Carbon Fuel Communities Storage

Institute on Science for Global Policy (ISGP)

Hydrogen Distribution Local

Offshore Energy Battery Global

Solar Priorities Resources Cost

Global Pathways to Hydrogen Energy Futures — *Island Community Priorities*

A program and conference organized, facilitated, and moderated by ISGP with funding from the Hawai'i Natural Energy Institute (HNEI) at the University of Hawai'i, Manoa, Hawaiian Electric Industries (HEI), HEI Charitable Foundation, Hawai'i Gas, the Ulupono Initiative and the ISGP.

Convened by the ISGP using internet platforms spanning fifteen (15) time zones on June 21-23, 2022 (Western Hemisphere)

Wind Emissions Island Generation

Environmental Fossil Implementation

Funding Infrastructure Development

Economic Sustainable Transportation

Utilization Challenges Production

Electricity Renewable Government

Institute on Science for Global Policy (ISGP)

Global Pathways to Hydrogen Energy Futures — *Island Community Priorities* *(GPHEF - ICP)*

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An ongoing series of dialogues, critical debates, and extended caucuses examining the role of plant breeding innovation in advancing effective domestic and international policy decisions concerning sustainable agriculture

Institute on Science for Global Policy (ISGP)

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ISBN: 978-1-7334375-3-0

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Introduction

Dr. George H. Atkinson
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and
Professor Emeritus, Department of Chemistry and Biochemistry and
College of Optical Sciences, University of Arizona
and
former Science and Technology Adviser to U.S. Secretaries of State
Colin Powell and Condoleezza Rice

Preface

Many of the myriad challenges currently impacting the global energy system originate from the increasingly significant environmental changes being observed, and reasonably anticipated, throughout all global communities. The relevance of these relationships between energy sources and climate changes is clear and often dramatic for island communities worldwide. Effectively addressing these complex, interrelated challenges requires fundamental changes in how energy is produced, transported, and utilized throughout global systems, with special attention on the sustainability of the economic, environmental, and human consequences. Given the diversity of geographical, economic, political, and cultural priorities found at local, regional, and national levels, these decisions require integrated leadership from governmental, private sector, and public advocacy communities that recognize both immediate and long-term challenges. Obviously, decisions need to be based on credible scientific understanding that can be implemented under practical, real-world conditions. Crucially, the significant, unexpectedly rapid changes in global environments being observed, and those reasonably anticipated, place an urgency on these decisions not historically encountered in the previous development of major technological transitions. The rapidity of changing climates imposes serious time constraints on obtaining an accurate understanding of how any energy source intensities, mitigates, and/or remediates evolving environmental challenges (e.g., population migration, human health, economic sustainability, and societal stability).

As with the evaluation of any emerging energy source, hydrogen-based energy also needs to be critically evaluated with respect to specific, real-world local, regional, national, and global issues (e.g., trade and transportation options, pricing criteria, production reliability and scale, certification of energy production sources and purity). Paramount among these issues is the establishment of trusted certification protocols to accurately characterize the purity, scale, and availability of hydrogen production (e.g., green versus blue versus gray).

The current transitions in the global energy system, encompassing production, transportation, storage, and usage, have focused on how to expand the introduction of renewable energy sources, while continuing to meet the immediate needs for energy historically derived from fossil fuels. The introduction of hydrogen energy has become a central topic in these transitions.

The potential incorporation of hydrogen energy into the global energy system requires a comprehensive review and critical assessment examining how to integrate different technological options, economic planning, and policy directions, while recognizing the diverse local, regional, and national priorities found worldwide. Significantly different geographic, transportation, infrastructure, economic, political, and cultural conditions routinely define the practical options for hydrogen energy production, distribution, and usage. Attention to public endorsement and acceptance remains a critical issue to be considered.

Current Realities

At the outset of the 21st century, most societies face difficult challenges concerning how to appropriately use, or reject, the dramatic new opportunities offered by modern scientific and technological advances. Since scientific research, and the commercially viable technologies that emerge from it, are now developed globally, such societal decisions require candid domestic and international debates among leaders from governmental, private sector, and public advocacy communities. The daunting challenge of simultaneously recognizing technological opportunities and potential risks requires an understanding of how scientific achievements foreshadow transformational changes that can impact human health, global stability, and sustainable environmental and economic prosperity. These complex responsibilities are directly shaped by a multitude of societal pressures exerted by policy makers holding diverse, and often conflicting, views, priorities, and goals. Successful decisions balance real-world practicality with a recognition of the cultural sensitivities and public understanding needed to ensure that science and technology are successfully integrated into effective societal actions that merit public acceptance.

ISGP programs and conferences are designed to provide the egalitarian environments in which governmental, private sector, and public advocacy leadership can engage in intense, respectful, and resourceful exchanges of views and priorities through critical debates and caucuses aimed at identifying Areas of Consensus (AoC) and Actionable Next Steps (ANS) for real-world, scientifically credible decisions.

ISGP-GPHEF Program

Encompassed within a three-year effort, the ISGP-GPHEF program focuses on sequentially convening in-person, invitation-only conferences in several international venues where hydrogen energy has been identified as a priority for sustainable local, regional, and/or national models. These functional models reflect the significantly different geographical, infrastructural, economic, political, and cultural conditions that exist in specific localities worldwide. Identifying and critiquing the practical approaches by which hydrogen energy, as with any energy source, might productively meet the often diverse local, regional, and/or national requirements are fundamental components of the ISGP-GPHEF agenda.

ISGP GPHEF-ICP Agenda

A. Topics

The content of this book was taken from material presented as part of the ISGP Global Pathways to Hydrogen Energy Futures (GPHEF) program, which is designed to encompass a multiyear series of conferences, convened in different venues, critically examining the potential value of hydrogen-based energy within the rapidly evolving energy system worldwide. This specific GPHEF conference, organized, facilitated, and moderated by the ISGP in cooperation with the Hawai'i community focused on the energy needs and perspectives of Island Community Priorities (ICP) in the Asia-Pacific region. In addition to direct financial support from the ISGP, the Hawai'i Natural Energy Institute (HNEI) at the University of Hawai'i, Manoa, Hawaiian Electric Industries, Hawai'i Gas, and the Ulupono Initiative provided funding. ISGP also benefited significantly from numerous conversations with and advice from an Informal Advisory Panel (IAP) focused on Hawai'i interests and activities in hydrogen-based energy (membership found in the Appendix).

The ISGP GPHEF-ICP conference examined the critical decisions needed by individual island communities within vastly different sized archipelagos that have populations ranging from a few thousand to several million. Even with the enormous diversity found in their geographical locations, topologies, populations, demographics, and cultural mores, areas of common interest and similar challenges with respect to current and future energy issues were identified. These overlapping interest and priorities informed candid discussions concerning how hydrogen-based energy might make productive contributions to the immediate and reasonably anticipated energy requirements in island communities and are expected to influence human health, environmental sustainability, economic prosperity, and societal stability worldwide.

B. Structure

The ISGP-GPHEF-ICP conference assembled a distinguished group of subject-matter experts and major stakeholders from governmental, private sector, and public advocacy communities to debate these issues by candidly exchanging views and priorities to be applied toward identifying the AoC and ANS needed to advance real-world societal decisions. ISGP invitation-only conferences, conducted under the Chatham House Rule (not-for-attribution), provide environments in which distinguished subject-matter experts and stakeholders holding diverse, often contradictory, views and priorities can directly and respectfully debate societally significant issues of both domestic and international importance. The individuals invited by the ISGP to participate in these conferences routinely make and/or significantly influence major governmental, private sector, and community decisions affecting the public *writ large*.

C. Format

The organization of the ISGP GPHEF-ICP conference began with extensive international interviews by ISGP staff (approaching 300) to identify highly credentialed, subject-matter experts and officials in governmental, private sector, public advocacy communities having expertise, experience, and responsibilities for decisions related to energy topics, including hydrogen-based energy. These interviewees included representatives from islands throughout the Asia-Pacific region as well as from Australia, Japan, the United States, United Arab Emirates, and Association of Southeast Asian Nations (ASEAN) members.

Nine individuals focused on describing the energy needs and aspirations of seven Asia Pacific islands, one individual describing the scientific and technological properties of hydrogen as an energy source, and one individual commenting on economic issues from the perspective of the Asian Development Bank were invited to prepare a concise, three-page position paper on their respective perspectives and priorities. The position papers on hydrogen-based energy were each organized around current realities, scientifically ad technologically credible opportunities and potential risks, and actionable next steps.

Structurally, the ISGP GPHEF-ICP conference was conducted using an internet format linking approximately 56 participants representing 30 different countries and locations spread over nine time zones. Given the exceptionally diverse time zones involved, participants engaged in the debates and caucuses for different periods of time. Nonetheless, all their contributions were recoded and integrated by the ISGP staff into the conference outcomes. The ISGP staff used recordings of all debates, discussions, and the plenary caucuses to prepare not-for-attribution summaries. These recordings were held in the custody of the ISGP before being destroyed. The position papers, commentaries, and the not-for-attribution summaries are included in this book. The AoC and ANS emerging from the plenary caucus are presented in this book.

The ISGP debate/caucus format was modified to have each of the nine position papers debated for forty-five (45) minutes by about 56 invited participants following a five (5) minute summary of the position paper by the respective authors. All debates and caucuses were moderated by ISGP staff.

Concluding Remarks

The modified ISGP format for presentation on an internet platform seeks to capture as much of the spontaneity, intensity, and effectiveness of its widely endorsed in-person debate/caucus conference format while recognizing the limitations imposed by current and anticipated health and travel restrictions.

The ISGP GPHEF-ICP conference was designed to provide an environment that facilitated candid, critical debates and discussions leading the practical, real-world AoC and ANS on how to examine the potential advantages and challenges associated with the introduction of hydrogen-based energy into the global energy system. As one of the most significant societal challenges in the 21st century, finding effective outcomes is anticipated to impact essentially all societies worldwide. The ISGP remains committed to facilitating the identification of such productive outcomes while remaining neutral. All aspects of the ISGP GPHEF-ICP conference conformed to the ISGP commitment to express no independent opinions nor lobby on any issue except rational thinking.

ISGP GPHEF-ICP Plenary Caucus Outcomes
Areas of Consensus and Actionable Next Steps

Area of Consensus 1:

The identification of adequate funding, and the timely prioritization of its allocation, is the major barrier to effectively transforming the existing energy infrastructure to be compatible with hydrogen-based energy usage, particularly for island communities facing rapidly evolving environmental, economic, and societal challenges. The timely establishment of resilient, sustainable infrastructure supporting renewable energy production, storage, and distribution within island communities is especially critical to (i) minimize island dependence on foreign energy sources, (ii) ensure available financial resources remain within the community, and (iii) enhance societal security under both normal and extraordinary weather conditions.

