH2, the production of ammonia as hydrogen carriers), (iii) sea transport, and (iv) preparation for unloading. The current cost of hydrogen supply (i.e., around ¥100 per normal cubic meter (Nm^3)) is projected to fall to ¥50–¥70/Nm^3 by 2030 and ¥30–¥50/Nm by 2040–2050.

The EAS Energy Outlook, updated by ERIA in 2021–2022, produced three energy outlook scenarios: (i) business as usual, (ii) an alternative policy scenario to reflect aggressive Energy Efficiency and Conservation and renewable energy targets, and (iii) the low-carbon energy transition (carbon-neutral) to reach a carbon-neutral society by 2050 or after. The EAS Energy Outlook covered the EAS 17 countries and forecasts hydrogen demand in 2050 in the final energy consumption sector to reach 100 million tons of oil equivalent (Mtoe) in ASEAN Member States and 229 Mtoe in the other seven countries. On the other hand, it projected hydrogen demand for power generation to be 252 Mtoe in ASEAN and 1,286 Mtoe in the other seven countries. Therefore, hydrogen potential for power use will be much higher than for final energy consumption use.

The ERIA hydrogen potential study phase 3 (2019–2020) conducted two interesting analyses: (i) an estimation of the hydrogen production potential based on unused energy (e.g., hydropower that cannot be developed economically, low-rank coal such as lignite and brown coal, gas flared at gas production sites) in the EAS region, and (ii) an optimal solution for hydrogen transportation in the EAS region. The estimated result was 10 billion–30 billion cubic meters (2–8 Mtoe) by 2040, which falls far below hydrogen demand until 2050. Nonetheless, as an initial step, hydrogen production using unused energy makes sense, especially for renewable energy. There are currently two transport modes for hydrogen: MCH and LH2. By applying an optimized approach (e.g., the linear programming method), hydrogen supply routes from origins to destinations are sought to minimize the hydrogen transport costs. MCH performs better in the case of short- and middle-distance and small to medium-sized hydrogen transport. Comparatively, LH2 is advantageous for long-distance and large-volume hydrogen transport.

Evidence-based options (EBO) and actionable next steps (ANS)

The cost of hydrogen supply is crucial to the penetration of hydrogen, and it is expected to decline to ¥10–¥20/Nm^3 by 2040–2050, according to Japan's National Hydrogen Strategic Plan. Extensive technological developments on both the hydrogen supply and demand sides will be indispensable.

- Provide strong government support, including funding, for EAS countries, especially developed countries, for research and development of technologies for hydrogen production, transportation, and storage.
- Promote innovative technological developments in hydrogen through private sector efforts on both the supply and demand sides, followed by hydrogen pilot or demonstration projects applying developing technologies with government financial support. The implementation of these pilot and demonstration projects will support the affordable supply and increased consumption of hydrogen across sectors, including in developing countries.
- Encourage the membership and engagement of developing countries in hydrogen alliance entities led by developed countries in Asia to promote education regarding technological developments in hydrogen supply and demand. When hydrogen becomes cost-competitive after 2040, developing countries can start to use it on a commercial basis.
- Develop a robust hydrogen supply network connecting hydrogen-producing and -consuming countries, similarly to the liquefied natural gas supply chain.
- Standardize hydrogen specifications (e.g., trading and statistics units, certificate system to define green, blue, and gray hydrogen) globally.

References

Kimura, S. and P. Han, eds. (forthcoming), *Energy Outlook and Energy Saving Potential in East Asia*. Jakarta: Economic Research Institute for ASEAN and East Asia.

Kimura, S. and Y. Li, eds. (2019), *Demand and Supply Potential of Hydrogen Energy in East Asia*. Jakarta: Economic Research Institute for ASEAN and East Asia.

Kimura, S., A.J. Purwanto, I. Kutani, T. Hiruma, D. Lutfiana, and C.E.N. Setyawati, eds. (2022), *Demand and Supply Potential of Hydrogen Energy in East Asia – Phase 3*. Jakarta: Economic Research Institute for ASEAN and East Asia.

Ministry of Economic, Trade and Industry (METI), Japan (2017), *Japan's National Hydrogen Strategic Plan.*

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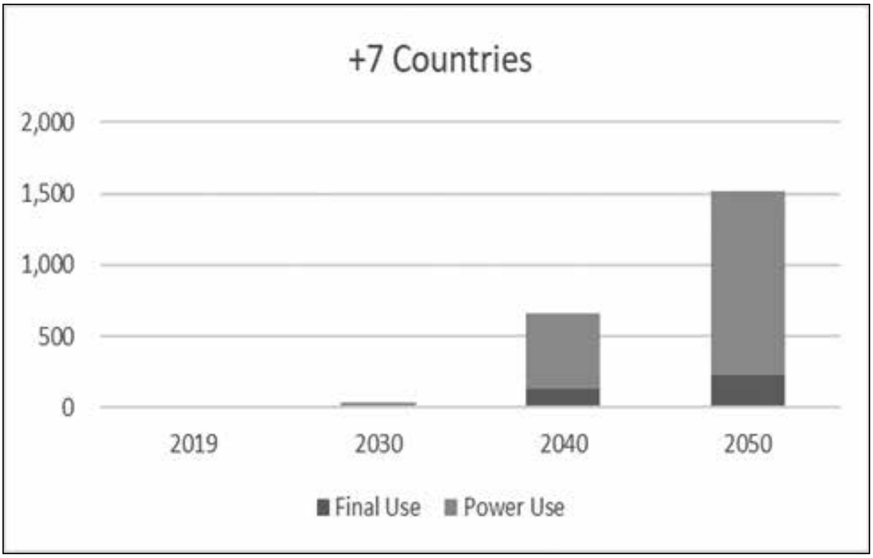
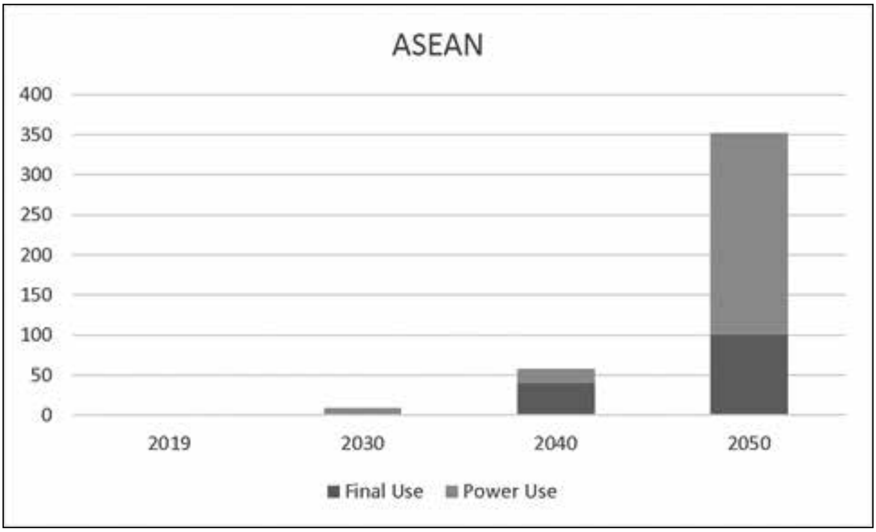
Figure 1. Forecast Hydrogen Demand, 2050 (Mtoe)



Note: The East Asia Summit +7 refer to Australia, China, India, Japan, the Republic of Korea, New Zealand, and United States.



ASEAN = Association of Southeast Asian Nations,Source: Author.

Source: Author

Debate Eight Summary

TOPIC: Policy recommendations toward the adoption of hydrogen/ammonia energy

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Mr. Shigeru Kimura (see position paper above and author biographical information in the Appendix). Mr. Kimura initiated the debate with a 5-minute statement of his views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Mr. Kimura and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Kimura, as evidenced by his position paper. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

Throughout the debate, there was a strong focus on the costs associated with transportation, production, labor, and certifications. It was asserted that the cost of hydrogen per cubic meter would not meet current price predictions set forth by countries. It was contended that other predictions report a continuous decrease in the cost of hydrogen and ammonia. Many emerging economies have lower price targets than developed economies that signal the entry point to the hydrogen energy markets. These economies lack adequate technology and infrastructure to support the adoption of hydrogen and hydrogen-derivative energy, which further increases the cost of utilizing hydrogen and ammonia.

Partnerships between various countries and regions were identified as crucial when networking with investors to support renewable energy. It was posited that governments need to stimulate these private partnerships to invest in desert areas (e.g., the Gobi Desert) as sunny, arid climates are optimal for renewable energy production. However, there were remaining concerns surrounding the transportation costs of exporting products and supplies to and from renewable energy production localities. It was identified that countries with advanced technologies need to serve as leaders in implementing renewable energy production and assist other countries in achieving the same goals through investments and aiding the planning process.

It was recognized by many that governmental support (e.g., funding, resources, personnel) is essential for hydrogen energy transitions, but questions arose regarding how and if countries with high economic development are prepared to support emerging economies. It was contended that domestic and international government support has the potential to accelerate hydrogen technology development and adoption via funding that incentivizes hydrogen energy adoption policies. A few member countries of the Association of Southeast Asian Nations (ASEAN) have the economic capability to subsidize technological development in the hydrogen sector, allowing for the quick adoption of hydrogen. In contrast, other countries in the ASEAN region need to import critical hydrogen energy technology (e.g., electrolyzers and Carbon Capture and Storage (CCS) equipment), a process that is not currently economically viable.

Presently, the main innovators of hydrogen energy technology are high-income countries. It was suggested that there need to be policies on the sharing of data, designs, and innovation of developed hydrogen technology with emerging countries when establishing pilot projects designed to develop a supply chain for hydrogen energy. It was expressed that Japan has developed essential technology in the hydrogen energy sector, however, to establish an international value chain in the East Asia region, the technology needs to be transferred and deployed through pilot projects in ASEAN countries that have the potential to become hydrogen exporters. The theme of government support for adopting hydrogen energy remained in the discussion concerning the ways in which the Japanese government is engaging and assisting ASEAN countries with decarbonization strategies. It was acknowledged that Japan currently conducts hydrogen and ammonia projects in the ASEAN region along with ammonia co-firing solar power plants, but concerns about how to help ASEAN as an entity were still present as many of the mentioned projects were designated for specific countries.

Concerns were expressed regarding the effects of hydrogen and ammonia on liquid natural gas (LNG) trade relationships between various regions. It was explained that this expansion to other countries is seen to be vital in aiding economic growth throughout ASEAN nations. Further concerns regarding the Japanese government's shifting priorities for engaging ASEAN countries in LNG trade and hydropower development were expressed. With current hydrogen projects conducted by Japan in ASEAN countries, along with ammonia co-firing solar power plants, Japan is aiding in the effort to move away from LNG and coal as primary fuel sources in the greater Southeast Asia region.

Many ASEAN countries, it was noted, have set a carbon neutrality target goal to be achieved by 2050, highlighting the importance of decarbonization for many countries. To achieve this shared goal of carbon neutrality, different countries will need to be in continuous communication and establish a detailed plan that concerns

(i) proper budget allocations, (ii) the promotion of innovative technologies, and (iii) commitments to transparent communication among countries. The likelihood of countries in the ASEAN region reaching an agreement on public funding to support a coordinated transition in the region was questioned. It was explained that as ASEAN countries start delineating their respective carbon neutrality roadmaps, governmental funding will need to be allocated to the sector that directly aids their specific decarbonization strategy. It was noted that numerous emerging economies in Asia currently provide subsidies to the fossil fuel industry to ensure affordable energy. The fossil fuel industry, it was argued, is interested in conserving its investments and is likely to finance decarbonizing technology (i.e., CCS technologies) to justify the continued use of fossil fuels. It was suggested that government subsidies are more economically and environmentally beneficial when allocated toward novel industries and technologies reducing greenhouse gases that need initial government support to become economically viable.