Actionable Next Steps:

1.1 Develop national and/or international public-private partnerships to facilitate resilient energy infrastructure within island communities, tailored to their respective geographical conditions, population demographics, and governmental structures while recognizing the importance of obtaining sustainable endorsements and support from the affected citizenry.

1.2 Utilize, where appropriate, third-party funding mechanisms based on public and private sector involvement to develop transportation infrastructure for hydrogen-based energy usage.

1.3 Adapt appropriate aspects of successful models for securing funding and resource allocation (e.g., power purchase agreements, public-private partnerships, various political agreements) to focus attention on governmental bureaucracies and private sector procedures to advance infrastructure proposals opposed by the interests vested in existing energy options.

1.4 Emphasize the "public right to transportation" concept as a bridge for developing widely accessible public transport systems for workforce and tourism (e.g., hydrogen/fuel cell buses) that garner strong public support and expand stakeholder mobility.

1.5 Provide tutorial outreach (e.g., podcast, webinar, directed conversations) to inform public and private sector stakeholders in island communities focused on facilitating the transfer of experiential information on bureaucratic models used to effectively implement new energy infrastructures (e.g., hydrogen-based energy).

1.6 Ensure funding decisions on energy infrastructure development accurately reflect constituent concerns for (i) security of access, (ii) resilience, (iii) cost effective sustainability, (iv) community-wide employment options, (v) environmental consequences, (vi) benefits from multiple end-uses, and (vii) community enrichment and cohesion, and avoid using island communities as testing grounds for projects of transitory value.

Area of Consensus 2:

Prioritizing local production of hydrogen-based energy, derived from renewable and/or sustainable sources, versus the importation of hydrogen and hydrogen derivatives (e.g., ammonia, e-fuels) promotes energy self-reliance in island communities. The immediate and long-term advantages and challenges of applying options for hydrogen-based energy (e.g., fossil fuels, wind, solar, geothermal, hydropower, nuclear) need to be tailored to specific island community characteristics and needs: (i) population centers versus remote communities, (ii) utilization priorities for prevalent hard-to-abate sectors (e.g., maritime and land shipping, diesel and coal generation), (iii) societal and economic resources, (iv) existing physical infrastructure, (v) governmental standards, and (vi) cultural mores.

Actionable Next Steps:

2.1 Identify egalitarian, internationally recognized organizations experienced in the multisector development of energy infrastructures, including those for hydrogen-based energy, to assist in structuring extramural funding commitments that (i) ensure the primacy of island community priorities and (ii) account for the global economic and environmental consequences on which the effectiveness of all such commitments rely.

2.2 Examine, through critical, publicly accessible discussions, how funding agreements (e.g., governmental, private sector, and multi-sector partnerships at national and international levels) influence immediate and long-term commitments to production, transportation, and storage for the introduction of hydrogen-based energy options in each island community.

2.3 Evaluate impacts of funding decisions (e.g., grants, financing options, public-private partnerships, national and international affiliations, etc.) for hydrogen-based energy production, storage, and utilization based on the resilience, sustainability, and community-wide acceptance of the resultant energy system.

Area of Consensus 3:
The externalities associated with the ongoing transformation of energy systems worldwide are manifested, directly and indirectly, in a wide range of geopolitical outcomes, especially throughout the Asia-Pacific region. These geopolitical consequences, arising from past, immediate, and future commitments for energy as well as the land and natural resources used in its production, are especially significant for island communities where the competition for geopolitical advantages and economic opportunities is intensifying. These externalities are anticipated to significantly impact (i) environmental sustainability, (ii) governmental priorities at all levels, and (iii) the geopolitical landscape *writ large*.

Actionable Next Steps:

3.1 Integrate into economic, policy, and infrastructure decisions the geopolitical consequences, recognized and reasonably anticipated, associated with transforming energy systems at local, regional, national, and international levels.

3.2 Recognize that the potentially serious impacts of geopolitical outcomes related to infrastructure transformations vary significantly for stakeholders in different geographical locations, topographies, and community demographics as well as those with diverse cultural mores and economic resources.

3.3 Establish evidence-based, trusted sources (i.e., egalitarian organizations and institutions) for accurately identifying the local, regional, national, and international geopolitical consequences of energy transformations, and the development of models that can effectively integrate those issues into the oversight of how energy systems are implemented.

3.4 Acknowledge the major, disproportionate impact of environmental changes on island communities associated with transformative energy decisions made by external entities (i.e., foreign governments, private sector companies, international policy organizations), especially those initiated by developed nations producing large amounts of greenhouse gasses.

Area of Consensus 4:
Decisions concerning hydrogen and ammonia production methodologies (e.g., electrolysis using renewable electricity sources, methane steam reformation with carbon capture, coal gasification with carbon capture) are often dominated by existing economic realities, anticipated financial benefits, and preservation of potentially stranded energy-related assets. Prioritizing hydrogen energy production methodologies throughout local, regional, national, and international communities requires the integration of an evidence-based understanding of (i) observed and

reasonably anticipated environmental challenges, (ii) resilience and sustainability of energy for specific geographical sites, (iii) issues of social license, (iv) consumer access to affordable energy, (v) the development of human capital, and (vi) cultural mores and perspectives.

Actionable Next Steps:

4.1 Prioritize the domestic production of hydrogen in island communities using renewable energy sources to meet local energy needs and to contribute to both localized and global decarbonization, especially in hard-to-abate economic sectors that exist and/or are under development.

4.2 Ensure constituent priorities concerning societal security, employment, environmental impact, and community enrichment and cohesion are embedded into energy decisions.

4.3 Prioritize electricity-based power production and storage methodologies to support island community transitions from fossil fuel usage to electricity-based options.

4.4 Emphasize the benefits of hydrogen energy applications for evolving (i) electric power grids, (ii) transportation applications, and (iii) industrial and manufacturing investments.

4.5 Evaluate each island energy system to understand its resilience to the normal variations of weather conditions currently experienced as well as for those episodic disastrous events anticipated under existing and/or reasonably anticipated climatic changes.

4.6 Utilize evidence-based indicators that evaluate overall environmental impact (e.g., carbon emissions indicators, carbon intensity index) to determine which hydrogen-based production, storage, and utilization options will meet the environmental goals (e.g., nationally determined contributions) for specific locations.

4.7 Ensure the certification of indicators/models for overall carbon emissions accurately reflect all processes for the production, transportation, and storage of hydrogen-based energy (e.g., direct emissions from hydrogen production, production of mechanical components, hydrogen processing, transportation fuel).

4.8 Assess the economic impacts (e.g., expansion/displacement of workforce resources, inflow/outflow of local resources) of hydrogen energy transitions utilizing evidence-based information and analysis that is consistent with environmental goals writ large.

4.9 Recognize the collateral benefits of applications for (i) medical/industrial oxygen, (ii) agriculture, (iii) maritime transport, and (iv) aviation.

Area of Consensus 5:

Governmental adjudication (e.g., via legislation, judicial decisions, regulation, and/or executive actions) needs to inform decisions focused on resolving competing priorities from commercial, environmental, and public advocacy communities engaged in current and anticipated transformations in energy systems. Legislative and regulatory clarity at local, regional, national, and global levels is essential to support effective private sector policies and investments and to protect the public interest in safe, economical access to energy while ensuring immediate and long-term environmental and ecological sustainability.

Actionable Next Steps:

5.1 Conduct rigorous consultation processes among key stakeholders (e.g., governments, private sector companies, public advocates, scientific researchers, safety experts) engaged in decisions concerning hydrogen-based energy production, transportation, storage, and utilization to accurately inform legislative and regulatory institutions focused on ensuring public safety, societal stability, environmental sustainability, and productive economic activity.

5.2 Ensure governmental adjudication considers practical business priorities, including consumer demand across the production, transportation, and storage of energy/energy carriers.

5.3 Prioritize legislative and regulatory structures that encourage the introduction of innovative energy systems (e.g., hydrogen-based energy) as critical steps toward environmental sustainability and resilient economic prosperity.

Area of Consensus 6:

Optimizing the cost-effectiveness of the transport and storage of hydrogen fuel and/or its derivatives, especially for maritime transport and potentially applications for aviation, is critical for developing viable economic models for incorporating hydrogen-based energy into island communities. The infrastructure modifications associated with maritime transport and storage vary significantly (e.g., variations in distances and end-use applications) from one island community to another, but in general, need to address: (i) adapting port facilities for acquiring hydrogen-based fuels from oceanic vessels and the fueling of different vessels, (ii) designing vessel propulsion systems for vessels operating both on inter-island and oceanic routes, (iii) introducing onboard fuel/auxiliary power equipment, and (iv) adapting ships and shipping facilities for storing hydrogen-based fuels and chemical commodities.

Actionable Next Steps:

6.1 Optimize the significantly different infrastructures and/or procedural methods used for maritime shipping *writ large* and for applications tailored to the specific transportation, storage, and end-point utilizations encountered in the vastly different island communities (e.g., geographical location, topographical features, population demographics, policy priorities, and cultural mores).

6.2 Ensure maritime transport of hydrogen-based fuels and related chemicals supports safety practices and decarbonization goals (e.g., nationally determined contributions) in island communities and globally.

6.3 Utilize credible, evidence-based methods to inform and enforce regulatory requirements designed to accurately reflect the "true impact" (e.g., environmental sustainability and resilience, geopolitical externalities) of infrastructure adaptations adopted to establish effective transportation and storage methodologies for hydrogen-based energy applications.

Area of Consensus 7:

Infrastructure development for hydrogen-based energy production, transportation, storage, and utilization needs to be compatible with, and supportive of, value chain factors throughout island societies, including: (i) workforce training and worker availability, (ii) life-cycle analyses of equipment placed on islands, (iii) safety of storage and distribution options, (iv) routine and long-term maintenance and repair costs, (v) competitive pricing regimes vis a' vis other fuel choices, (vi) regional viability of supply chains for specific islands, (vii) projected evolution of marketplace demand, (viii) sustainability of public endorsements concerning accessibility, costs, and safety, and (ix) breadth and consistency of consumer markets.

Actionable Next Steps:

7.1 Appraise the current and reasonably anticipated discrepancies of pricing and availability of competing regional energy sources that are relevant to specific island communities with respect to hydrogen-based energy across the global economic landscape, especially prior to long-term commitments dependent on the rapidly changing economic realities for all energy sources.