It was broadly accepted by several participants that demand for hydrogen energy needs to increase, which was supported by energy producers identifying that the primary purpose is to scale up hydrogen production to reduce the cost of hydrogen, thus making it more economically accessible. It was recognized that an understanding of future energy demand is crucial for producers to set appropriate target goals. It was further expressed that demand for hydrogen and ammonia energy needs to be higher for investors to feel comfortable financing large projects. Pilot projects are an essential part of providing security in the growing hydrogen energy sector, but projects need to be larger at scale than the current ones to signal to financial institutions that there is financial security in investing in this new sector.

It was identified that while there are several carriers for transporting hydrogen and ammonia, the importance of having a variety of carrier options was questioned, and many agreed that there were necessary considerations to take into account (e.g., energy security and transportation capacity). The accessibility of carrier options also posed challenges, as different regions may be unable to afford certain carriers depending on the renewable energy source utilized.

Coupling hydrogen and ammonia was discussed among stakeholders concerning the use of upscale technologies across different industries to expand economies. It was viewed as important to couple hydrogen and ammonia as it will increase efficacy in the production process. Subsequently, questions arose challenging the practical opportunities for hydrogen and ammonia coupling production processes as well as end-use applications of hydrogen and ammonia. This challenge was viewed as especially important for Japan which utilizes hydrogen and ammonia as separate entities that are individually co-firing out of gas and coal plants. Answers were inconclusive since there is uncertainty regarding how coupling between hydrogen and ammonia would develop.

Position Paper Nine
Energy Security and Geopolitical Implications of Hydrogen Adoption in the Indo-Pacific Region without Resilient Technology Supply Chains**

Jane Nakano, Senior Fellow, Energy Security and Climate Change Program, Center for Strategic and International Studies, United States

Summary

Hydrogen adoption would help to enhance energy security in the Indo-Pacific region. However, its potential could be undermined if the supply chains for key hydrogen technology components grow under China's dominance. Geographical diversity of manufacturing capacities and funding sources are essential in making the supply chain resilient against supply disruptions, including geopolitical tension. The G7 includes several countries with leading capacities for innovating and manufacturing electrolysis technologies, which is key for clean hydrogen production. The G7 should seek to build consensus that the geographical diversity of electrolyzer manufacturing capacities and funding sources should underpin supply chain security, and consider launching a consultative platform to maximize the synergy among individual efforts, which could otherwise erode each other's effort and thus lead to a failure to prevent the concentration of key hydrogen technologies in China.

Current realities

Hydrogen adoption would help to enhance regional energy security. Hydrogen adoption in the Indo-Pacific region presents opportunities to strengthen regional energy security. First, domestic production of clean hydrogen by large energy consumer economies, such as China and India, could alleviate their growing reliance on energy imports. Insofar as China and India already have a heavy and growing import dependence on hydrocarbons such as natural gas, they seem partial to pursuing the capability to produce renewable-based hydrogen, so as not to further their hydrocarbon needs. Even if their supply is to largely satisfy their domestic demand, hydrogen adoption will likely be a net positive for regional energy security if it moderates regional resource competition.

Second, for countries such as Japan and South Korea that already rely heavily on imports to meet their large energy requirements, hydrogen adoption may not readily provide energy security benefits. Both countries are severely limited in domestic hydrocarbon endowment; this situation does not lend local production of hydrocarbon-based hydrogen to become an energy security solution. Additionally, geographical characteristics constrain the prospect of massive deployment of renewable capacity to support renewable-based hydrogen production to the level that can materially reduce their energy import reliance. Meanwhile, nuclear energy has an import substitution potential for Japan and South Korea, both of which have decades of nuclear energy research and innovation expertise, as well as operational capacity.

Third, supply diversity as a measure of energy security can be augmented if hydrogen adoption unlocks new energy ties with countries that are outside the current menu of energy suppliers to the region. In particular, clean hydrogen trade that does not rely on prevailing maritime transit choke points (e.g., the Straits of Hormuz, Malacca), would improve the energy security of the importer countries. For example, Chile seeks to become a leading global exporter of green hydrogen/ammonia by 2040 and sees Asia as a top-level destination.

Fourth, hydrogen adoption could revitalize energy ties between countries with shared values and norms. Against the backdrop of rising geopolitical tension with China, Australia has explored a number of low-emissions energy partnerships that incorporate hydrogen commitments with Japan and Korea as part of its effort to minimize its economic exposure to China. Hydrogen is emerging as a key vehicle to help Australia rebalance its regional energy ties that have become dominated by China. To those regional economies with a strong hydrogen import prospect, such a revitalized energy tie through hydrogen trade could strengthen energy security.

Scientifically credible approaches and challenges

Energy security benefits could be negated if hydrogen technology supply chains are not secure. Hydrogen adoption has the potential to strengthen energy security in the Indo-Pacific region. However, such energy security benefits would go unfulfilled without the security of supply chains for key hydrogen technologies. In fact, hydrogen technology supply chains that lack a diverse and robust pool of manufacturers and investors could become a geopolitical liability that can undermine regional energy security.

Hydrogen can be produced from various sources. As such, the availability of hydrocarbon resource wealth is not the primary determinant of participation in clean hydrogen supply chains. Instead, access to technology to convert resources into various forms of hydrogen is an important license to participate in. Specifically, geographical concentrations of key hydrogen technology components could pose a geopolitical concern if they were in a country with a different set of political values and norms and a competing set of national interests.

Where the question of hydrogen technology supply chains and geopolitical uncertainty meet most profoundly is the supply chain for electrolyzers. Electrolyzer components, which can be mass-produced and easily distributed globally, are currently manufactured mostly in China. The country accounts for over 40% of global capacity, followed by Europe at 25%.

China's current competitiveness lies with alkaline electrolysis technology, which is well-established and cheap, but much less compatible with intermittent renewable energy sources than more advanced technologies, such as polymer electrolyte membrane (PEM) electrolyzers. PEM electrolyzers account for less than 10% of the Chinese market, which is otherwise dominated by alkaline electrolyzers. Owing to cheaper materials, lower labor costs, as well as a generally more mature component supply chain that is locally based, China is beginning to attract international manufacturers to deploy large manufacturing capacities there. As China becomes increasingly focused on PEM electrolyzers, the country might soon dominate the manufacturing and global supply as well.

Whether China would successfully replicate its commanding position along the supply chains for clean energy technologies is a major question with significant geopolitical implications. For example, China's shares in the global manufacturing capacity are about 50% for wind turbines, over 60% for solar PV modules, and about 90% for energy storage batteries, mostly electric vehicle batteries. In the fall of 2010, China exercised its leverage as a globally dominant supplier of rare earth and imposed an unofficial embargo on rare earth shipments to Japan over a territorial dispute. In the event of a major confrontation between China and the advanced industrial democracies, including some of the G7 member countries, hydrogen technology supply chains that are dominated by China could paralyze electrolyzer component markets and hamper hydrogen adoption.

Evidence-based options (EBO) and actionable next steps (ANS)

The growth of supply chains for hydrogen technology components need to avoid the same geographical concentration that currently exists for such clean energy technologies as solar PV and electric vehicle components. Geographical diversity among component manufacturers and funders would make the supply chains resilient against supply disruptions. Such resilience, in turn, renders energy security benefits from hydrogen adoption viable. Following are some of the actionable steps to achieve the objective:

- Build policymaker consensus that the geographical diversity of electrolyzer manufacturing capacities and funding sources would underpin their supply chain security. The secure and resilient supply chains are key to the sustained growth of hydrogen usage, whether to unlock energy security benefits or facilitate industrial emission reduction.

- Increase political support for electrolysis cost reduction, manufacturing capacity, and deployment in advanced industrialized democracies. The United States, Japan, and the European Union (EU) are among the top five global manufacturers of electrolyzers today.
    - The U.S. is beginning to attract more electrolysis manufacturing investments thanks to the Clean Hydrogen Production Tax Credit under the Inflation Reduction Act. But, sustained, strong support is required to meet other objectives, such as hydrogen project deployments through the Regional Clean Hydrogen Hubs, and hydrogen cost reduction through the Hydrogen Earth-shot.
    - Japan facilitates private-sector hydrogen technology development and deployment efforts through the Green Innovation Fund ($20 billion for 10 years), while its national R&D agency focuses on the R&D phases. They could emphasize innovation and manufacturing of advanced electrolysis technologies like PEM.
    - The EU has an articulated vision for hydrogen usage, but would benefit from enhancing its competitiveness in innovating and manufacturing hydrogen technology components (e.g., the proposed Green Deal Industrial Plan).
- Initiate a consultative group/platform to seek ways in which hydrogen technology development and supply efforts in advanced, industrialized democracies would expand the global supply chains and their geographical diversity, rather than erode each other's capacity.
    - Such a consultative platform may consist of policymakers from the United States, Japan, the European Union, and other partner countries (e.g., Australia) who oversee strategy developments and policy implementations related to energy technology research, development & deployment (RD&D), industrial competitiveness, manufacturing, and foreign investment regulations.
    - The scope of such a group/platform should be dynamic to allow for proactive stocktaking of concerns and discussion on

emerging/future issues that sit at the intersection of hydrogen technology supply chains and the changing geopolitical landscape. Such technologies could be in the area of material science for hydrogen-compatible infrastructure and technology components for long-distance maritime transport of hydrogen (in various carrier forms).

References

International Energy Agency (2022). Global Hydrogen Review 2022. (Paris): IEA.

International Energy Agency (2023). Energy Technology Perspectives 2023. (Paris): IEA.

*** **A position paper prepared for presentation at the ISGP conference on the "Global Pathways to Hydrogen Energy Futures - Japan (GPHEF - Japan)," organized and convened by the ISGP in Yokohama, Japan, on April 6–9, 2023.***

Debate Nine Summary

TOPIC: Geopolitical implications of hydrogen/ammonia energy adoption

This not-for-attribution Debate Summary was prepared by the ISGP staff from an audio recording and its transcription of the debate of the position paper prepared by Ms. Jane Nakano (see position paper above and author biographical information in the Appendix). Ms. Nakano initiated the debate with a 5-minute statement of her views and then actively engaged the conference participants, including other authors, throughout the remainder of the 90-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by all participants, as well as those responses made by Ms. Nakano and other participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Ms. Nakano, as evidenced by her position paper. Rather, it is, and should be read as, an overview of the discussion and exchange of views and priorities, both in support and opposition, to points expressed by all those participating in the debate.

The debate session provided insight into the geopolitical issues affecting the Indo-Pacific region, with a particular emphasis pertaining to the United States and Japan. The issues discussed naturally extended to their impact on other major economic entities in Asia. Despite the often-contentious nature of geopolitical issues and diverse national perspectives and priorities, the debate emphatically addressed political concerns and developed positions and considerations from a

G7+ standpoint (i.e., G7 countries in addition to regional countries with convergent geopolitical interests) while also addressing the geopolitical concerns of other countries not in the G7+ sphere. Throughout the discussion, the roles of various economic powers in the global energy systems were discussed in detail, with some participants supporting the full participation of all potential countries in a global hydrogen market. Other participants expressed concern regarding the possibility of an individual economic power controlling a large portion of the hydrogen economy, citing potential challenges from mounting bilateral tensions between countries. It was claimed that cooperation between countries is essential to the growth of hydrogen as a commercialized energy source, and that divergent national interests must be leveraged in a way that (i) maintains a democratized global value chain for electrolyzers and hydrogen energy and (ii) prevents any individual nation from dominating the market.

Technological limitations of electrolyzers were explored, primarily regarding the minerals used to produce them and how geopolitical interests influence preferred models (e.g., rare earth minerals, all of which have supply chains that are located in select geographic areas and have attracted specific economic investments). The importance of research and development, given the hydrogen economy's influence, was asserted as critical for existing and future areas of research, including (i) the role of nuclear energy in the production of hydrogen, (ii) the effect of critical mineral supply disruptions on global electrolyzer supply chains, and (iii) the impact of supply chain monopolization on geopolitical relationships.

The extent that all countries of varying geopolitical alignments could participate in a global hydrogen economy was a major point of debate, with multiple participants asserting that there may be an individual economic power which would do more harm than good if integrated into the hydrogen economy, while several participants contended that the global hydrogen economy could not be properly developed without universal involvement. A few participants argued that some countries may seek to achieve dominance in the global hydrogen economy, and other countries collaborating with them would assist these potentially dominating economies in reaching this goal. The sheer size of some countries' global economic influence was also noted as a concern due to possible monopolization of the electrolyzer market.

In response to the exclusion of economic powers from the global hydrogen economy, it was asserted that excluding these countries would (i) upset private sector entities that operate internationally and (ii) inhibit international cooperation for the development of a hydrogen economy. It was emphasized that the role of all major economic powers in renewable energy finance is too large to ignore, with China spending approximately USD $545 billion in 2022 on energy transition technologies and the U.S. spending USD $370 billion on climate finance in the 2023 Inflation Reduction Act, with more money invested from other government policies.

Debaters acknowledged that bilateral interaction with economic powers could occur directly and indirectly. For instance, it was mentioned that even though approximately 70% of cobalt (i.e., a material commonly used in batteries) comes from the Democratic Republic of the Congo, approximately three-quarters of the Congo's industrial cobalt mines are owned or financed by Chinese-owned firms. Similarly, the U.S. and Japan have large stakes in the economies of ASEAN countries as well, where a significant portion of renewable energy technology manufacturing is based. While diversifying manufacturing facilities to developing economies may appear to diminish the influence of economic powers, it was recognized that proxy ownership must be considered as well.

Several participants acknowledged concern over the disruption capabilities of international supply chains for electrolyzers from economic powers. It was argued that such capabilities give economic powers more leverage in shipping lanes that may function as geopolitical choke points (e.g., the Taiwan Strait) if geopolitical conflicts arise. It was also recognized that past bans on essential components in manufacturing (e.g., rare minerals used to develop permanent magnets) caused serious disruptions to supply chains that motivated some states to develop emergency stockpiles of these materials. It was then suggested that a similar ban or limitation could occur for electrolyzers, raising concerns for economies active in energy supply chains.

It was broadly agreed upon that an international hydrogen collaborative framework needs to be developed, but it was contested as to which countries would play which roles. Several participants argued that international coordination has a paramount role in the development of a hydrogen economy and warned that divergent national interests could become a barrier to achieving the necessary cooperation required to develop a global-scale hydrogen economy. It was argued that energy importers competing against one another, as well as energy exporters competing among themselves, could challenge collaboration. Purchasing fuel in joint blocks (e.g., Japan with Korea or the European Union within itself) rather than individual countries was recommended as an approach that could mitigate divergent national interests while supplying steady demand for producers. However, it was then raised as a concern that purchasing fuel in joint blocks had little economic credibility in its efficacy in lowering prices.

While national strengths (e.g., China with manufacturing and Japan with innovation) can be leveraged to enhance collaboration, it was argued that countries would attempt to gain the largest advantages possible, even at the cost of the national advancement of other countries. It was acknowledged that a nation's status as a hydrocarbon producer could influence its choice between green or blue hydrogen (i.e., hydrocarbon exporters would have a higher proclivity towards blue hydrogen), and this may hamper the development of renewable energy technologies. It was raised as a concern that the U.S. is developing a national hydrogen plan with only domestic consumption and production capacities, potentially influencing other countries to do the same, and lowering prospects towards global collaboration. In response to the U.S. self-sufficiency model, a question was raised as to what fundamental risk this model seeks to solve. It was then contended that the self-sufficiency model bolsters energy security and protects from market fluctuations from geopolitical tensions.

It was repeatedly asserted that a model of mutual dependence, regarding hydrogen and ammonia markets, would enhance ties between countries and create a healthy global hydrogen landscape. A concern was raised by debaters that relationships of mutual dependence may not have an equal balance of power, and efforts from economic powers to monopolize the market could undermine the empowerment of smaller economies that the mutual dependence model aims to assist.

Multiple participants argued that international cooperation could result in a hydrogen landscape in which some nations group with one another and dominate the export market, particularly if blue hydrogen is to become the standard in a commercialized hydrogen market. These concerns were addressed alongside concerns of jointly buying energy since collective demand results in fewer buyers in the market. It was also asserted that similar trends in a renewable energy economy are observed, with resource extraction industries for oil functioning similarly to the industries surrounding critical minerals necessary for electrolyzer production. It was questioned how fossil fuel exporters, which hold much geopolitical and economic leverage, would react to the growth of the hydrogen economy. In response, it was recognized that current energy exporters are actively trying to hold onto their power and see hydrogen as an area for growth, potentially increasing demand for hydrogen.

Recognizing that the hydrogen economy would not look like the present fossil fuel market due to the structural differences between hydrogen and fossil fuels (e.g., differences in points of condensation, making shipping of hydrogen costlier than shipping of fossil fuels), debaters argued that these structural differences warrant more research in optimal handling of hydrogen, particularly not just in deployment but manufacturing of electrolyzers as well. The tendency for hydrogen to be consumed at the same petrochemical complex that it was produced was also another point expressed by debaters. The importance of critical minerals in hydrogen production was emphasized through an example of the U.S. government issuing a presidential determination to protect critical minerals necessary for electrolyzers. Preferring different electrolyzer types (e.g., alkaline-based) over others was recognized as a partial political choice since different countries have abundances of different materials. It was then noted that a common challenge for national plans on hydrogen adoption is the expensive nature of electrolyzers, largely due to their material requirements, highlighting a potential area of research, where new technologies would be considered in the context of the availability of materials.

Exploring the structural differences between fossil fuels and hydrogen, as well as possible innovations for electrolyzers, a debater raised concerns that alkaline-based electrolyzers (i) synergize poorly with renewable energy sources and (ii) are more susceptible to market monopolization. It was argued that alternative nickel-based electrolyzer models (i.e., rather than platinum-based) can potentially lower electrolyzer unit costs while also shifting manufacturing closer to the required minerals, if manufacturing moves to countries such as Indonesia. Furthermore, the choice of electrolyzer type was observed to have geopolitical implications as well due to local advantages in manufacturing and resource allocation influencing national interests. Moreover, it was emphasized that despite technological limitations, whenever a technical problem arises, researchers are keen to invent a way out of it. This innovative research needs to be encouraged.

The importance of research and development in the growth of a hydrogen economy was also emphasized by several participants. It was suggested that research and development's key role is due to the hydrogen economy's infancy, as hydrogen still has yet to be widely used in commercial applications. Regarding the hydrogen economy's infancy, one stakeholder mentioned the U.S. bipartisan infrastructure law, which earmarked USD $1 billion for research and development on hydrogen energy. It was contended that research and development need to focus on hydrogen's role in hard-to-electrify sectors such as long-distance shipping and steelmaking. Additionally, supply chain resilience was identified as an aspect of the hydrogen economy that deserves extra research. Competing with one another in research efforts, one major economic power slowing their progress will likely not cause others to slow down. Thus, competition was emphasized as critical to motivating rapid research efforts.

The debate also gave rise to several other potential areas of research requiring further assessment. The unprecedented nature of a hydrogen-based economy in a globalized geopolitical landscape was acknowledged by multiple participants, especially regarding the source of energy for hydrogen production and whether energy derived from nuclear and fossil fuels with Carbon Capture and Utilization would be considered sustainable sources of hydrogen given their negative impacts on the environment. Debaters also suggested further research that focuses on establishing a democratized and accessible structure of market influence where states can leverage their natural resources without overbearing outside influences. It was further expressed that post-alkaline electrolyzers warrant more attention since they may cause market disruption in a manner that undercuts the stability of the hydrogen economy. Finally, an essential area for further research was recognized to be the effects of critical mineral disruptions on supply chains and the potential impacts of large national stockpiles (e.g., in Japan, the U.S.)

While the effects of energy supply disruptions have been acknowledged to be difficult to quantify, the potential impacts of disruption were agreed upon by multiple participants to be an area requiring additional research, especially with respect to their underlying geopolitical causes. The unpredictability of international conflicts was mentioned with an example of the spontaneous nature of the 2022 Russo-Ukrainian war and Russia's subsequent embargo, that limits Russia from participating in the international energy market. It was expressed that a degree of caution is essential in addressing cooperation as the unpredictability of international conflict and the potential for monopolization in international cooperation can challenge national goals surrounding the advancement of hydrogen energy.

Regarding energy security, many debaters stressed that green hydrogen could be regarded as a solution to the volatility of fossil fuel energy prices, a notable energy security risk. However, there was disagreement about whether price stability must come about from the adoption of green hydrogen or from diversification with a variety of hydrogen energy variations. It was acknowledged that energy importers such as Singapore and Japan often suffer from price volatility and unpredictable supply chains, making hydrogen energy a more attractive choice. One concern that was raised by a few participants was the difficulty in storing hydrogen energy, compared to fuels such as liquefied natural gas (LNG). A participant suggested large-scale implementation of electric batteries as a solution for long-term energy storage, and it was also noted that such a solution would distance hydrogen from the renewable energy economy. Meanwhile, the creation of a strategic hydrogen reserve modeled after the strategic petroleum reserve was criticized by participants due to the difficulty of storing hydrogen.

In developing a prosperous global hydrogen economy, it was asserted by multiple participants that diversification in stakeholders does not only include countries, but the private sector as well. It was noted that restricting China from conversations regarding hydrogen would limit the private sector given many multinational corporations' operations in China (i.e., for manufacturing and for selling finished products), which would also limit countries with strong private sectors, such as those in the E.U. as well as the U.S. and Japan. It was further asserted that one of the aims of the American Inflation Reduction was to increase the number of U.S. and non-U.S. stakeholders in the energy economy. While states were expressed to be at the center of such negotiations surrounding the global hydrogen economy, the possibility of a G7+ framework with multinational corporations participating was suggested.

Debaters also emphasized the importance of a diversified, and therefore resilient, energy supply chain with hydrogen. However, concerns were raised that the E.U., the U.S., and Japan together could dominate the hydrogen market, to which it was asserted that it is preferable that no country dominates supply chains. It was suggested that a democratized structure of global supply chains is preferable, as it would empower smaller economies as well as ensure increased accessibility to energy markets. It was questioned as to what role small states would have in a diversified hydrogen supply chain, particularly Small Island Developing States (SIDS). It was contended that hydrogen infrastructure for SIDS this early in the lifecycle may not be prudent, but large economies using less fossil fuels would free up demand in the market and give small developing economies the means to develop further.

Bilateral geopolitical tensions were expressed as a concern for the development of a global hydrogen economy throughout the debate. The specific bilateral tensions addressed were those between G7+ countries (e.g., U.S., Japan, and those in the E.U.) and other large economic powers (e.g., China and Russia). Current shipping routes becoming geopolitical choke points for naval conflict was raised as a potential concern. It was acknowledged that in a hydrogen economy, if electrolyzer supply chains are vertically integrated in a supply chain dominated by one country, other countries would be especially vulnerable to geopolitically motivated hostilities from the dominating country (e.g., blockades, tariffs, conflict).

Despite these concerns, it was argued by multiple participants that bilateral tensions could be mitigated through enhanced collaboration between countries. Mitigating such tensions was expressed in an example raised that referred to Malaysia and China, where both countries have a territorial dispute in the South China Sea, but have strong economic ties. Another example of curbing tension is that of China signing several long-term liquified natural gas (LNG) contracts with the U.S., in which the LNG could potentially be replaced by hydrogen in the future. Participants argued that the private sector could also have a large role in this as the "firewall" between political tensions and collaboration was observed to be less applicable to commercial entities. Finally, it was asserted that an entirely diversified hydrogen economy would have more total actors involved, making the economy less vulnerable to bilateral tensions.