7.2 Evaluate the accessibility of ammonia for maritime transport on inter-island and oceanic routes and for long-term storage facilities as an integral part of the practical utilization of hydrogen-based energy in island communities.

7.3 Empower cooperation among diverse stakeholders (e.g., national governments, local governments, industry associations, public advocacy groups) in the development of certification standards and regulatory enforcement procedures, across multiple jurisdictions, to facilitate safe operational control and efficient utilization of hydrogen-based energy, while ensuring rapid, low-cost permitting processes.

7.4 Develop hydrogen-based energy infrastructure that emulates current habits and preferences familiar to consumers (e.g., rapid and accessible vehicle fueling at distributed fuel stations, heating and appliance usage with electric grids, existing power systems for large-scale industrial applications).

7.5 Expedite bureaucratic decisions by governmental and non-governmental stakeholders to support the introduction of innovative energy infrastructure as part of public-private sector investments.

7.6 Introduce hydrogen-based fuels into governmental vehicle fleets to demonstrate the technological, economic, and reliability characteristics commensurate with the development of the large-scale infrastructure needed for broad public applications (e.g., general vehicular usage).

7.7 Ensure public-private sector infrastructure funding focuses on long-term goals and avoids inconsistent, transitory commitments arising from changing priorities fostering inefficiencies detrimental to timely project completion.

7.8 Support the logistical stability throughout the complex, interconnected supply chains required to efficiently produce, transport, and store hydrogen-based energy.

7.9 Leverage the expertise and experience of stakeholders currently addressing infrastructure challenges analogous to those encountered in hydrogen-based energy.

7.10 Engage stakeholders supporting existing supply chains utilizing hydrogen-based products (e.g., rocket fuel, silicon, fertilizer) to find proven procedures and technologies that strengthen capacity in hydrogen-based energy supply chains and prevent single points of failure.

7.11 Integrate widely accepted international codes and standards used to ensure the compatibility of mechanical parts and related materials fundamental to the efficient operation of hydrogen-based energy infrastructure, including maritime shipping.

Area of Consensus 8:

Trusted evaluations of the accurate costs for optimizing the efficiency, scalability, and effectiveness of infrastructure technologies are critical for prioritizing early-stage, private sector investments concerning (i) hydrogen-based energy production (e.g., water electrolysis, carbon capture used with fossil fuel-derived hydrogen, methane pyrolysis), (ii) safe transportation and storage of hydrogen fuel and its derivatives, and (iii) specific consumer and industrial applications (e.g., grid stabilization, light and heavy weight land and maritime transportation, industrial manufacturing).

Actionable Next Steps:

8.1 Identify evidence-based information and analyses focused on verifiable strategies to encourage early-stage and long-term investments in hydrogen-based energy (e.g., proprietary engineering, technological, and/or scientific results).

8.2 Build robust supply chains and logistical options around specific products (e.g., prioritization based on the selection of different forms of hydrogen fuel and derivatives).

8.3 Examine the realistic impact of societal benefits connected with the environmental sustainability related to hydrogen-based energy adaptation as an integral part of economic strategies and decarbonization schemes having regional and global significance.

8.4 Explore institutional cooperatives among energy stakeholders in different locations to establish integrated, standardized procurement and maintenance programs to optimize interconnected advantages and requirements (e.g., different island communities acting as either collective producers and/or importers of hydrogen-based energy and associated equipment).

8.5 Standardize construction, oversight, management, maintenance, and repair procedures within well-trained workforces to minimize infrastructure and operational costs while maximizing scalability to meet large-scale demands for hydrogen-based energy.

8.6 Invest significant resources (i.e., "go big and go fast") in research and development programs focused on identifying the demonstrable economic and environmental advantages (i.e., achieving economies of scale), and potential risks, associated with implementing hydrogen-based energy (e.g., large, sustainable market opportunities as net zero emissions regimes are pursued).

8.7 Ensure detailed, realistic evaluations of potential barriers to deploying and maintaining hydrogen-based energy assets in island environments as core design priorities in technological infrastructure.

Area of Consensus 9:

The realistic evaluation of the timeline over which the large-scale use of fossil fuel in the production of hydrogen-based energy can be maintained is essential for accurately informing major stakeholder decisions consistent with regimes for environmental sustainability (e.g., net zero emission). Trusted communication of the evidence-based, certified conclusions on the impact of continuing the use of fossil fuels can critically influence consumer support for energy strategies proposed to effectively address observed and anticipated climatic changes.

Actionable Next Steps:

9.1 Design and install small-scale infrastructure projects that leverage advantages of existing energy economies on island communities that currently depend on fossil fuels to facilitate long-term transitions to hydrogen-based energy systems.

9.2 Assess the societal challenges at the local and regional levels (e.g., employment opportunities, potential economic disruptions, public perception of safety, regulatory and licensing policies) impacting energy transitions as a critical component in the design and implementation of hydrogen-based energy infrastructure.

Area of Consensus 10:

Significant investments in the education and training of a new generation of local, regional, and national employees are essential for the effective management and maintenance of the infrastructure and economic system required for a sustainable hydrogen-based energy system. Well-paid, highly skilled individuals (i.e., human capital) focused on the ongoing design, operational, engineering, maintenance, and safety challenges of a hydrogen-based energy system are critical to creating a viable, functioning economy, especially in island communities where workforces require ongoing governmental/private sector coordination and commitments.

Actionable Next Steps:

10.1 Build fundamental educational curricula (e.g., short tutorial courses, on-line and in-person instruction, field training) available to a broad cross-section of local, regional, and national citizenry.

10.2 Leverage available international cooperation for access to instruction from individuals with specialized expertise and experience to ensure educational outcomes meet global standards (e.g., maintenance of advanced infrastructure, international safety guidelines and operational information, access to supply chains for replacement parts).

10.3 Examine educational/training programs for technological infrastructure in related fields relying on advanced workforce development (solar photovoltaics, wind turbines).

10.4 Ensure ongoing training programs are continually used to update all members of the workforce and that certifications of outcomes are publicly accessible.

Area of Consensus 11:
Coordinate and implement communication models to effectively address potential public concerns pertaining to the safety of unfamiliar technologies (e.g., technologies associated with hydrogen-based energy).

Actionable Next Steps:

11.1 Communicate accurately the safety requirements that have been studied and developed in existing applications (e.g., vehicular fueling, home appliance usage, industrial processes).

11.2 Highlight results from studies by reputable safety institutions and certification programs pertaining to hydrogen-based energy applications for real-world utilization.

Institute on Science for Global Policy (ISGP)
program on
Global Pathways to Hydrogen Energy Futures (GPHEF)

Conference One:
Island Community Priorities (ICP)

Internet Format
(Western Hemisphere: June 21-23, 2022 /
Eastern Hemisphere: June 22-24, 2022)

Conference Agenda

DAY ONE

Three (3) debates (moderated by ISGP staff), and plenary caucus (moderated/scribed by ISGP staff). All debates and caucuses held under Chatham House Rule (not-for-attribution). Participants take breaks, as needed.

Check-in, Instructions, and Introductions

1100 - 1115 HST* (1700 - 1715 AST/EDT**) (0900 - 0915 MHT***)	**Online Technical Start** *ISGP staff available to assist with any technological questions by contacting Katie Durante (+1 (267) 542-8841 or kdurante@scienceforglobalpolicy.org) or Manuel de la Puerta (+1 (352) 226-0234 or mdelapuerta@scienceforglobalpolicy.org)*
1115 - 1130 HST (1715 - 1730 AST/EDT) (0915 - 0930 MHT)	**Technical Instructions and Online Participant Check-in** *Please be fully connected to the ISGP GPHEF-ICP conference by 1130 HST.* *ISGP staff will work to check you in.*

Debate Session I: Emerging Technology, Practical Applications, and Scalability

1130 - 1215 HST (1730 - 1815 AST/EDT) (0930 - 1015 MHT)	**Position Paper 1:** **"Do We Need Hydrogen for Sustainable & Zero Emissions Energy Conversion?"**

Dr. Jack Brouwer, Director, The National Fuel Cell Research Center (NFCRC) at the Advanced Power and Energy Program (APEP), University of California - Irvine
Moderated by ISGP staff: Mr. Ciaran Fitzpatrick, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

* HST - Hawai'i Standard Time
**AST/EDT - Atlantic Standard Time/Eastern Daylight Time
***MHT - Marshall Islands Time

Debate Session II: Archipelago (Tuvalu) Perspectives

1215 - 1300 HST (1815 - 1900 AST/EDT) (1015 - 1100 MHT)	**Position Paper 2: "Archipelago (Tuvalu) Perspectives on Energy, Challenges, Priorities, and Opportunities for Hydrogen Energy"**

Mr. Simona Kilei, Director of Energy, Government of Tuvalu
Moderated by ISGP staff: Ms. Euphemia Anderson, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Moderated Plenary Caucus I: 120 Minutes

1300 - 1500 HST (1900 - 2100 AST/EDT) (1100 - 1300 MHT)	*Moderated and scribed by ISGP staff: Dr. George Atkinson, ISGP Founder and Executive Director and Mr. Ciaran Fitzpatrick, ISGP Senior Fellow, under Chatham House Rule (not-for-attribution)*
1500 HST (2100 AST/EDT) (1300 MHT)	**Day One Adjournment**

DAY TWO

Three (3) debates (moderated by ISGP staff), and plenary caucus (moderated/scribed by ISGP staff) All debates and caucuses held under Chatham House Rule (not-for-attribution) Participants take breaks, as needed.

Check-in, Instructions, and Introductions

1045 - 1100 HST (1645 - 1700 AST/EDT) (0845 - 0900 MHT)	**Online Technical Start** *ISGP staff available to assist with any technological questions*
1100 - 1115 HST (1700 - 1715 AST/EDT) (0900 - 0915 MHT)	**Participant Check-in** *Online participants, please be fully connected to the event by 1115 HST. ISGP staff will work to check you in.*

Debate Session III: Large Island (Hawai'i) Perspectives

1115 - 1200 HST (1715 - 1800 AST/EDT) (0915 - 1000 MHT)	**Position Paper 3: "Elimination of Fossil Fuel Imports and Decarbonization of County Vehicle Assets by Way of Hydrogen Energy"**

Mr. Riley Saito, Energy Specialist, County of Hawai'i
Moderated by ISGP staff: Ms. Euphemia Anderson, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Debate Session IV: Archipelago (Tonga) Perspectives

1200 - 1245 HST (1800 - 1845 AST/EDT) (1000 - 1045 MHT)	**Position Paper 4:** **"Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy of Tonga"**

Mr. Talolakepa Fonua, Acting Manager for Strategic Business & Development Unit, Tonga Power Limited
Moderated by ISGP staff: Ms. Katie Durante, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Debate Session V: Large Island (Tasmania) Perspectives

1245 - 1330 HST (1845 - 1930 AST/EDT) (1045 - 1130 MHT)	**Position Paper 5:** **"Hydrogen Production in an Island Energy System"**

Mr. Nick Sallmann, Head of Strategy, Hydro-Tasmania
Moderated by ISGP staff: Mr. Manuel de la Puerta, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Moderated Plenary Caucus II: 90 Minutes

1330 - 1500 HST (1930 - 2100 AST/EDT) (1130 - 1300 MHT)	*Moderated and scribed by ISGP staff: Ms. Euphemia Anderson, ISGP Senior Fellow, and Mr. Ciaran Fitzpatrick, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)*

Debate Session VI: Archipelago (Indonesia) Perspectives

1500 - 1545 HST (2100 - 2145 AST/EDT) (1300 - 1345 MHT)	**Position Paper 6:** **"Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy in Indonesia"**

Dr. Bambang Brodjonegoro, Professor of Economics, University of Indonesia; Former Minister of Research and Technology of Indonesia; Former Minister of National Development Planning of Indonesia; Former Minister of Finance of Indonesia
Moderated by ISGP staff: Mr. Manuel de la Puerta, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

1545 HST (2145 AST/EDT) (1345 MHT)	**Day Two Adjournment**

DAY THREE

Three (3) debates (moderated by ISGP staff), and plenary caucus (moderated/scribed by ISGP staff) All debates and caucuses held under Chatham House Rule (not-for-attribution) Participants take breaks, as needed.

Check-in, Instructions, and Introductions

1045 - 1100 HST (1645 - 1700 AST/EDT) (0845 - 0900 MHT)	**Online Technical Start** *ISGP staff available to assist with any technological questions*
1100 - 1115 HST (1700 - 1715 AST/EDT) (0900 - 0915 MHT)	**Participant Check-in** *Online participants, please be fully connected to the event by 1115 HST. ISGP staff will work to check you in.*

Debate Session VII: Archipelago (Fiji) Perspectives

1115 - 1200 HST (1715 - 1800 AST/EDT) (0915 - 1000 MHT)	**Position Paper 7:** **"The Future of Fiji Energy System: Supporting the Transition of Achieving Fiji's SDG7 and NDC Targets by 2030"**

Mr. Inia D. Saula, Principal Planning Analyst, Department of Policy & Planning, Ministry of Infrastructure and Transport, Government of Fiji *(did not attend the conference, nor participated in the debate)*
Moderated by ISGP staff: Ms. Katie Durante, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Debate Session VIII: Large Island (New Zealand) Perspectives

1200 - 1245 HST (1800 - 1845 AST/EDT) (1000 - 1045 MHT)	**Position Paper 8:** **"Economic Viability Considerations for Green Hydrogen in New Zealand"**

Mr. Andreas Heuser, Director, Castalia
Moderated by ISGP staff: Ms. Euphemia Anderson, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Debate Session IX: Economic Development and Sustainable Energy Systems

1245 - 1330 HST (1845 - 1930 AST/EDT) (1045 - 1130 MHT)	**Debate IX: International Development Perspectives:** **"How Our Ocean Can Save Our Planet"**

Mr. Dan Millison, Consultant, Sustainable Development and Climate Change Department, Asian Development Bank
Moderated by ISGP staff: Mr. Manuel de la Puerta, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)

Moderated Plenary Caucus III: 180 Minutes

1330 - 1630 HST (1930 - 2230 AST/EDT) (1130 - 1430 MHT)	*Moderated and scribed by ISGP staff: Dr. George Atkinson, Executive Director and Founder, ISGP; Mr. Ciaran Fitzpatrick, ISGP Senior Fellow; Ms. Euphemia Anderson, ISGP Senior Fellow under Chatham House Rule (not-for-attribution)*
1630 HST (2230 AST/EDT) (1430 MHT)	**Closing Remarks from Dr. George Atkinson, Event Adjournment**

Do We Need Hydrogen for Sustainable & Zero Emissions Energy Conversion?**

Jack Brouwer, Ph.D.
Professor, Mechanical and Aerospace Engineering, University of California, Irvine and Director, National Fuel Cell Research Center, Irvine, California, U.S.A.

Summary

More than a dozen features of hydrogen that are needed for economy-wide decarbonization and depollution include, but are not limited to: (i) lighter weight compared to batteries to enable zero emissions in heavy duty transport, aviation, shipping, and freight, (ii) separate power and energy scaling that makes massive energy storage more cost effective (even if it is less efficient), (iii) more rapid vehicle fueling that makes continuous 24/7 operations, such as those in warehouse distribution centers, possible with zero emissions, (iv) longer vehicle range compared to batteries, (v) little self-discharge compared to batteries to enable seasonal (i.e., long duration) storage, (vi) sufficient raw materials on earth and high levels of proven recyclability (especially for platinum), (vii) potential to be produced primarily from renewable power (i.e., via water electrolysis) and converted back to water in fuel cells in a short time on earth (i.e., a virtuous cycle), (viii) high flame temperature for special industry needs that demand high-quality heat, (ix) functionality as a feedstock for industry chemicals (e.g., ammonia), (x) applicability to product manufacturing processes (e.g., cement, steel, computer chips) for reduced fossil fuel use, (xi) functionality as a precursor chemical for high energy density renewable liquid fuels (e.g., for shipping, aviation), and (xii) potential for facilitating the re-use and repurposing of existing natural gas infrastructure for a zero emissions energy system with better resilience and lower cost. While hydrogen is not the only zero-emissions solution that meets many of these listed criteria, it is the only known zero-emissions vector that meets all of these criteria. As a result, hydrogen is expected to significantly contribute to the future of sustainable and zero-emissions energy conversion.

Current realities

Sustainable energy conversion requires zero emissions of greenhouse gasses and criteria pollutants using primary energy sources that the earth naturally replenishes quickly (e.g., renewable resources). Solar and wind power technologies have become cost effective recently, but challenges remain for managing electrical grid dynamics and meeting end-use requirements for energy-dense fuels and chemicals. Renewable hydrogen provides the best opportunity for a zero-emissions fuel and is the best feedstock for production of zero-emission liquid fuels as well as some chemical and heat end-uses. Renewable hydrogen can be made at efficiencies greater than 75% (greater than 90% for some emerging technologies) using electrolysis systems that are dynamically operated to complement renewable wind and solar power dynamics.

Currently more than 90% of all hydrogen is produced by steam methane reformation (SMR) of natural gas. Renewable and clean pathways for producing hydrogen, including biogenic pathways (e.g., gasification of biomass, digester gas SMR) and electrolytic pathways that use clean electricity generation from solar, wind, or nuclear technologies are those that are growing most rapidly and those that will be increasingly demanded in a carbon-free world.

While it is critical to electrify as many end-uses as possible and to power end-uses with zero- emissions sources (e.g., solar, wind) complemented by battery energy storage, this strategy alone cannot achieve the sustainable and zero emissions future that we need. The electrification plus battery strategy using lithium-ion batteries, currently, is limited due to immutable features of insufficient global reserves of lithium and cobalt to produce enough batteries for all the storage required, challenges with self-discharge that preclude seasonal storage, challenges with recycling and waste, insufficient energy density for heavy duty transport, and inability to produce chemicals or fertilizer. Hydrogen has unique features as a zero-emissions fuel, long-term energy storage medium, and industrial and chemical feedstock that can enable the massive and seasonal energy storage that is required for a zero-emissions electric grid and introduce zero-emissions energy conversion into most sectors of the economy (Saeedmanesh et al., 2018).

Scientifically and technologically credible approaches and challenges

The infrastructure associated with a zero-emissions transition for all transportation applications will inevitably require the transport/transmission, distribution, and customer delivery/dispensing of both zero-emissions fuels and zero-emissions electricity. The development of zero-emissions transportation applications that require fast fueling, long range, or heavy payload will be most effectively facilitated by energy technologies utilizing hydrogen and its derivative fuels. Most transit agencies in the state of California are confirming the need for fuel cell electric buses for their longest routes and heaviest payloads. In addition, due to the cost of recharging equipment plus electric utility upgrades compared to the cost of a large hydrogen fueling station, total cost of ownership for hydrogen fuel cell buses becomes less than battery electric buses (even though electric buses cost less), due to the life-cycle cost of hydrogen fueling infrastructure compared to electric charging infrastructure. Utilization of hydrogen energy in transportation sectors also requires less infrastructural development and investment compared to direct electrical charging. Compared with extensive electrical infrastructure development in all existing neighborhoods, relatively modest investments in corner hydrogen fueling stations together with modest electric system upgrades can cost effectively enable 100% zero emissions transport in almost any jurisdiction in the world. Thus, even light-duty transit will have a mixture of battery electric and fuel-cell electric vehicles and fueling/charging infrastructure (Mac Kinnon et al., 2018).

Hydrogen gas can be stored within the existing natural gas system to provide low-cost massive storage capacity that (i) could be sufficient to enable a 100% zero-emissions electric grid; (ii) has sufficient energy density for end-uses including heavy duty transport, shipping, and freight; (iii) is a building block for zero-emissions fertilizer & chemicals; and (iv) enables sustainable primary energy in sectors of the economy that are difficult to directly electrify. Full conversion of the pipelines and storage facilities to hydrogen use will require investments for safety, leakage, and other functions together with shutting down and sealing of current fossil natural gas production and transmission operations.

Some industrial needs for high-temperature heat (e.g., cement, glass), reducing chemical (e.g., steel), chemical feedstock (e.g., oil hydrogenation, ammonia), reducing gas (e.g., computer chip manufacturing) cannot be decarbonized and made zero-emissions without the features of renewable hydrogen.

There are many possible technological pathways for changing the energy resources and associated transmission, distribution, and conversion infrastructure to build a zero-emission energy system. These pathways, however, are not equivalent in terms of how they distribute the environmental, social, and economic benefits of the energy system transformation, so it is critical to strive to maximize the societal co-benefits of this transition. As an example, backup power services during extreme weather or other contingencies are critically important to disadvantaged communities and technologies, including batteries, electrolyzers, fuel cells, and hydrogen storage, can serve as critical buffers for communities during outages. Underground delivery of renewable fuel will increase energy resiliency and reliability in all neighborhoods, especially those vulnerable to extreme weather events. Finally, the heavy-duty freight sectors (e.g., trucking, trains, ships, aviation) and industrial sectors, which emit pollutants that affect air quality in primarily disadvantaged communities, can be decarbonized and made zero-emissions most effectively by using renewable hydrogen and its derivatives (Borup et al., 2021).