Acknowledgment

The Institute on Science for Global Policy (ISGP) wishes to acknowledge the numerous individuals and organizations that made important contributions to the organization of the invitation-only ISGP "Global Pathways to Hydrogen Energy Futures - Japan" (GPHEF – Japan) program. The ISGP GPHEF – Japan conference, convened as part of the GPHEF-Japan program, was conducted under the Chatham House rule (no attribution) and in a hybrid format (e.g., participants joined in person and via Zoom) on April 6, 7, 8, and 9 in Yokohama, Japan.

The ISGP is especially indebted to the authors of 12 Position Papers addressing a variety of critical topics fundamental to obtaining an accurate understanding of the energy needs and priorities of global communities as well as the scientific and economic options for using hydrogen-based energy. The topics of these Position Papers provided the material on which each debate and caucus focused throughout the four-day event. Biographical information for these 12 authors is provided in this ISGP Book.

The ISGP greatly appreciates the willingness of the more than 300 subject-matter experts and leaders in the scientific, governmental, public advocacy, and private sector communities worldwide who agreed to be interviewed by the ISGP staff as they prepared and organized the content of and participation in the GPHEF – Japan conference.

The success of every ISGP conference critically depends on the active engagement of all invited participants and authors in the often-intense debates and probing caucuses, all of which are conducted under the Chatham House Rule (no attribution). The exchange of strongly held views, innovative proposals, and critiques generated from comments and questions throughout the debates and caucuses fosters an unusual, and perhaps unique, environment focused on clarifying understanding for both the specialist and non-specialist. These debates and caucuses address specific questions related to formulating and implementing effective research, analyses, and policies throughout governmental, private sector, and public advocacy communities worldwide. The debates and caucuses span scientific, technological, regulatory, public messaging, and business decisions. The ISGP is greatly indebted to all participants for their active participation willingness to share their expertise and perspectives.

The members of the ISGP Board of Directors also deserve recognition for

their time and efforts in helping to create a viable, increasingly relevant, not-for-profit organization committed to addressing many of the most important scientific, technological, and societal questions of our time. Their brief biographical backgrounds are presented in this ISGP Book.

The energetic, highly professional interviewing, analysis, moderating, and writing skills of the ISGP staff were essential to organizing and convening all aspects of the GPHEF program and conference, as well as preparing material from the debates and caucuses for publication. Brief ISGP staff biographies are provided here.

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Biographical Information of Presenters/Authors

Dr. Keigo Akimoto, Group Leader, Systems Analysis Group, Research Institute of Innovative Technology for the Earth (RITE); Specially Appointed Professor, Institute of Innovative Research (IIR), Tokyo Institute of Technology

Dr. Akimoto received a Ph.D. from Yokohama National University in 1999 and upon graduating joined the Research Institute of Innovative Technology for the Earth (RITE), where he currently serves as Group Leader of the Systems Analysis Group and Chief Researcher. Dr. Akimoto was a guest professor at the Graduate School of Arts and Sciences at the University of Tokyo between 2009 and 2014. Since November 2022, he has served as a Specially Appointed Professor at the Institute of Innovative Research (IIR) at the Tokyo Institute of Technology. He was a lead author for the Fifth and Sixth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), and is a member of several advisory bodies focusing on energy and environmental policy for the Japanese government including the Strategic Policy Committee and the Advisory Committee for Natural Resources and Energy. His scientific interests center around the modeling and analysis of energy and environmental systems. He received the Peccei Scholarship from IIASA in 1997, and an award from the Japan Society of Energy and Resources in 2004.

Mr. Radhanon Diewvilai, Researcher, Energy Research Institute, Chulalongkorn University

Mr. Diewvilai has more than 10 years of experience in power generation and energy policy. Currently, he is a researcher at the Energy Research Institute, Chulalongkorn University, and a Ph.D. student in the Electrical Engineering Department at Chulalongkorn University. Additionally, he has served as a Project Engineer and is responsible for the development of several conventional and renewable energy projects in Thailand. Mr. Diewvilai's main research interests include power system reliability, planning, and optimization, as well as energy policy related to electricity. He has been involved in several research projects of the Ministry of Energy and the Energy Regulatory Commission of Thailand, which concern Thailand's power development planning and the impact of energy transition in Thailand. Mr. Diewvilai has several publications related to power system reliability and generation expansion planning.

Mr. Koji Hosono, General Manager, New Power Generation Fuels Business Department, Next-Generation Energy Business Group, Mitsubishi Corporation

Mr. Hosono has served as the General Manager of the New Power Generation Fuels Business Department in Mitsubishi Corporation since April 2021. Mr. Hosono has extensive experience in the wood pallet business, in addition to the introduction of ammonia as a fuel source, particularly in Asia. He is also leading Japan's Clean Fuel Ammonia Association (CFAA) as Vice-Chairman of the Steering Committee, Chairman of the Strategy Committee, and Leader of the Certification Working Group. Prior to his current position, he was engaged in developing and implementing Chlor-Alkali business for 23 years.

Dr. Yuki Ishimoto, Vice Director, Hydrogen Program, The Institute of Applied Energy (IAE)

Dr. Ishimoto has more than 15 years of experience in economic and environmental research of hydrogen energy systems, including hydrogen production, transport storage, and utilization processes. His research interests are the economic and environmental aspects of large-scale and long-distance hydrogen supply chains and their effects on total energy systems. In parallel with his research at the Institute of Applied Energy (IAE), he carried out his studies at Kyoto University from 2021 to 2023, where he worked to clarify the cost structures of the international hydrogen supply chains. He received a Ph.D. in Science from the University of Tsukuba and an M.B.A.from Waseda University.

Mr. Shigeru Kimura, Special Adviser to the President on Energy Affairs, Economic Research Institute for ASEAN and East Asia (ERIA)

Mr. Kimura graduated from the Computer and Information Sciences Department at Hosei University in 1973. After graduation, he worked for Century Research Center Co. (CRC), a Japanese think tank, and became manager of the Economic Group, Research Institute of CRC in 1988. He joined the Energy Data and Modelling Center (EDMC) at the Institute of Energy Economics, Japan (IEEJ) as Head of the Statistics Information Office in 1993. Mr. Kimura became a Senior Research Fellow in 2005. He has been engaged in the preparation of energy statistics in the APEC region, including the execution of energy modeling work applying econometrics and input-output approaches. Using these expertises, he has been conducting capacity building on energy statistics and energy outlook modeling in the Association of Southeast Asian Nations (ASEAN) region for more than 10 years. He has also been a Leader of the Working Group for Preparation of Energy Outlook and Analysis of Energy Saving Potential in East Asia, Economic Research Institute for ASEAN and East Asia (ERIA) from 2007 onward. Since August 2013, he has served as the Special Adviser to the Executive Director on Energy Affairs of ERIA. He retired from IEEJ in September 2015 and moved to ERIA entirely.

Mr. James Laybourn, Hydrogen & CCS Segment Lead, DNV Energy Systems, Asia Pacific

Mr. Laybourn is the Regional Sales Director for Energy Systems in the Asia Pacific based in Singapore. He joined DNV in London in 2002 and has since held various technical and managerial positions within DNV in Singapore, Malaysia, and Australia. In addition, he currently manages DNV's Hydrogen and CCUS segment in the Asia Pacific. He previously managed the upstream/midstream gas segments for DNV in South East Asia and Australia, focusing on Floating Storage Regasification Units (FSRU) and the gas-to-power market. As a consultant, he has been responsible for a wide range of consultancy studies covering the LNG and offshore industries. Mr. Laybourn is a Chartered Engineer and holds a Master of Engineering (M.Eng.) from the University of Cambridge and a Master of Science (M.S.) in Business Analytics from the National University of Singapore (NUS).

Mr. Matthew Loughrey, Principal Consultant, Global CCS Institute

Mr. Loughrey is the Global CCS Institute's Principal Consultant to CCS Technologies, based in Melbourne, Australia. Mr. Loughrey's engineering skills and expertise have been developed from over 13 years of experience in contracting, design, and operations in Australia and the U.K. within the oil and gas industry. Mr. Loughrey is a process engineer, with key strengths in strategic planning, concept and feasibility studies, process design, industrial energy efficiency, project management, and technical support and troubleshooting. He holds a master's degree in Refinery Design and Operation from the University of Manchester in the United Kingdom, and bachelor's degrees in Chemical Engineering and Science from Monash University, Australia.

Mr. Shigeru Muraki, President, Clean Fuel Ammonia Association

Mr. Muraki graduated from the Applied Chemistry Department of the University of Tokyo in 1972. He joined Tokyo Gas Co., Ltd. shortly thereafter and was appointed Chief Representative in New York from 1989 to 1994. From 1996 through 2004, he worked at the Gas Resources Department and was promoted to Senior Executive Officer and Chief Technology Officer in 2004. In 2007, he moved to the Energy

Solution Division and was in charge of marketing in commercial and industrial markets and power business. Mr. Muraki was appointed as the Executive Vice President of Tokyo Gas in 2010, and Vice Chairman in 2014. Since April 2015, he has been serving as the Executive Adviser for the company. He was Program Director of Energy Carriers for SIP (Cross-Ministerial Strategic Innovation Promotion Program) from June 2014 to March 2019. Mr. Muraki also served as the Representative Director of the Clean Fuel Ammonia Association (CFAA) from July 2019 to June 2022, and has been President of CFAA since July 2022. He was appointed Regional Vice Chair, Asia Pacific and South Asia, of the World Energy Council from May 2016 to October 2022. He was awarded the Medal of Honor with Blue Ribbon in May 2017.

Ms. Jane Nakano, Senior Fellow, Energy Security and Climate Change Program, Center for Strategic and International Studies

Ms. Nakano is a Senior Fellow in the Energy Security and Climate Change Program at the Center for Strategic and International Studies (CSIS). Her research interests include U.S. energy policy, global market and policy developments concerning natural gas, nuclear energy, and critical minerals, and energy security and climate issues in the Asia-Pacific region. She frequently writes and speaks on these issues at domestic and international conferences and to media around the world. She has also testified before Congress on China's competitiveness in energy technology manufacturing and exports as well as U.S. liquefied natural gas (LNG) exports and before the U.S.-China Economic and Security Review Commission on U.S.-China nuclear energy cooperation. Prior to joining CSIS in 2010, Ms. Nakano worked in the Office of International Affairs in the U.S. Department of Energy, where she covered a host of energy, economic, and political issues in Asia. From 2001 to 2002, she served at the U.S. embassy in Tokyo as a special assistant to the energy attaché. Ms. Nakano graduated from Georgetown University's School of Foreign Service and holds a master's degree from Columbia University's School of International and Public Affairs.

Dr. Kazunari Sasaki, Senior Vice President and Director, International Research Center for Hydrogen Energy, Kyushu University

Dr. Sasaki graduated from the Tokyo Institute of Technology with bachelor's and master's degrees in inorganic materials, later graduating from the Swiss Federal Institute of Technology (ETH-Zürich), Switzerland, with a Ph.D. in 1993. After spending 10 years in Europe conducting Solid State Research at the Max-Planck-Institute, he became an Associate Professor at the Interdisciplinary Graduate School of Engineering Sciences, Kyushu University in 1999, where he later became a Professor of the Faculty of Engineering in 2005. He was appointed as a Distinguished Professor of Kyushu University in 2011 for his outstanding contributions as a professor. He is currently serving as the Senior Vice President of Kyushu University (since 2016), Director of the Next-Generation Fuel Cell Research Center (since 2012), and Director of the International Research Center for Hydrogen Energy (since 2006). Dr. Sasaki's research focuses on materials and electrochemical processes of fuel cells and related devices. Dr. Sasaki has published more than 250 papers in international journals or conferences, and earned major awards, including the Christian Friedrich Schönbein Silver Medal from European Fuel Cell Forum in 2008, and the Ministerial Award of the Environment of Japan in 2019.