Evidence-based options and actionable next steps

Given these features of hydrogen, the current realities of our energy conversion economy, and the scientifically credible approaches and challenges associated with hydrogen, I suggest the following evidence-based options and actionable next steps:

1. Pursue large-scale production (e.g., manufactured surface area, quantity of product) of fuel cells and electrolyzers to reduce their capital costs.
2. Promote regional corporate investment in the production, distribution, and use of hydrogen globally to enable high renewable use in the electric utility grid network and to achieve zero emissions in all sectors of the economy.
3. Provide initial government support (e.g., tax incentives, production credits) for hydrogen technologies in the next decade that is scaled down over time to assist with mass adoption and cost reduction.
4. Allocate portions of investments from government and major corporations to the development and advancement of all three major types of electrolyzers (i.e., alkaline, proton exchange membrane, and solid oxide).
5. Allocate portions of investments from government and major corporations to the development and advancement of all four major types of fuel cells (i.e., proton exchange membrane, solid oxide, molten carbonate, and phosphoric acid).
6. Invest government and utility company funds in the development of hydrogen infrastructure (e.g., pipelines, storage vessels, liquefaction, vehicles for transport, fueling stations).
7. Integrate the production and fueling operations of new hydrogen energy sectors (e.g., heavy duty trucks, light duty vehicles) with the substantial existing physical, logistical, and human infrastructure being actively utilized for facilitating global, large-scale use of fuel cell forklifts.
8. Deploy hydrogen powered heavy duty vehicles and buses (e.g., those being developed by General Motors, Nikola, Hyundai, Hyzon) as well as ships and trains in and near disadvantaged communities (e.g., near ports and freeways) to reduce the community health impacts of current fossil fuel emissions.
9. Develop and expand the use of stationary backup power fuel cell systems (e.g., for telecom) to eliminate backup diesel generator use, especially in disadvantaged communities.

References

Saeedmanesh, A., Mac Kinnon, M. A., & Brouwer, J. (2018). Hydrogen is essential for sustainability. *Current Opinion in Electrochemistry,* 12, 166-181.

Mac Kinnon, M. A., Brouwer, J., & Samuelsen, S. (2018). The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration. *Progress in Energy and Combustion science*, 64, 62-92.

Borup, R., Krause, T., & Brouwer, J. (2021). Hydrogen is Essential for Industry and Transportation Decarbonization. *The Electrochemical Society Interface*, 30(4), 79.

** ***A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP.***

Debate 1 Summary

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 Dr. Jack Brouwer (see position paper above and author biographical information in the Appendix). Dr. Brouwer 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 45-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 Dr. Brouwer and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Dr. Brouwer, 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 challenges associated with developing a hydrogen-based energy economy. The development of distribution infrastructure for hydrogen-based fuels was strongly contended to be both the greatest technological challenge and the most expensive requirement for implementing hydrogen energy systems today. It was suggested that overall decreases in the production cost of hydrogen energy will likely continue as a result of international priorities and policy decisions being enacted globally to promote hydrogen-based energy systems. However, it was acknowledged, that definitive methodologies, underlying the development of infrastructure optimizing the cost-effective transportation of hydrogen-based fuels, are still being analyzed and compared. Reducing the cost of electrochemical energy conversion technologies (e.g. electrolysis, fuel cell systems) was also suggested to be a key challenge/goal, and it was asserted that increased investment and innovation are both required to simultaneously reduce cost and increase scalability.

Developing large storage facilities for the continuing and seasonal storage of massive amounts of hydrogen-based fuels was also identified as an important challenge. It was strongly asserted that the use of salt caverns, proven to be a viable option for hydrogen-based fuel storage, need to be expanded. Other potential storage sites (e.g., depleted oil and gas fields) have not yet been extensively assessed (e.g., in terms of effectiveness, safety, environmental impact) to justify their viability for general use.

While developing new and/or updated infrastructure (e.g., natural gas networks, industrial gas turbine engines) for utilization of hydrogen-based energy needs to be given priority, it was argued that focusing attention on how to leverage existing hydrogen/hydrogen-adjacent supply-chains is an important component in any effort to update infrastructure *writ large*. It was claimed that plastic piping, sometimes utilized for natural gas distribution infrastructure, is likely compatible with hydrogen distribution. In contrast, the steel used to make longer distance natural gas transmission systems, as well as additional materials used in other infrastructural elements (e.g., compressor stations, seals, gaskets, etc.), are subject to enhanced fatigue crack growth rates (i.e., embrittlement) and are likely to require increased material investment. Regarding the use of hydrogen in industrial turbine engines, it was claimed that a vast majority of power generation companies and gas turbine manufacturers (e.g., Siemens, General Electric Company, Mitsubishi Motors) are already manufacturing hydrogen-ready gas turbine engines. While powering gas turbine engines with hydrogen combustion would reduce the greenhouse gas emissions of related industrial processes, stakeholders warned that hydrogen combustion also results in the emission of criteria pollutants (e.g., gaseous molecules that contribute to air pollution). It was urged that the impacts of criteria pollutant emission need to be thoroughly assessed and understood. To decrease greenhouse gas emissions and criteria pollutants when utilizing hydrogen-based energy, it was vehemently argued that the development and implementation of hydrogen fuel cells needs to be the highest priority among energy conversion technologies.

After noting that most hydrogen being utilized today is produced using non-renewable energy sources (e.g., fossil fuels), one stakeholder inquired whether converting existing non-renewable hydrogen production to utilize renewable energy sources needs to be prioritized as a fundamental step in the overall energy transition, especially in the petroleum and chemical manufacturing industries. The ammonia/fertilizer industry was purported to account for the largest consumption of hydrogen produced currently, and it was suggested that the ammonia manufacturing sector could be a very attractive industry for renewable hydrogen (i.e., "green hydrogen") to reduce emissions. Some stakeholders contended that ammonia is an effective hydrogen carrier molecule that may be particularly advantageous due the presence of existing, highly developed infrastructural systems for ammonia transport and storage. It was strongly asserted that investment into ammonia needs to be a prominent component of hydrogen-based energy system development. It was posited that decarbonizing the petroleum refinement industry with renewable hydrogen poses a challenging question, not only because the industry could introduce a large demand for renewable hydrogen, but also the associated emission reductions may not be significant compared to the long-term perpetuation of the fossil fuel energy industry.

Questions were raised concerning the viability of hydrogen-based energy systems in small island communities, with particular consideration to the previously proposed prioritization of hydrogen fuel cell technologies. It was suggested that the purportedly high-purity standard/requirements of the hydrogen used by fuel cells may be a significant barrier for small island implementation, and whether other options need to be considered for small islands. While it was acknowledged that fuel cells in the transportation sector require high-purity hydrogen, it was suggested that fuel cells used for other applications (e.g., gas turbine engines, diesel engines, high-temperature fuel cells) may be able to utilize lower-quality hydrogen. It was further suggested that these lower-purity hydrogen applications could act as a short-term or transitional option, but it was affirmed that investment in renewable, high-purity hydrogen production needs to be prioritized for long-term solutions.

Within the diverse "ecosystem" of energy challenges in island communities, it was suggested that marine inter-island transport may be a hard-to-abate sector that needs to be a priority for investment and innovation. It was asserted that hydrogen and its derivatives have been proven to be among the most practical and feasible energy vectors for decarbonizing maritime shipping sectors. Sandia National Laboratories have published several reports containing detailed analyses of various shipping types that can be effectively decarbonized using hydrogen-based energy. However, it was contended that the use of renewable hydrogen in marine applications is not yet cost effective.

Several stakeholders questioned the ability of island communities with limited available land to produce sufficient renewable energy to support the production of renewable hydrogen, and speculated that the importation of hydrogen-based energy may be a necessary consideration. While it was argued that the global hydrogen trade sector offers promising opportunities, it was also noted that one of the proposed benefits of implementing hydrogen production in island communities was improved energy security and energy independence. If improving energy security/independence is viewed as a critical goal for island communities, it was argued that developing importation and exportation systems needs to be a lower priority than developing hydrogen production systems.

A main theme that persisted throughout the debate was the economic viability of hydrogen in small island communities. The National Rural Electric Cooperative Association (NRECA) is reported to be focusing on the application and utilization of hydrogen-based energy in rural areas, but it was suggested that more investment and research are needed in this arena. Additionally, concerns were voiced regarding the seemingly unrealistic expectations for small island communities to meet the environmental targets within their energy systems while simultaneously working to overcome other urgent challenges (e.g., obtaining grant funding). It was speculated that small countries and island communities will benefit from global reductions in costs associated with specific hydrogen technologies, hydrogen infrastructure, and associated equipment as wealthy countries continue to expand investment, research, and development of hydrogen-based energy technologies (e.g., electrolyzers, fuel cells).

When considering practical options for stakeholder decision-making, several stakeholders focused on the trade-offs and relative prioritization of hydrogen-based energy technologies in comparison with existing battery technologies, particularly considering the significant uncertainty surrounding future technological improvements and breakthroughs resulting from continuous research. There was general consensus that some degree of market competition exists between hydrogen and battery technologies, but it was strongly asserted that both need investments to effectively leverage the unique features that each respective type of technology offers. It was asserted that the energy storage needs of all potential applications for renewable energy globally could not be fulfilled by existing, and reasonably foreseen, battery technologies (e.g., lithium-ion) alone, emphasizing the argument that investment needs to be made in both batteries and hydrogen-based energy. It was posited that battery-electric energy storage systems are currently more cost effective and energy efficient for short durations. Small-magnitude energy storage, compared to energy storage via hydrogen production, is more efficient, particularly when considering implementation in the immediate to short term. Conversely, it was posited that many energy storage needs are more effectively addressed by hydrogen technologies than batteries (e.g., in aviation). It was emphatically argued that initial and sustained investment in hydrogen-based energy systems is critical to improving the cost effectiveness and energy efficiency of hydrogen technologies. It was suggested that hydrogen investment will increase as renewable energy investment and development increase, creating a demand for large-scale seasonal storage. Concerns about the recyclability of lithium-ion batteries were voiced by several stakeholders, and it was noted that ongoing research efforts are being undertaken to assess and improve battery recyclability. It was suggested that considerations of relative performance requirements, material availability, and recyclability will influence choices to utilize hydrogen under some circumstances, and batteries under different circumstances.

Several stakeholders questioned what the appropriate next steps may be for transitioning energy systems and developing a hydrogen economy. It was posited that the critical first steps for any country, state, or community are to develop and invest in renewable energy production systems and to continually increase the adoption of renewable energies over time. It was subsequently noted that, following the development and adoption of renewable energies, there needs to be a focus on developing diurnal storage mechanisms (e.g., battery energy storage systems, pumped storage hydropower, hydrogen storage) that allow the storage and postponed use of electricity during times of lower renewable energy output (e.g., night time, winter). Regarding potential policy decisions, subsidies for other renewable energy technologies (i.e., solar, wind, batteries) that decline over time were identified as policy options that could be equally appropriate for hydrogen technologies.

Archipelago (Tuvalu) Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy**

Simona Kilei, B.Sc.
Director, Department of Energy, Ministry of Transport, Energy and Tourism, Government of Tuvalu, Funafuti,Tuvalu

Summary

Tuvalu is currently heavily reliant on diesel energy generation. With the increasing Climate Change awareness, and the realization that renewable energy (RE) is the solution, Tuvalu is prompted to phase out fossil fuel and transition to RE. Tuvalu aims to reach 100% RE-generated electricity by the year 2030. Currently, Tuvalu is prioritizing the development of energy systems using solar energy generation although wind energy has also been identified as a potentially feasible option in Tuvalu. To date, Tuvalu energy systems consist of 84% fossil fuel energy (e.g., diesel) and 16% alternative energy sources (e.g., solar). There may be opportunities for green hydrogen production and utilization for maritime transport between islands in Tuvalu. To achieve Tuvalu's energy transition goals, project funding and workforce capacity building is needed.

Current realities

Tuvalu is an island nation located midway between New Zealand and Hawai'i. Tuvalu consists of 9 island groups with a land area totaling to 26 km2 (10 square miles), with a dispersed Exclusive Economic Zone of 49,790 km2 (289,500 sq mi), and has a highest elevation of 4.6 m (15 ft). The population of 10,645 (2017 census) primarily consists of people of Polynesian descent. Approximately 100% of people in Tuvalu have access to electricity. Currently, Tuvalu's energy needs are primarily met by fossil fuels (accounting for 84% of national energy generation) and solar photovoltaic electricity (accounting for 16% of national energy generation). Tuvalu imports approximately 137 Terajoules of energy (2018 figures). Energy is primarily consumed by households and other public sectors, with very little domestic energy consumption in industrial or transportation sectors.

Tuvalu is situated near the equator, so it is without wonder that solar energy is the only utilized RE energy source. Research has also confirmed the viability of wind energy as a potential source of significant energy on Tuvalu if specific projects are funded and implemented. As indicated by Tuvalu's Nationally Determined

Contributions (NDC), Tuvalu is committed to the reduction of emissions of greenhouse gasses from the electricity generation (power) sector by 100% (i.e., almost zero emissions) by 2030. After achieving approximately 100% emissions reduction in the power sector, the focus of Tuvalu's government is expected to be on electrifying land transport. Reducing environmental impacts from maritime transportation is also a potential future target.

Scientifically and technologically credible approaches and challenges

The Government of Tuvalu is looking to expand sustainable energy production through projects such as the Energy Sector Development Project (ESDP) that is being undertaken with support from the international development organizations. Recent and ongoing renewable energy programs have focused on solar energy projects, with the ESDP aiming to facilitate the increase in production of renewable electricity in Funafuti from 15% to 32% and from around 70% to over 90% in the outer islands of Tuvalu. Feasibility studies have confirmed potential opportunities for wind energy production, but no wind energy projects are currently underway.

Current priorities for electricity production within Tuvalu focus on replacing fossil fuels with solar and, potentially, wind energy. Therefore, it is more likely that stakeholders in Tuvalu would be interested in maritime transport applications of hydrogen energy technologies. With the Tuvalu islands dispersed in a large ocean area, hydrogen-fueled marine vessels could help cater to long inter island voyages and may become an important avenue reducing Tuvalu reliance on imported fossil fuel in this sector. There are many challenges for a commencement towards green hydrogen production in Tuvalu. The limitation of funding for new energy projects in Tuvalu is a critical barrier. Additionally, lack of local experts and knowledge on the technology presents a critical challenge. Opportunities to learn from the experiences and/or lessons from other nations within the Pacific Region will be important for informing the actions that Tuvalu might take.

Evidence-based options and actionable next steps

To meet Tuvalu's energy needs and to reach its energy commitments, continued effort to establish 100% electricity generation from renewables is needed. If hydrogen is to play a role in the future of Tuvalu's energy system, it would be most effectively applied in the form of green hydrogen production and utilization for maritime transportation applications.

1. Ensure that electricity production is 100% sourced from RE sources by 2030.
2. Provide funding for energy system development programs in Tuvalu.

3. Conduct a feasibility study on utilizing available RE sources in Tuvalu for hydrogen production.
4. Assess viable technologies for the fueling of marine vessels with hydrogen technologies.
5. Build the capacity within the society of Tuvalu to develop and continuously maintain local energy generation plants one they are operational

*** A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP*

Debate 2 Summary

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Tuvalu is a small, independent island nation in the South Pacific comprising nine (9) islands with a total population of 11,792. The energy within Tuvalu, as a country, is very dependent on diesel fuel and utilizes a minimal percentage of renewable energy, primarily solar. To increase the percentage use of renewable energy, it was broadly recognized that the biggest challenges were obtaining funding for the associated infrastructure and the limited amount of land available. The options that were presented by stakeholders from other countries (e.g., U.S. and Australia) to implement new and/or update existing infrastructure was discussed in detail. Tuvalu has committed to a goal of meeting 100% renewable energy by 2030.

Due to the current absence of efficient renewable energy technology on the islands of Tuvalu, several stakeholders emphasized the importance of considering renewable energy technologies that already have been examined in detail and shown to be effective in producing renewable energy within island communities. It was noted that the Micronesian Center for Transport, based in the Marshall Islands, has reviewed prototypes of ships that can utilize traditional propulsion (e.g., sails or flapped rotors) for use in island communities. It was suggested that, given the challenges encountered on smaller islands, developing experimental renewable energy technologies are not suitable for implementation in smaller islands unless they have been thoroughly tested and demonstrated to have high probability of success. It was considered especially important to avoid the failure of renewable energy technologies on smaller islands because that failure would encourage a retreat to re-establishing diesel based generators for energy production.

Since it was noted that the priority within the islands of Tuvalu focuses on the transport of fuel and goods via inter island routes, maritime transportation is critical to providing each individual island with the fundamental resources needed by citizens. The importance of a reliable inter-island transportation system, perhaps relying heavily on hydrogen-based energy, cannot be overstated given the immediate- and long-term need to ensure stability for energy and food throughout the archipelago. Economically, attention was given to the fact that Tuvalu has one of the highest importation tariffs worldwide and that therefore, importing energy is not likely to become economically viable. Options for domestic production of energy were identified as a priority within island archipelagos, such as Tuvalu, if environmentally sustainable methods can be identified.

Throughout the debate, solar energy was repeatedly discussed as the potential main source of renewable energy generation on Tuvalu. Solar energy is the sole renewable energy source currently available on Tuvalu, but it is not especially useful with maritime transportation. While the maritime transportation sector in Tuvalu currently relies on diesel for fuel, it was recognized that the Asian Development Bank has provided technical assistance to Tuvalu for the development and implementation of floating solar platforms (e.g., Solar PLUS). Floating solar platforms support the production of hydrogen energy over the water and are proposed to increase the energy available for maritime transport from island to island. However, debaters repeatedly identified concerns within the Tuvalu community that the importation of hydrogen presents serious financial challenges for small islands, especially concerning the reliability and long-term financial commitments associated with extramural funding. Funding for the infrastructure associated with hydrogen energy importation was thought to require agreements with donors and international partners that often include commitments that may or may not be consistent with island community priorities.

Debaters noted that chief among these issues was the price point for hydrogen-based energy worldwide versus alternative energy sources (e.g., diesel fuel) that are subject to the financial pressures now affecting all fossil fuels, which are expected to significantly increase in the foreseeable future. In addition to financial obstacles, it was posited that the most important challenge for the islands of Tuvalu is achieving reliable, renewable energy production during the nighttime. It was strongly suggested by many that wind generation is a potential source of energy for nighttime usage, in addition to coconut biodiesel. However, due to the COVID-19 pandemic, battery installation has been stalled making it difficult to receive implementation consultations and personnel for infrastructure development. It was noted, in the foreseeable future, that these energy systems can be installed to help with the transition to total renewable energy generation.

Throughout the debate, hydrogen energy was noted to be potentially beneficial to the islands of Tuvalu. Considering Tuvalu's size and population, it was suggested that importing 37 terra joules, with an average power of 4.3 megawatts for hydrogen fuel cells, would essentially serve as a diesel replacement and could perform as a decent importation for electricity use. In addition to that, it was strongly asserted that it would be highly possible to install rubber lined dams that would increase water security and produce 10 megawatts for seven hours daily to generate hydrogen, costing less than $4/kilo, compressed to about 45 Megapascal Pressure Unit (MPa). Economically, having reliable renewable energy could decrease the need for tariffs, but it would be offset by the maintenance cost needed of the renewable energy farms. Trying to balance having ship propulsion transition to solely hydrogen-based energy could help the government financially by minimizing the high subsidies currently used for shipping. It was posited that these government vessels can subsidize hydrogen fuel over petroleum and increase the demand of hydrogen.

There was a vigorous discussion during the debate concerning how to practically establish the trained workforce needed to both implement and maintain the renewable energy systems needed for the Tuvalu community to achieve the 100% renewable energy goal set for 2030. Beyond the infrastructure improvements, having a trained workforce within the Tuvalu community is an essential component of any sustainable, renewable energy system. While numerous stakeholders emphasized the challenges of such a citizen-based training program in remote geographical areas, The University of The South Pacific in Fiji was identified in having developed an appropriate curricula leading to degree programs focused on clean renewable energy applications tailored to island communities. It was also emphasized that in addition installing and maintaining new renewable energy technologies, training programs and regulatory structures are needed to certify the quality, reliability, and sustainability of any energy source, including hydrogen-based energy. It was recognized that while these more advanced curricula are needed for the Asia- Pacific region, cooperation among island institutions is likely to be needed to support such training and certification since individual island communities may not have the resources to support these efforts individually.

Elimination of Fossil Fuel Imports and Decarbonization of County Vehicle Assets by way of Hydrogen Energy**

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Summary

Hydrogen is the among the best available fuel source due to its high energy molecules and zero greenhouse gas emissions (GHGs). Hawai'i's remote location and susceptibility to natural disasters create a scenario of an extremely vulnerable energy system dependent on imported fuel. However, Hawai'i's location also presents an opportunity to become energy independent and less reliant on imports. Currently, there is a dependence on volatile oil prices with high premiums and extremely long supply-chain response times for fuel and/or energy equipment. As a result, the County of Hawai'i (i.e., the County) in 2022, started a fuel cell electric bus pilot project and brown hydrogen production on the island using utility grid energy initially.