Mr. Kenji Takahashi, General Manager, Decarbonization Promotion Section, Planning Division, JERA Co., Inc.

Mr. Takahashi has worked for 25 years in the power generation and energy sector, beginning his career at Chubu Electric Power Co. Inc. in 1997, where he engaged in construction and operations and maintenance for thermal power plants. Currently, he is leading the development of decarbonization strategy and planning as well as demonstration projects of ammonia generation at JERA Co, Inc. Since 2008, he has been engaged in climate change policy at the Federation of Electric Power Companies (FEPC). From 2013 to 2019, Mr. Takahashi was seconded to Chubu Electric Power and JERA's subsidiary in the United States where he engaged in management and construction of the power generation business and natural gas liquefaction business. He has served as CEO of JERA Power USA Inc., and Director & Chief Strategy Officer of JERA Americas Inc. Mr. Takahashi received a master's degree in Metallurgical Engineering from Tohoku University in Japan.

Mr. Masakazu Toyoda, Chairman and Chief Executive Officer, Japan Economic Foundation (JEF)

Mr. Toyoda has been Chairman and CEO of the Japan Economic Foundation (JEF), a think tank for international economic affairs, since 2021. Mr. Toyoda also serves as the Special Adviser for the Institute for Energy Economics, Japan (IEEJ), for which he formerly served as the Chairman and CEO for twelve years. IEEJ has been ranked among the top three energy and resource policy think tanks for seven consecutive years. Mr. Toyoda was the Vice Minister for International Affairs at the Ministry of Economy, Trade and Industry (METI) of Japan, where he served for over 30 years. Additionally, during his time as Chairman of IEEJ, he served as a member of the Strategic Policy Committee, Agency for Natural Resources for Energy at METI. He contributed to compiling several Strategic Energy Plans, which were approved by the Cabinet. He received a bachelor's degree in Law from the University of Tokyo and a master's degree in Public Affairs from Princeton University.

Biographical Information of ISGP Board of Directors

Dr. George Atkinson, Chairman

Dr. Atkinson founded the Institute on Science for Global Policy (ISGP) and is an Emeritus Professor of Chemistry, Biochemistry, and Optical Science at the University of Arizona. He is former head of the Department of Chemistry at the University of Arizona, the founder of a laser sensor company serving the semiconductor industry, and Science and Technology Adviser (STAS) to U.S. Secretaries of State Colin Powell and Condoleezza Rice. Together with the U.S. Department of Energy, he led the U.S. Department of State's negotiations on the lTER - Nuclear Fusion Program, and coordinated State Department engagement on H5N1 Avian Influenza. He also created and launched the Jefferson Science Fellows program for senior U.S. scientists to become directly engaged with the U.S. Department of State. He founded and launched the ISGP in 2008 as a new type of international forum in which credible experts provide governmental and societal leaders with understanding of the science and technology that can be reasonably anticipated to help shape the increasingly global societies of the 21st century. Dr. Atkinson has received National Science Foundation and National Institutes of Health graduate fellowships, a National Academy of Sciences Post-Doctoral Fellowship, a Senior Fulbright Award, the SERC Award (U.K.), the Senior Alexander von Humboldt Award (Germany), a Lady Davis Professorship (Israel), the first American Institute of Physics' Scientist Diplomat Award, a Titular Director of the International Union of Pure and Applied Chemistry, the Distinguished Service Award (Indiana University), an Honorary Doctorate (Eckerd College), the Distinguished Achievement Award (University of California, Irvine), and was selected by students as the Outstanding Teacher at the University of Arizona. He received his B.S. (high honors, Phi Beta Kappa) from Eckerd College and his Ph.D. in physical chemistry from Indiana University. He was the former President of Sigma Xi, The Scientific Research Society. His educational scientific research and diplomatic achievements have been recognized with distinguished appointments and awards in 16 countries.

Dr. Janet Bingham, Member

Dr. Bingham is former President of the George Mason University (GMU) Foundation and Vice President of Advancement and Alumni Relations. GMU is the largest research university in Virginia. Previously, she was President and CEO of the

Huntsman Cancer Foundation (HCF) in Salt Lake City, Utah. The foundation is a charitable organization that provides financial support to the Huntsman Cancer Institute, the only cancer specialty research center and hospital in the Intermountain West. Dr. Bingham also managed Huntsman Cancer Biotechnology Inc. In addition, she served as Executive Vice President and Chief Operating Officer with the Huntsman Foundation, the private charitable foundation established by Jon M. Huntsman Sr. to support education, cancer interests, programs for abused women and children, and programs for the homeless. Before joining the Huntsman philanthropic organizations, Dr. Bingham was the Vice President for External Relations and Advancement at the University of Arizona. Prior to her seven years in that capacity, she served as Assistant Vice President for Health Sciences at the University of Arizona Health Sciences Center. Dr. Bingham was recognized as one of the Ten Most Powerful Women in Arizona.

Mr. Fred Downey, Member

Mr. Downey is a former U.S. Army strategist and longtime defense and international affairs expert on Capitol Hill and was vice president of national security at Aerospace Industries Association (AIA). Downey joined AIA from the office of Connecticut Senator Joe Lieberman where he served as Senior Counselor and Legislative Aide for Defense and Foreign Affairs. He had been the senator's key staff person on these issues for 12 years. As Lieberman's representative to the Senate Armed Services Committee, Downey staffed the senator in his role as chairman of the Airland Subcommittee, overseeing Army and Air Force policy and budget issues and the annual defense authorization bill. Before joining Lieberman, Downey worked on defense analytical services for TASC. That came after a 24-year career in the U.S. Army, including Pentagon postings as Assistant to the Director of Net Assessments at OSD and Strategy Team Chief for the Strategic Plans and Policy Directorate on the Department of the Army Staff.

Dr. Linda Duffy, Member

Dr. Duffy recently retired as a U.S. Federal Government Senior Scientist Administrator in the Department of Health Human Services, National Institutes of Health, at the National Center for Complementary and Integrative Health, where she currently serves as a post-retirement Special Volunteer to the Director. Among her many service achievements at the NIH, she launched and chaired the Trans-NIH Probiotics/Prebiotics and Microbiome Inter-agency Work Group and served for many years as an Inter-agency Subject Matter Expert in ad hoc advisory capacities as committee member and Chair. Dr. Duffy received a DHHS Innovation Award in 2016 and was appointed to serve in the dual role of Senior Scientific Advisor in the DHHS Office of the Secretary, within the Office of the National Coordinator, Division of Science Technology. Prior to her distinguished federal government career, she was a former Peace Corps Volunteer in Cote d'Ivoire, West Africa and subsequently served in a dual capacity as Scientific Director of the Women and Children's Health Research Foundation and as a Distinguished Professor Emeritus with former joint appointments in the Departments of Pediatrics, Epidemiology, and Microbial Pathogenesis at the University of Buffalo. She received her Master's degree from Dartmouth College and completed her doctoral and postdoctoral studies under NIH National Cancer Institute Research Fellowships at the University of Buffalo

Adm. Thomas B. Fargo, USN (Ret.), Member,

Adm. Fargo became the Chairman of Hawaiian Electric Industries (HEI) in May 2020. HEI is the parent company for Hawaiian Electric Company, American Savings Bank and Pacific Current. He previously served for nine years as the Chairman of Huntington Ingalls Industries. Following a 35-year career serving the U.S. Navy and the Department of Defense, Adm. Fargo transitioned to corporate leadership in 2005 as President of Trex Enterprises, a privately held high technology company. He also served as a Managing Director of J.F. Lehman and Co, with principal responsibilities as President and CEO of HSF Holdings/Hawaii Superferry. He held the John M. Shalikashvili Chair in National Security Studies at the National Bureau of Asian Research from 2009 to 2016. He completed his military career as Commander of the U.S. Pacific Command. As the senior U.S. military commander in East Asia, the Pacific and Indian Ocean areas, he led the largest unified command while directing the joint operations of the Army, Navy, Marine Corps and Air Force across 100 million square miles. His 35 years of service included five commands in the Pacific, Indian Ocean, and Middle East as well as six tours in Washington, DC. He graduated from the United States Naval Academy and has additional Governance, Business and Financial training from Harvard and Stanford Universities. He is a 1989 recipient of the Vice Admiral James Bond Stockdale Award for Inspirational Leadership, and a 2013 recipient of the Naval Academy Distinguished Graduate Award. In September 2022, he was a recipient of the Lone Sailor Award.

Dr. Thomas Fingar, Member

Dr. Fingar is a Shorenstein APARC Fellow in the Freeman Spogli Institute for International Studies at Stanford University. He was the inaugural Oksenberg-Rohlen Distinguished Fellow in 2010-2015 and the Payne Distinguished Lecturer at Stanford in 2009. From 2005 through 2008, he served as the first Deputy Director of National Intelligence for Analysis and, concurrently, as Chairman of the National Intelligence Council. Dr. Fingar served previously as Assistant Secretary of the State

Department's Bureau of Intelligence and Research (2000-2001 and 2004-2005), Principal Deputy Assistant Secretary (2001-2003), Deputy Assistant Secretary for Analysis (1994-2000), Director of the Office of Analysis for East Asia and the Pacific (1989-1994), and Chief of the China Division (1986-1989). Between 1975 and 1986 he held positions at Stanford University, including Senior Research Associate in the Center for International Security and Arms Control. Dr. Fingar is a graduate of Cornell University (A.B. in Government and History, 1968), and Stanford University (M.A., 1969 and Ph.D., 1977 both in Political Science). He has authored or edited six books, dozens of articles, and served as the approving editor on approximately 20,000 US government assessments.

Dr. Claire Fraser, Member

Dr. Fraser is the Dean's Endowed Professor, and the Director of the Institute for Genome Sciences at the University of Maryland School of Medicine in Baltimore, where she holds joint faculty appointments in the Departments of Medicine and Microbiology and Immunology. Until 2007, she was President and Director of The Institute for Genomic Research (TIGR) in Rockville, MD, and was involved in the early phases of the Human Genome Project. She led the teams that sequenced the genomes of nearly 100 microbial organisms, an effort that launched the new field of microbial genomics. Her current research interests are focused on the role of the human microbiome in health and disease. Her previous work with the FBI on the Amerithrax investigation between 2001 and 2008 led to the identification of four genetic mutations in the anthrax spores that allowed the FBI to trace the material back to its original source. She is one of the world's experts in microbial forensics and the growing concern about its dual uses – research that can provide knowledge and technologies that could be misapplied. Dr. Fraser has authored more than 300 publications, edited three books, and served on the editorial boards of nine scientific journals. Her list of numerous awards include: the E.O. Lawrence Award, the highest honor bestowed on research scientists by the Department of Energy; the Promega Biotechnology Award from the American Society of Microbiology; and the Charles Thom Award from the Society for Industrial Microbiology. She has been elected to the Maryland Women's Hall of Fame, been named an Influential Marylander honoree, and was awarded the World Trade Center Institute's International Leadership Award. Dr. Fraser is a member of the National Academy of Medicine, and in 2019, she served as President of the American Association for the Advancement of Science (AAAS) from 2020 – 2021.