With transportation as the highest emitter of greenhouse gasses, the County's primary objectives are to divorce the use of the utility grid to produce green hydrogen from 100% renewable energy sources on the island and reduce/stabilize energy costs. The main goals discussed in this position paper are: (i) convert the County vehicles from fossil fuel power systems to hydrogen and electric, (ii) develop a Renewable Technical Center to train the local workforces on assembly, maintenance, etc. of hydrogen and electric vehicles, and (iii) increase hydrogen production, storage and use through a clean, closed-loop energy system via landfill gas and anaerobic digestion of biomass.

Current realities

The electrification of transportation is critical to achieving Hawai'i's zero-emission clean economy goal of 100% renewable energy by 2045. Establishing a zero-emissions transportation system is complex for several reasons. First, the County infrastructure is geographically dispersed around 10,359 square kilometers. Driving from one side of the island (Kailua Kona) to another (Hilo) takes 2 hours (125.5 km or 78 mi) and reaches a maximum elevation of 2,021 m (6,630 ft) from sea level. Second, only 60% of the energy currently generated from the utility grid is renewable. While the island has the potential to increase geothermal, wind, hydro, and solar energy production, the cultural and community support is tempestuous. Thus, choosing the right zero-emission fuel source requires careful consideration and community input.

One fuel source of priority consideration for transportation is green hydrogen because of its potential to meet the needs of the island's topographical demands in elevation, lengthy travel distances, trip types, and potential cost savings. The County has started its post-carbon journey by owning a 65 kg/day brown hydrogen production facility with one stationary refueling station and three distribution trailers (100 kg each). This production of hydrogen is enough to run 780 bus vehicle miles. With that, the County procured 3 hydrogen buses to operate. To support a post-carbon economy, a few more hurdles exist including: (i) storage and distribution, (ii) supply chain and turnaround time for technology procurement, (iii) demand and competition, and (iv) sustainable management of the production, storage, consumption, and (iv) retirement/disposal of equipment. The short-term plan (two to three years) is to add seven additional fuel cell buses and build out three hydrogen production facilities and another hydrogen fueling station. The medium- to long-term plan (four to 12 years) is to convert the entire fleet to zero-emission vehicles (ZEV) and add additional hydrogen fueling stations.

For the past nine years, the County has operated a shared-use battery electric vehicle (BEV) program and has some lessons learned. Within the fleet are five BEV and six County-owned electric vehicle charging stations. The first pitfall of the BEV is using the electrical utility grid to charge, which only a portion of the energy is renewable (60%) and produces GHGs. As illustrated by the energy Sankey (Figure 1), transportation consumes the highest amount of petroleum. Electricity generation is the second-highest consumer of petroleum products. The second pitfall is the range anxiety for traveling long distances. Lastly, the first-generation charging stations installed in 2012, along with the vehicles, are coming to the end of life or are not working.

There is an opportunity for the County to produce green hydrogen with an unsuspecting asset: the County Sanitary Landfill where methane gas is produced by a build-up of biomass and subsequently flared. Significant amounts of energy are contained in food and other organics as well as in the landfill gas being flared at 270 standard cubic feet per minute (SCFM) (43% methane). The Hilo Sanitary Landfill is permanently closed and produces 300 SCFM and 50% methane, which will last for approximately 15 years and then decrease. This is enough energy from the landfills to run all the County's current vehicle miles traveled for 30 years.

To fund the transition to zero-emission infrastructure, the State legislature passed a bill allowing third-party financing. As a result, the County contracted Sustainability Partners (SP), a third-party financer, to assist with converting County assets to zero emissions. Under this agreement, SP maintains ownership and maintenance of all assets for the estimated useful life. The County makes payments to SP based on the use of the assets, saving money for the county, and allowing for a complete overhaul up front rather than gradually over time.

Scientifically and technologically credible approaches and challenges

Converting County vehicles to zero emissions is low-hanging fruit for reducing GHG emissions. Using hydrogen as the main fuel source requires the development and expansion of on-island technologies to support this plan. The project steps consist of the following: (i) capture and utilize landfill gasses to produce hydrogen on-island, (ii) procure and maintain a fleet of fuel cell electric vehicles (FCEV), (iii) install and maintain fueling infrastructure, (iv) develop, procure, and maintain a hydrogen distribution system to transport stored hydrogen island-wide, (v) advance renewable energy workforce opportunities, and (vi) build a Renewable Technical Center for educational training, licensing, and certification.

Utilizing the stockpile of energy requires a combination of established technologies to produce green hydrogen. One technology to transform waste into energy utilizes a process called anaerobic digestion. This involves the degradation of organic matter biologically in an oxygen-free environment and releases the product in the form of biogas composed mainly of methane. Another technology captures and cleans the landfill gas to yield pipeline-quality methane gas. The County takes this one step further by capturing the carbon and cleaning it through a progression of filters. The captured carbon is to be used with hydrogen to produce aviation jet fuel rather than being flared. The heat value of methane then powers a steam-electric generator to operate a proton exchange membrane electrolyzer to produce green hydrogen.

Evidence-based options and actionable next steps

The County's primary objectives are to: (i) transform the County vehicle fleet to net-zero carbon using green hydrogen, (ii) produce 100% renewable energy on the island, and (iii) reduce costs.

The Joint Initiative for Hydrogen Vehicles Across Europe (JIVE) is a leading example of hydrogen-based transportation within the government sector. JIVE is an impressive collaboration project among 22 partners from seven countries on the European continent. The program framework plans to (i) deploy 300 new zero-emission FCEV, (ii) construct 100% reliable hydrogen refueling stations, and (iii) demonstrate the feasibility of low-cost, renewable hydrogen. The objective and targets are synonymous with Hawai'i County. The County's actionable next steps are:

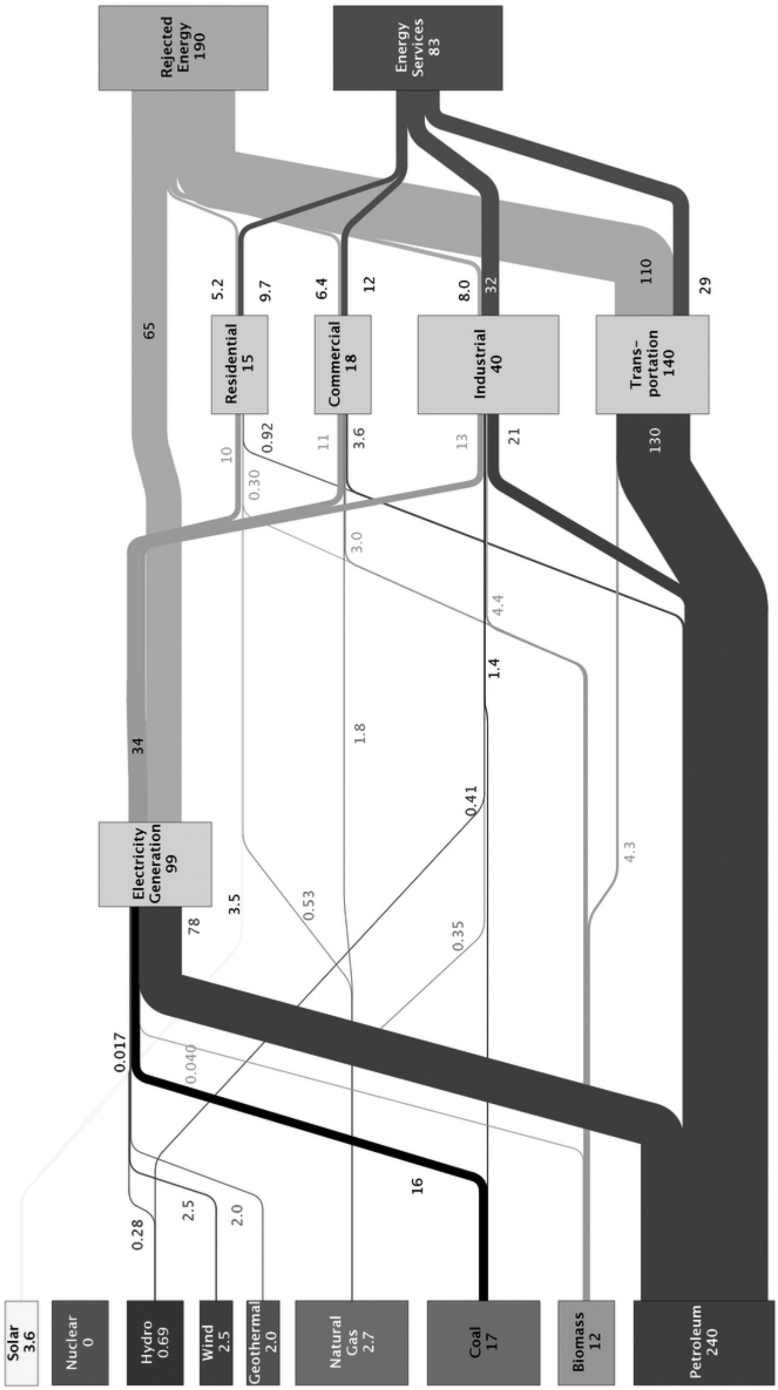
1. Strengthen collaboration between Hawai'i State government and other county governments in Hawai'i in analogy with the JIVE collaboration model.
2. Accelerate the adoption of ZEV and scale-up equipment to support ZEV within the County fleet.
3. Site the Renewable Technical Center near the hydrogen production facility for a regional workforce development and training center.
4. Collect data on the hydrogen bus route pilot project to make informed decisions and identify renewable energy fueling station locations for the County vehicle fleet.
5. Analyze heavy- and light-duty fleet transformation across the County facilities including the determination of sites, vehicles, and charging requirements.
6. Convene public events and community information meetings regarding hydrogen as a safe source of energy.
7. Conduct a feasibility assessment to determine the optimal storage locations and delivery of hydrogen gas resilient to natural disasters and climate change resilience.
8. Draft and sign a professional services contract with a third-party financer for hydrogen technology procurement and supporting infrastructure.
9. Collaborate with the County Department of Environmental Management to develop a recycling plan for renewable energy systems and equipment.