Dr. George Korch, Member

Dr. Korch is currently the President of GeoBIO LLC, a consulting entity established to provide advice and expertise in biodefense, medical countermeasure development and public health policy, and is the former director of Battelle National Biodefense Institute's National Biodefense Analysis and Countermeasures Center (NBACC), a government biodefense research laboratory created by the Department of Homeland Security. He was part of the creation of the NBACC in the wake of the establishment of the Department of Homeland Security in 2003. Dr. Korch previously served in Fort Detrick as the commander of the U.S. Army Medical Research Institute of Infectious Diseases. Previously, Korch served for several years as the science adviser to the assistant secretary of preparedness and response for the Department of Health and Human Services. He briefly served as acting assistant secretary for preparedness and response due to the departure of a colleague from the role to the Department of Defense. Dr. George Korch holds a doctorate from the Department of Immunology and Infectious Diseases at the Johns Hopkins University Bloomberg School of Hygiene and Public Health, where he is a visiting professor in the Department of Microbiology and Immunology. He is also a member of the American Association for the Advancement of Science, has several scientific publications and has been awarded numerous civilian and military awards and honors.

Dr. David Moran, Member

Dr. Moran is President of Technology International Partnerships, LLC, and Past-Publisher of Sigma Xi, The Scientific Research Society, "American Scientist" and the "Chronicle of the New Researcher." He has served as President of the National Technology Transfer Center; Director of Industrial Advanced Development & Industrial Outreach, Advanced Technology, Office of Naval Research; Program Element Administrator for Nuclear Propulsion, R&D, Naval Material Command; Director, David Taylor Institute; Assistant Technical Director, Director of Research, and Technology Director, Naval Ship R&D Center. His professional experience in research and teaching at universities includes the U.S. Naval Academy, Full Professor, Navy Chair; West Virginia University; George Washington University; Research Naval Architect, US Navy. He earned a Ph.D. in Hydrodynamics & Mathematics, IIHR; Sc.M., M.I.T, Ocean Engineering, Hydrodynamics; Sc.B., M.I.T.; Harvard University; University of Iowa; and Graduate, Federal Executive Institute. He served at Harvard University's JFK School as Senior Official for National Security. He is a member of the Boards of: Tucker Community Foundation; Community Trust Foundation; Preston Community Fund; and Past-Treasurer, Board of Directors, Maryland Garrett College. His publications include 102 scientific papers, 12 patents in Hydrodynamics and Aerodynamics, and two published books.

Mr. Joseph Nimmich, Member

Mr. Nimmich is a Partner at Potomac Ridge Consulting. He formerly was Senior Executive Advisor at Booz Allen Hamilton's Civil and Commercial Group. Prior to Booz Allen Hamilton, he served as the Deputy Administrator of the Federal Emergency Management Agency (FEMA) from September 2014 until January 2017. During his tenure, his primary focus was on strengthening and institutionalizing FEMA's business architecture over the long term to achieve the Agency's mission. He joined FEMA in 2013, as the Associate Administrator for the Office of Response and Recovery. He was responsible for directing the Response, Recovery, and Logistics Directorates, as well as the Office of Federal Disaster Coordination. Prior to joining FEMA, he was the Director of Maritime Surveillance and Security at Raytheon Corp., where he directed maritime surveillance and security operations, as well as their emergency response capabilities. He served in the U.S. Coast Guard for more than 33 years, retiring as a Rear Admiral. His Coast Guard assignments included the First Coast Guard District based in Boston, Massachusetts, where he was responsible for all Coast Guard operations across eight states in the northeast and 2,000 miles of coastline from the U.S.-Canadian border to northern New Jersey. He earned his M.B.A. from the Stern School of Business at New York University.

Dr. Charles Parmenter, Member

Dr. Parmenter is a Distinguished Professor Emeritus of Chemistry at Indiana University. He also served as Professor and Assistant and Associate Professor at Indiana University in a career there that spanned nearly half a century (1964-2010). He earned his bachelor's degree from the University of Pennsylvania and served as a Lieutenant in the U.S. Air Force from 1955-57. He worked at DuPont after serving in the military and received his Ph.D. from the University of Rochester and was a Postdoctoral Fellow at Harvard University. He has been elected a Member of the National Academy of Sciences and the American Academy of Arts and Sciences, and a Fellow of the American Physical Society and the American Association for the Advancement of Science. He was a Guggenheim Fellow, a Fulbright Senior Scholar, and received the Senior Alexander von Humboldt Award in 1984. He has received the Earle K. Plyler Prize, was a Spiers Medalist and Lecturer at the Faraday Society, and served as Chair of the Division of Physical Chemistry of the American Chemical Society, Co-Chair of the First Gordon Conference on Molecular Energy Transfer, Co-organizer of the Telluride Workshop on Large Amplitude Motion and Molecular Dynamics, and Councilor of Division of Chemical Physics, American Physical Society.

Ambassador (ret.) Thomas Pickering, Member

Mr. Pickering is Vice Chairman of Hills & Co, international consultants. He co-chaired a State-Department- sponsored panel investigating the September 2012 attack on the U.S. diplomatic mission in Benghazi. He served as U.S. ambassador to the United Nations in New York, the Russian Federation, India, Israel, El Salvador, Nigeria, and the Hashemite Kingdom of Jordan. Mr. Pickering also served on assignments in Zanzibar and Dar es Salaam, Tanzania. He was U.S. Under Secretary of State for Political Affairs, president of the Eurasia Foundation, Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs, and Boeing Senior Vice President for International Relations. He also co-chaired an international task force on Afghanistan, organized by the Century Foundation. He received the Distinguished Presidential Award in 1983 and again in 1986 and was awarded the Department of State's highest award, the Distinguished Service Award in 1996. He holds the personal rank of Career Ambassador, the highest in the U.S. Foreign Service. He graduated from Bowdoin College and received a master's degree from the Fletcher School of Law and Diplomacy at Tufts University and a second master's degree from the University of Melbourne in Australia.

Mr. Tom Quinlan, Member

Mr. Quinlan has specialized expertise in rebranding traditional businesses and pivoting physical content into the digital space by leveraging digital marketing, data analytics, business intelligence, and data management solutions. He is currently the CEO and President of R. R. Donnelley & Sons Company, and has served as Chairman and CEO of LSC Communications, Executive Vice President of Operations and Business Integration at Moore Wallace, and Senior Vice President and Treasurer of World Color Press. He has served on the Boards of Trustees of Pace University, YMCA of Greater New York, Curry College, The American Ireland Fund, and the US Army War College. He received the Franklin Award for Distinguished Service. He received a Masters in Business Administration in Finance from St. John's University and graduated with a Bachelor of Science degree in Business Administration, Pace University

Dr. Eugene Sander, Member

Dr. Sander served as the 20th president of the University of Arizona (UA), stepping down in 2012. He formerly was vice provost and dean of the UA's College of Agriculture and Life Sciences, overseeing 11 academic departments and two schools, with research stations and offices throughout Arizona. He also served as UA Executive Vice President and Provost, Vice President for University Outreach and Director of the Agricultural Experiment Station and Acting Director of Cooperative

Extension Service. Prior to his move to Arizona, Dr. Sander served as the Deputy Chancellor for biotechnology development, Director of the Institute of Biosciences and Technology, and head of the Department of Biochemistry and Biophysics for the Texas A&M University system. He was Chairman of the Department of Biochemistry at West Virginia University Medical Center and Associate Chairman of the Department of Biochemistry and Molecular Biology at the College of Medicine, University of Florida. As an officer in the United States Air Force, he was the assistant chief of the biospecialties section at the Aerospace Medical Research Laboratory. He graduated with a bachelor's degree from the University of Minnesota, received his master's degree and Ph.D. from Cornell University and completed postdoctoral study at Brandeis University. As a biochemist, Dr. Sander worked in the field of mechanisms by which enzymes catalyze reactions.

Dr. David Schejbal, Member

Dr. Schejbal is the President of Excelsior University. He was appointed in 2020, after two years as Vice President and Chief of Digital Learning at Marquette University. This followed 11 years as Dean of Continuing Education, Outreach and E-Learning at the University of Wisconsin-Extension. In this role, Dr. Schejbal helped launch the new UW Flexible Option, the first system-wide competency-based, self-paced learning option in the nation. Prior to coming to Wisconsin, Dr. Schejbal spent eight years at the University of Illinois at Urbana-Champaign. There he was associate vice chancellor and director of Continuing Education. Dr. Schejbal previously served as the Associate Dean of the University College and the Director of Summer Sessions and Special Programs at Northwestern University. He is a member of the executive committee of the Council of Environmental Deans and Directors and served four terms on the board of the University Professional and Continuing Education Association. Dr. Schejbal earned his B.A .from Iowa State University, and earned a Ph.D. in Philosophy from the University of Connecticut in 1990. His affiliations with industry organizations include serving as a member of the executive committee of the Council of Environmental Deans and Directors, a member of the governing board of the Competency-Based Education Network, chair of the Board of Visitors of the Army War College, and the past president of the University Professional and Continuing Education Association. Dr. Schejbal has earned several professional awards including the University of Wisconsin-Extension Chancellor's Award for Excellence; and the University Professional and Continuing Education Association Outstanding Program Award for the Bachelor of Science in Sustainable Management.

Dr. Ben Tuchi, Member and Secretary/Treasurer

Dr. Tuchi serves on the boards of two additional non-profit corporations; he is

Treasurer of the Campus Research Corporation and President of the Arizona Research Park Authority. He received his B.S. and M.S. degrees in Business Administration from the Pennsylvania State University and his Ph.D. in Finance from St. Louis University. His full time teaching career began in 1961 at St. Francis College and continued until 1976 at West Virginia University. From 1976 through 1996 he served in cabinet levels at West Virginia University, The University of Arizona, The University of North Carolina at Chapel Hill, and finally as Senior Vice Chancellor for Business and Finance of the University of Pittsburgh. During those assignments he was simultaneously a tenured professor of finance. He retired from the last executive post in 1996 and returned to a full-time teaching position as Professor of Finance at the University of Pittsburgh, until his retirement in 1999. For the two years prior to his retirement he was the Director of Graduate Programs in Business in Central Europe, at Comenius University, making his home in Bratislava, The Slovak Republic.

Ms. Frances Ulmer, Member

Ms. Ulmer is a Visiting Senior Fellow at the Belfer Center's Arctic Initiative and is the former Chair of The Nature Conservancy's Global Board of Directors. She was a Visiting Professor in the Department of Earth System Science at Stanford University from 2017 to 2018. Ms. Ulmer was appointed by President Obama as the Chair of the U.S. Arctic Research Commission in March 2011 and served in that role until August 2020. From 2014 to 2017, Ulmer was a Special Advisor on Arctic Science and Policy at the State Department. In June 2010, President Obama appointed her to the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. From 2007 to 2011, she served as Chancellor of the University of Alaska, Anchorage (UAA), Alaska's largest public university. Before that, she was a Distinguished Visiting Professor of Public Policy and Director of the Institute of Social and Economic Research at UAA. She served as an elected official for 18 years as the mayor of Juneau, a state representative and as Lieutenant Governor of Alaska. She previously worked as legal counsel to the Alaska Legislature, legislative assistant to Governor Jay Hammond and Director of Policy Development for the state. In addition, she was the first Chair of the Alaska Coastal Policy Council and served for more than 10 years on the North Pacific Anadromous Fish Commission. Ms. Ulmer earned a J.D. cum laude from the University of Wisconsin Law School, and has been a Fellow at the Institute of Politics at Harvard Kennedy School.

Dr. Maria Velissariou, Member

Dr. Velissariou is a Fortune 100 R&D executive with diverse global experience driving vision and strategy, innovation, and advocacy in high-impact corporate and nonprofit organizations. Throughout her career she has been strategically focused on translating science and technology opportunities into scalable innovation solutions. She is an advocate for sustainable food systems, science-based policy, and funding for food research. She served as the Global Corporate R&D VP and CSO for Mars. She led the function's enterprise-wide approach for Quality and Science in partnership with the business segments and equipped R&D with new digital capabilities. Before Mars, she held senior leadership positions including the Institute of Food Technologists. Quaker Foods North America, and PepsiCo. Additionally, she served in various roles at Kraft Foods and Dow Corning Europe. She founded Maria Velissariou Consulting LLC, providing advisory services in Food and Beverage and adjacent sectors. She also partners with the Kirchner Group as Managing Director focused on Innovation, Growth and Development. Dr. Velissariou received a Ph.D. and M.S. in Biochemical Engineering from the University of Birmingham (UK), and a B.E. in Chemical Engineering from the Aristotle University of Thessaloniki (Greece). She also completed executive studies at Oxford and Cornell. Dr. Velissariou serves in various board and advisory positions in the profit and nonprofit sectors, is a mentor to entrepreneurs, and has been a long-standing advocate for women in STEM with a focus on the underserved. She has presented at various global conferences and featured in diverse media.

Additional ISGP Board Participants

Mr. Richard Armitage, Special Adviser

Mr. Armitage is the President at Armitage International, where he assists companies in developing strategic business opportunities. He served as Deputy Secretary of State from March 2001 to February 2005. Mr. Armitage, with the personal rank of Ambassador, directed U.S. assistance to the new independent states (NIS) of the former Soviet Union. He filled key diplomatic positions as Presidential Special Negotiator for the Philippines Military Bases Agreement and Special Mediator for Water in the Middle East. President Bush sent him as a Special Emissary to Jordan's King Hussein during the 1991 Gulf War. Mr. Armitage also was Deputy Assistant Secretary of Defense for East Asia and Pacific Affairs in the Office of the Secretary of Defense. He graduated from the U.S. Naval Academy. He has received numerous U.S. military decorations as well as decorations from the governments of Thailand, the Republic of Korea, Bahrain, and Pakistan. Most recently, he was appointed an Honorary Companion of The New Zealand Order of Merit. He serves on the Board of Directors of ConocoPhillips, ManTech International Corporation, and Transcu

Ltd., is a member of The American Academy of Diplomacy as well as a member of the Board of Trustees of the Center for Strategic and International Studies.

Jennifer Boice, Special Assistant to the Board

Ms. Boice worked for the ISGP in a number of capacities since 2010. Before that, she worked in the newspaper industry for 25 years, primarily at the Tucson Citizen and briefly at USA Today. She was the Editor of the Tucson Citizen when it was closed in 2009. Additional appointments at the Tucson Citizen included Business News Editor, Editor of the Online Department, and Senior Editor. She was also a business columnist. She received her M.B.A. from the University of Arizona and graduated from Pomona College in California with a degree in Economics.

In Memoriam

Mr. Jim Kolbe, Member

For 22 years, Mr. Kolbe served in the United States House of Representatives, elected in Arizona for 11 consecutive terms, from 1985 to 2007. Mr. Kolbe served as a Senior Transatlantic Fellow at the German Marshall Fund of the United States, and as a Senior Adviser to McLarty Associates, a strategic consulting firm. He advised on trade matters as well as issues of effectiveness of U.S. assistance to foreign countries, on U.S.-European Union relationships, and on migration and its relationship to development. He was also Co-Chair of the Transatlantic Taskforce on Development with Gunilla Carlsson, the Swedish Minister for International Development Cooperation. He was an adjunct Professor in the College of Business at the University of Arizona. While in Congress, he served for 20 years on the Appropriations Committee of the House of Representatives, was chairman of the Treasury, Post Office and Related Agencies subcommittee for four years, and for his final six years in Congress, he chaired the Foreign Operations, Export Financing and Related Agencies subcommittee. He graduated from Northwestern University with a B.A. degree in Political Science and then from Stanford University with an M.B.A. and a concentration in economics.

Dr. Mike Buch, Member

Dr. Buch held B.A., M.S., and Ph.D. degrees in Analytical Chemistry and Biotechnology. He had nearly three decades of experience in the consumer healthcare industry in various roles of increasing responsibility with some of the world's leading companies. He served as Chief Science Officer and Board Member at Young Living Essential Oils and had expertise in leading global strategic development programs, open innovation programs, licensing programs, consumer healthcare

R&D, advanced technologies labs, advanced optical analysis labs, and biosensor design and research. He was also a member of several prestigious associations, including the American Chemical Society, The New York Academy of Science, and the American Association for the Advancement of Science.

Dr. Henry Koffler

Dr. Koffler served as President of the UA from 1982-1991. He also held UA professorships in the Departments of Biochemistry, Molecular, and Cellular Biology, and Microbiology and Immunology, positions from which he retired in 1997 as Professor Emeritus of Biochemistry. He was Vice President for Academic Affairs, University of Minnesota, and Chancellor, University of Massachusetts/Amherst, before coming to the UA. Dr. Koffler served as a founding Governor and founding Vice-Chairman of the American Academy of Microbiology, and as a member of the governing boards of the Fermi National Accelerator Laboratory, the Argonne National Laboratory, and the Superconducting Super Collider Laboratory. Among the honors that Dr. Koffler has received are a Guggenheim Fellowship and the Eli Lilly Award in Bacteriology and Immunology.

Biographical Information of ISGP Leadership and Staff

Dr. George Atkinson, Executive Director, and Founder

Dr. George Atkinson is an Emeritus Professor of Chemistry, Biochemistry, and Optical Science at the University of Arizona. His professional career includes academic teaching, research, administration, roles as a corporate founder and executive, and public service at the federal level. He is the former Head of the Department of Chemistry at the University of Arizona, the founder of a laser sensor company serving the semiconductor industry, and the Science and Technology Advisor (STAS) to U.S. Secretaries of State Colin Powell and Condoleeza Rice. In 2014, Dr. Atkinson was named president of Sigma Xi, The Scientific Research Society. Based on principles derived from his personal experiences, he launched the ISGP in 2008 as a new type of international forum in which credible experts provide governmental and societal leaders with the objective understanding of the science and technology that can be reasonably anticipated to help shape the increasingly global societies of the 21st century.

Euphemia Anderson, Program Manager, Senior Fellow

Ms. Anderson graduated from the College of Agricultural Life Science at The University of Vermont, where she received a B.S. in Environmental Studies with a focus on Sustainability. Her interest in sustainable systems and the intersection of science and business ignited during her internship with the Sustainable Economies Program at Manomet, a non-profit organization based in Massachusetts, where she worked directly with businesses and communities on practices that enhanced their economic viability while also reducing their environmental footprint. She also held an internship with ECHO Leahy Center for Lake Champlain in Burlington, Vermont, where she facilitated broad-scale access to science education within the Burlington community. She holds a special interest in climate change mitigation, renewable energy, and small business sustainability.

Daniela Baeza-Breinbaur, Senior Fellow

Ms. Daniela Baeza Breinbauer is a Project Manager and Researcher at the LSE where she leads the Food Systems and Security Hub (FSSH) and oversees projects in the fields of Food Security; Environmental Economics; Development Economics; and Human Rights. By training, she is a Development and Environmental Economist with a background in Human Rights and Science Policy. She has previously consulted for a variety of government and non-government institutions. Some of her recent work includes evaluating the effectiveness of interventions to strengthen rural governance for food security on behalf of Welthungerhilfe, investigating zoonotic disease risks of livestock farming practices for the European Parliament, exploring sustainable food consumption choices for WWF, and assessing the food security implications of trade negotiations between the EU and Mercosur for the European Commission. She holds an M.Sc. in International Development Management (Applied Development Economics Specialism) from the LSE, an M.Sc. in Environmental Economics from the LSE, and an Advanced Diploma in Agriculture and Farming Systems from Capel Manor. She is also a current PhD candidate in Environmental Economics at LSE's Grantham Research Institute where she is using Bayesian Machine Learning techniques to develop an early warning system focused on the food security consequences of climate risks across East Africa.

Sophie Bartholomaus, Fellow

Ms. Bartholomaus is a graduate of Roanoke College, where she earned a B.A. in Public Health. Sophie has a strong desire to teach others and help communities which is rooted in her work with the Local Environmental Agriculture Program (LEAP), a nonprofit located in southwestern Virginia. Through her work with LEAP, she was able to inform the local public on the importance of local, sustainable farming, and bringing green spaces and community gardens to areas with food insecurity. She has gained experience in program development, grant proposal writing, budgeting, and community outreach through working with various nonprofits. As a student, she was able to not only gain these skills but also expand on them to see what primary-level implementations may be needed to promote positive impacts.

Camelia Bou, Senior Fellow

Ms. Bou graduated from Northeastern University with a Bachelor's in International Affairs and Economics and continued her studies in the Environmental Science and Policy Master's Program. During her time at Northeastern University, she participated in Genocide and its Aftermath Dialogue of Civilizations Program, a faculty-led study focused on the effects of genocide in Greek society. As part of one of her graduate courses, she attended COP 26 Glasgow virtually as an observer, where she had the opportunity to explore her interest in international climate policy. She worked at the Rian Immigrant Center in the Learning Exchange Program as a program assistant, helping students and recent graduates from Ireland on the J-1 visa with their job search in the United States. She is fluent in English and Spanish and is at a beginner level French. She hopes to continue to work in the environmental justice and policy field.

Tory Brewster, Fellow

Ms. Brewster graduated from the University of Redlands, receiving a B.A. in Political Science, Public Policy, and Environmental Studies. Upon graduating from the University of Redlands, she worked as an Americorp CivicSpark Fellow completing her first service year with the Coachella Valley Association of Governments and her second service year with the City of Beverly Hills. As a CivicSpark Fellow, she completed urban greening research and created a volunteer program to map land management issues on conservation lands. Additionally, she assisted in drafting a plastic and polystyrene ban ordinance, supported local efforts to comply with a statewide food recovery initiative (SB1383), developed a local Green Business Program, and supported the development of a local Climate Action and Adaptation Plan. After completing two service years as a CivicSpark Fellow, she became a Climate Campaign Fellow for Pacific Environment. At Pacific Environment, she supported the "Ship It Zero" Campaign and Pacific Environment's climate program legislative initiatives. Tory holds a special interest in environmental justice, conservation, as well as climate change mitigation and adaptation.

Billy FitzGerald-Lowry, Adjunct Fellow

Mr. FitzGerald-Lowry is a Ph.D. candidate at the University of Technology Sydney (Australia). He graduated with biology (B.Sc.) and oceanography (M.Sc.) degrees from both Swansea and Southampton University (United Kingdom) respectively. His current research investigates how ocean acidification will affect silica deposition to diatom (marine algae) frustules, part of an Australian Research Council (ARC) grant. Alongside this, Mr. FitzGerald-Lowry works on projects in the Southern Ocean Sub-Antarctic Zone and the Great Barrier Reef. His extensive fieldwork is complemented by laboratory studies to present a comprehensive insight into diatom silicification. He has joined projects that aim to highlight and mitigate climate change, aiming to present novel issues and put forward solutions. His love of science has now stemmed an interest in both marine biological and terrestrial carbon sequestration which he hopes may help to abate greenhouse gas emissions and solve one of the most salient issues we are currently facing.

Katie Durante, Senior Fellow

Ms. Durante is a graduate of Eckerd College, where she received a double B.A. in Biology with a focus on Ecology and Environmental Studies. Her interest in land management and environmental education stems from her internship at Boyd Hill, a nature preserve in Saint Petersburg, Florida. There she effectively removed invasive species and became well-versed in plant identification. Katie's interest in education was also formed through her co-presidency of the beekeeping club at Eckerd College, where she collaborated with the school to create more favorable conditions for the hive. She hopes to work at national parks through environmental education programs to spread knowledge of the importance of environmental sustainability.

Ciaran Fitzpatrick, Program Manager, Senior Fellow

Mr. Fitzpatrick graduated with Honors from Eckerd College, where he received a B.S. in Biology (Molecular), a B.A. in International Relations & Global Affairs, and minors in Chemistry and Spanish. At Eckerd, he was a Ford Apprentice Scholar and worked as a cell biology research assistant, studying *C. elegans* as model genetic organisms for researching Parkinson's disease. In the Summer of 2018, he completed an internship with Heart to Heart International, an organization that provides health access, humanitarian development, and crisis relief locally and abroad. He aims to conduct impactful biological research and to use scientific communication to bridge the gap between research and policy. He takes a special interest in the fields of genomics, global health, and biodiversity.

Adam Greco, Fellow

Mr. Greco is an undergraduate student at the University of Florida, double majoring in International Studies and Political Science. He is also one of the founding members and former Vice President of the Florida John Quincy Adams Society, the university's largest club dedicated to International Relations. Mr. Greco studied with Sciences Po Paris in the Summer of 2022, focusing on European Union policy, and studies with them currently with a more varied course load. In addition, He has academic publications with the Center for International Maritime Security and the Journal of Strategic Security. He holds a special passion for developmental economics, geopolitical affairs, and sustainability.

Kyaw "Joe" Khine, Fellow

Mr. Khine graduated from the University of Virginia, where he earned his Master's degree in Public Policy. Upon graduating, he worked at the Weldon Cooper Center for Public Service as a research and policy analyst, providing demographics research and data analysis support to the Virginia Department of Education. Before joining ISGP, Joe worked remotely as a consultant for Thibi Consultancy. He worked on data journalism projects, provided research, and created data visualizations for media organizations and non-profits based in Southeast Asia. As a student, he interned with WWF and Proximity Designs Social Enterprise in Myanmar, where he developed his passion for sustainability and economic development. He also holds a B.Sc. in Environmental Geosciences and is fluent in English and Burmese.

He hopes to continue working on the intersection of sustainability, food security, and environmental policy in Southeast Asia.

Mattia Anfosso Lembo, Fellow

Mr. Anfosso Lembo is a former employee of the Embassy of Italy in Accra, Ghana. He graduated with honors from the University of Trieste in 2019, where he earned a Master's degree in Diplomacy and International Cooperation. He also holds a Master's course in Diplomatic Studies from the Italian Society for International Organization (SIOI) based in Rome, Italy. During his time at the Embassy of Italy in Accra, Mattia had the chance to immerse himself in an international environment. Through daily analysis and the preparation of reports on West African politics and economy, he acquired a great knowledge on how African countries, with the help of Western and Asian countries, are working to overcome major problems that afflict their population, such as terrorism, famine, and drought. Mr. Anfosso Lembo ultimately hopes to work at the United Nations to foster positive relations with various audiences from different political and economic organizations as well as with national and international institutions. He is passionate about science, history, geopolitics, international relations, and philosophy. He is fluent in Italian, English and has a good working knowledge of French.

Ian Shotts, Senior Fellow

Mr. Shotts is a graduate of The Ohio State University where he earned a B.A. in International Relations and Diplomacy, a degree he was led to by his passion for policy and multilingual background. One of his most valuable professional experiences was a research project in the Central Valley of Costa Rica where he measured the ecological and social impacts of climate change on local farmers. His dedication to investigation continued as he researched state and federal law in the private sector, in addition to undertaking supplemental positions at the Environmental and Social Sustainability Research Program and Center for Life Sciences Education at Ohio State. His continued studies at the graduate level at the Universidad Autónoma de Madrid and his former undergraduate institution in cemented his passion for the public policy and science, ultimately leading him to the ISGP. Mr. Shotts' interests primarily lie in the environment, climate change, public policy, and political philosophy.

Haileyesus Tadesse, Fellow

Mr. Tadesse is a graduate of Loughborough University in the United Kingdom, where he earned his M.S. in Environmental Monitoring for Management. After graduating, he joined the development sector, where he worked with government offices and donors on projects with a focus on livelihood improvement, watershed management, stakeholder coordination and engagement, and natural resources governance. In the past, he has participated in various research projects and led the development of successful project proposals with partners. He enjoys working with communities and strives to see the coordination of policies and institutions for effective delivery of solutions to current global challenges.

Bruce Texeira, Adjunct Fellow

Mr. Texeira graduated from Shenandoah University at the Conservatory of Music, where he received his Bachelor of Arts in Music Education. He continued his education receiving his Master's Degree at SUNY Stony Brook University. Mr. Texeira taught Instrumental Music at Rocky Point School District on Long Island where he served as the Director of Music for the district for 32 years. During his time there, he was awarded Man of the Year in Education from a local newspaper. He also served as the Director of the marching band that played at the opening day for the New York Mets for seven years, and led the New York State School Music Association Solo and Ensemble competition for his region. Mr. Texeira also served as Moderator of UCC Church of Christ for 6 years, where he also served as the Chairman of Trustees and Chairperson for Outreach. Mr. Texeria ran a local food pantry to support those less fortunate in the community.

Rebecca Simison, Senior Fellow

Ms. Simison is a graduate of the University at Albany with a B.A. in World History and American Politics. Rebecca has experience in political research, government, and advocacy work. Since graduating, they have served as a Legislative Aide in the New York State Assembly, as well as the Associate Vice President for Research and Policy at the New York State Coalition for Children's Behavioral Health. As a student, she also served as a Policy Research Intern at the Rockefeller Institute of Government in Albany, NY, where she conducted research and published a policy brief on the economic and structural barriers to higher education in the U.S. She has a passion for nuanced and well-researched policies that will improve people's lives.

Kat Wheeler, Senior Fellow

Ms. Wheeler has more than seven years of experience in food and agriculture systems. She is currently a graduate student and Research Assistant at the Washington State University (WSU) Sustainable Seed Systems Lab in the Department of Crop and Soil Sciences. Prior to joining WSU, Kat was Project Officer at London School of Economics and Political Science (LSE) Consulting. At LSE Consulting, she worked on topics ranging from urban food systems governance, the right to food, and zoonotic disease as a part of her research under LSE Consulting's Food Systems and Security Hub. Prior to joining LSE Consulting, Ms. Wheeler spent more than three years facilitating stakeholder dialogues on science- and policy-related issues including plant breeding innovation, food traceability, climate impacts on agriculture, communication and food labeling, medical supply chain security, and veterinary medical countermeasures. Kat has also supported farm-to-school in Michigan, conducted research on coffee farmers' views on third party certifications in Costa Rica, and has been an advocate for farmworker rights in Florida. She received a B.A. in Environmental Studies with a minor in Biology from Eckerd College.

ISGP Programs and Conferences

ISGP books from ISGP conferences listed below are available to the public without charge and can be downloaded from the ISGP Web site: www.scienceforglobalpolicy.org. Hardcopies of these books are available by contacting info@scienceforglobalpolicy.org.

Most recent

- *Global Pathways to Hydrogen Energy Futures – Japan, con*onvened by the ISGP at the Pacifico Yokohama Conference Center in Yokohama, Japan, April 6 - 9, 2023.
- Foresight from the COVID-19 Pandemic: Science, Policy, and Communication, convened using an internet format February 27-March 1, 2023.

ISGP Signature Conferences (ISC) conferences and books:

Emerging and Persistent Infectious Diseases (EPID):

- *Focus on Antimicrobial Resistance,* convened March 19–22, 2013, in Houston, Texas, U.S., in partnership with the Baylor College of Medicine.
- *21st Century Borders/Synthetic Biology: Focus on Responsibility and Governance*, convened December 4–7, 2012, in Tucson, Arizona, U.S., in partnership with the University of Arizona.
- *Focus on Societal and Economic Context*, convened July 8–11, 2012, in Fairfax, Virginia, U.S., in partnership with George Mason University.
- *Focus on Mitigation*, convened October 23–26, 2011, in Edinburgh, Scotland, U.K., in partnership with the University of Edinburgh.
- *Focus on Prevention*, convened June 5–8, 2011, in San Diego, California, U.S.
- *Focus on Surveillance*, convened October 17–20, 2010, in Warrenton, Virginia, U.S.
- *Global Perspectives* convened December 6–9, 2009, in Tucson, Arizona, U.S., in partnership with the University of Arizona.

Food Safety, Security, and Defense (FSSD):

- *Equitable, Sustainable, and Healthy Food Environments*, convened May 1–4, 2016 in Vancouver, British Columbia, Canada, in partnership with Simon Fraser University.
- *Food Security and Diet-linked Public Health Challenges* convened September 20–23, 2015 in Fargo, North Dakota, in partnership with North Dakota State University.

- *Focus on Food and the Environment*, convened October 5–8, 2014, in Ithaca, New York, in partnership with Cornell University.
- *Focus on Food and Water,* convened October 14–18, 2013, in Lincoln, Nebraska, U.S., in partnership with the University of Nebraska–Lincoln.
- *Focus on Innovations and Technologies,* convened April 14–17, 2013, in Verona, Italy.
- *Global Perspectives* convened October 24, 2012, in Arlington, Virginia, U.S., in partnership with George Mason University.

ISGP Global Challenges (IGC) conferences and books:

ISGP Climate Change Program (ICCP)

- *The Shore's Future: Living with Storms & Sea Level Rise*, convened November 20–21, 2015, in Toms River, New Jersey, in cooperation with the Toms River Working Group, Barnegat Bay Partnership, Barnegat Bay Foundation, and the Jay and Linda Grunin Foundation.
- *Sea Level Rise: What's Our Next Move?*, convened October 2–3, 2015, in St. Petersburg, Florida, in cooperation with the St. Petersburg Working Group.

ISGP Climate Change Arctic Program (ICCAP)

- *Sustainability Challenges: Coping with Less Water and Energy,* convened June 5, 2015, in Whittier, California, in cooperation with the Whittier Working Group.
- *Living with Less Water*, convened February 20–21, 2015, in Tucson Arizona, in cooperation with the Tucson Working Group.

ISGP Academic Partnerships (IAP) conferences and books:

- *Socioeconomic Contexts of Sustainable Agriculture* convened October 14–15, 2016, in Danbury, Connecticut, in partnership with Western Connecticut State University.
- *Water and Fire: Impacts of Climate Change*, convened April 10–11, 2016, in Sacramento, California, in partnership with California State University.
- *Communicating Science for Policy*, convened August 10–11, 2015, in Durham, North Carolina, in partnership with Sigma Xi, The Scientific Research Society.
- *Food Security: Production and Sustainability*, convened April 24–25, 2015, in St. Petersburg, Florida, in partnership with Sigma Xi, The Scientific Research Society, and Eckerd College.
- *Safeguarding the American Food* Supply, convened April 10–11, 2015, in Collegeville, Pennsylvania, in partnership with Sigma Xi, The Scientific Research Society, and Ursinus College.

- *Focus on Pandemic Preparedness,* convened April 11–12, 2014, in Collegeville, Pennsylvania, U.S., in partnership with Ursinus College.

ISGP Science and Governance (S&G) conferences and books:

- *Global Pathways to Hydrogen Energy Futures - Island Community Priorities*, convened using internet platforms spanning fifteen (15) time zones on June 21-23, 2022 (Western Hemisphere).
- *The Future of Modern Agriculture conference, convened September 22, 2020, in a hybrid in-person (Rome, Italy) / internet format, with support from The Office of Agricultural Policy, U.S. Department of State.*
- *Sustainable Agriculture: The Role of Plant Breeding Innovation conference, convened November 17-19, 2020, in an internet format, with support from the American Seed Trade Association and Euroseeds.*
- *Climate Impact on National Security (CINS–1, CINS–2A, CINS–2B), convened November* 28–December 1, 2016, April 3–4, 2017, and May 17–19, 2017 in partnership with the U.S. Army War College in Carlisle, Pennsylvania.
- *The Genomic Revolution* convened September 6, 2014, in cooperation with the Parliamentary Office on Science and Technology of the British Parliament within the House of Lords. London, United Kingdom.

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