*****A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP***

Lawrence Livermore National Laboratory

Figure 1

Estimated Hawaii Energy Use In 2010
~280 Trillion BTU



Source: LLNL 2013. Data is based on DOE/EIA-0214(2011), June 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. Interstate and international electricity trade are lumped into net imports or exports and are calculated using a system-wide generation efficiency. End use efficiency is estimated for each sector as 65% residential, 65% commercial, 80% industrial and 21% transportation. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Debate 3 Summary

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. Riley Saito (see position paper above and author biographical information in the Appendix). Mr. Saito 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 45-minute debate period. This Debate Summary represents the best effort of the ISGP to accurately capture the comments offered and questions posed by participants, as well as those responses made by Mr. Saito and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Saito, 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 broadly recognized that identifying and allocating sufficient funding was the greatest challenge to energy transitions in island communities. Stakeholders noted that the County of Hawai'i is implementing plans to achieve zero county-wide greenhouse gas (GHG) emissions by 2030, compared to the commitment of the State of Hawai'i to reach zero GHG emissions by 2045. Practical aspects of the methodology being utilized by stakeholders on the big island of Hawai'i (i.e., the County of Hawai'i/Hawai'i County, the focus area of the author's position paper) to implement local energy transitions were discussed in detail. Using domestic renewable energy sources to produce hydrogen fuel for local consumption by government fleet vehicles was discussed and debated regarding the potential to: (i) improve environmental sustainability of transportation/mobility sectors, (ii) reduce and stabilize energy costs, (iii) simultaneously develop reliable market supply, demand, and associated infrastructure, (iv) initiate broader energy transitions in transportation sectors (e.g., consumer adoption), (v) improve energy independence, and (vi) provide substantive societal benefits to local communities. Many stakeholders contended that the approach being used by the County of Hawai'i can serve as an instructive model for other island communities in the South Pacific.

Achieving price parity between environmentally sustainable energy options and traditional fossil fuels was identified as a critical threshold for energy transitions. It was contended that renewable electricity achieves price parity with fossil fuel-produced electricity at approximately \$0.10 per KWh. It was also noted that many localities purportedly can produce renewable grid electricity for significantly less than \$0.10/KWh to supply their power sector, (e.g., including the County of Hawai'i, which is reported to be producing solar electricity at $0.08-$0.09/KWh). With grid electricity likely being addressed directly by renewable energy generation, it was suggested that the transportation sector is both a priority for energy system transitions in island communities and a sector in which hydrogen-based energy technologies can be highly beneficial.

Diverse stakeholders from Hawai'i asserted that the financing and implementation mechanisms utilized by the County of Hawai'i to develop hydrogen energy systems are integral to the reported successes of the transportation sector-focused energy transitions on the big island. Stakeholders stated that local energy transitions in the transportation sector on the big island were initiated when the County of Hawai'i Department of Transportation Highways solicited a request for proposals to private sector stakeholders, with the goal of "providing transportation as a service" through the implementation of zero-emissions vehicles. Stakeholders conveyed that the County of Hawai'i subsequently awarded a private sector company with a "transportation services contracting agreement" to implement hydrogen and battery-electric transportation options. The strategy being implemented through the transportation services contracting agreement reportedly included: (i) replacing all county mass transit vehicles with zero-emissions alternatives, (ii) establishing zero-emissions fleets for various government agencies, and (iii) developing infrastructure for hydrogen production, storage, transportation, and utilization. Multiple stakeholders supported the idea that transitioning government fleets, and especially public transportation/mass transit vehicles, is also a highly effective way to initiate broad overall transitions in energy systems.

The "third-party funding mechanism" utilized by the contracting agreement was viewed by several stakeholders to be an essential and innovative element of energy systems transitions in the County of Hawai'i. Several characteristics of the third-party funding mechanism, regarding how it might apply in other locations, were debated. It was asserted that the approach promotes investment, due to the perception that governments are less likely to go bankrupt than commercial enterprises, thereby making government agencies the least risk "offtaker." It was contended that this model is particularly attractive to investors focused on long-term investments (e.g., 20-30 years) and stable returns, even under 1%. These firms generally prioritize the protection of their principal funds, and include insurance companies and light retirement funds. It was claimed that investors viewed the program as a guaranteed return on investment, guaranteed by a government. It was also noted that, in addition to resources from the county government, the private sector contractor, investors, and the energy transitions in the County of Hawai'i received federal funding support. It was argued that the arranged contracting agreement provides greater savings to the County of Hawai'i than existing fossil fuel energy arrangements within the transportation sector, due to cash flow generated from the vehicles and associated infrastructure.

One active hydrogen fuel cell bus, one active hydrogen production site, one refueling facility at the production site, and two mobile fuel distribution tanks were identified as some of the current assets held by the County of Hawai'i and its partners for the developing hydrogen energy system. It was noted that the County of Hawai'i has also allocated hydrogen fuel cell and battery electric vehicles to its Parks Department and its Research and Development Department. Stakeholders noted that other County of Hawai'i government agencies can sign on as participants of the program, using the master agreement outlined by the transportation services contracting agreement, to fuel additional department-specific fleets. Plans to deploy 10 hydrogen fuel cell buses and 18 battery electric buses over the next 3-4 years were described as being "in the implementation phase."

As the zero-emissions mass transit vehicles are being deployed by the County of Hawai'i, including both hydrogen fuel cell and battery electric vehicles, some comparisons between the two technologies were discussed. It was contended that financial analyses assessing the full lifecycle of the vehicles indicate that the hydrogen fuel cell buses are more cost efficient at current hydrogen production prices (e.g., approximately $4/kg) than battery-electric buses driving the same routes on the big island of Hawai'i. It was also argued that future plans to utilize additional energy sources (e.g., the heat value from methane produced at landfills) to produce hydrogen fuel was expected to reduce production costs to approximately $2/kg or $3/kg. It was also argued that short refueling times (i.e., compared to battery charging times) allowed the hydrogen fuel cell buses to spend more time active/available.

It was stated that the transportation services contracting agreement framework being utilized by the County of Hawai'i allows the private sector partner to maintain ownership of the County zero-emissions vehicles. It was argued that this arrangement improved capital utilization in the transportation sector by allocating responsibility for maintenance and associated costs to the private sector partner/financier, while allowing the financier to collect funds by renting county vehicles to the local community when the vehicles are not being actively used by the government.

Effectively planning, implementing, and developing infrastructure was viewed as both challenging and critically important for successful energy systems transitions. Deploying charging and fueling infrastructure in tandem with the introduction of a hydrogen-powered mass-transit fleet (i.e., developed simultaneously) was argued to be essential to the time-sensitive and cost-efficient development of energy systems. Incorporating infrastructure hydrogen fuel production, storage, and distribution into public-private contract agreements was also considered as being an effective way of ensuring a supply of affordable hydrogen fuel and a reliable source of demand (i.e., regular use by government vehicles) for the fuel. It was suggested that focusing initially on transitioning mass-transit fleets (e.g., buses) to support early-stage infrastructure development was effective because mass transit vehicles typically refuel at one location and their use is alternated at regular intervals. However, the eventual deployment of additional fueling sites was identified as an important consideration for meeting the needs of other hydrogen vehicles. Semitrucks, bulldozers, and light-duty government vehicles were all identified as potential targets for implementing hydrogen fuel. Mobile fueling stations were proposed to be an effective early-stage option for meeting government and/or individual fueling needs in different locations. The County of Hawai'i has deployed two mobile hydrogen fueling stations.

"Whole-of-island" or "whole-of-transport-network" approaches were argued to be most effective for energy system decarbonization in island communities. It was suggested that sites under government jurisdiction (e.g., military bases, maritime ports, airports) were opportune targets for the initial implementation of infrastructure for energy transitions. Maritime ports and airports were noted to be important elements in island economies as well as important, "hard-to-abate" targets for decarbonization that could benefit significantly from the deployment of hydrogen energy technologies. These hard-to-abate targets often have a diversity of energy needs (e.g., fuel for maritime vessels, aircraft, trucks, cranes, and many types of light-duty vehicles) and a high intensity of GHG emissions in concentrated locations. However, it was also noted that varying governmental jurisdictions over these areas can complicate efforts to implement "whole-of-island" energy transitions. Airports in the County of Hawai'i were identified as being maintained under state government authority, and piers were identified as being maintained under federal authority. It was posited that differing priorities between different levels of government can be a barrier to the execution of timely, synergistic transitions in energy systems. It was strongly asserted that collaboration and resource sharing between government agencies at multiple levels (e.g., county, state, national) was highly desirable for implementing broad infrastructure transitions. Fostering jurisdictional collaboration among government agencies was alleged to be a goal requiring more significant action among the county, state, and federal agencies in the state of Hawai'i, in particular. It was posited that concerted efforts among and between the legislatures at each level of government were critical to the implementation of energy systems transitions.

Multiple stakeholders asserted that the deployment of zero-emissions vehicle fleets and the development of associated infrastructure also needs to be accompanied by the development of a local workforce, consisting of individuals who are trained to fill specific roles throughout the value chain (e.g., operating, servicing, and maintaining equipment for hydrogen production, storage, transportation, and distribution). It was suggested that shifts to hydrogen energy technologies may involve significant workforce-related changes to utilize new tools and equipment, in some cases.

While several stakeholders attributed various potential economic benefits to the development of hydrogen economies within island communities, it was asserted that the environmental benefits associated with energy transitions in the County of Hawai'i were the most critical incentive for related initiatives to develop hydrogen energy systems. The reason for identifying the hydrogen fuel currently being produced in the County of Hawai'i as "brown" hydrogen was questioned. It was affirmed that, while the County of Hawai'i has already transitioned its grid to be 60% sourced from renewable energy sources, it is still partly sourced from fossil fuels. Since the County of Hawai'i is using grid electricity to produce hydrogen, it was implied that the resulting hydrogen is more like a "light-beige," because it is produced from both renewable and fossil fuel sources. It was noted that the grid in Hawai'i County is in the process of being converted to 100% renewable energy by 2030, and that the county will also soon be implementing the use of methane collected from municipal bio-waste (e.g., anaerobically digested wastewater sludge, biomass from landfills) to produce electricity for hydrogen production using steam turbines. Once these targets/initiatives are implemented/achieved, it was contended that hydrogen produced in the County of Hawai'i would theoretically be green hydrogen.

Many stakeholders reiterated the importance of using energy systems to provide broad societal benefits to communities. Viewing transportation as a service to the community, or even a right, was posited to be an important consideration and justification for developing environmentally sustainable, affordable, and accessible transportation systems. Several Debaters provided examples of how they think the specific energy system transitions being implemented on the big island of Hawai'i can help to address societal needs, rather than simply replace existing energy sources. It was asserted that more stable energy costs are associated with local energy production, which can be especially beneficial to marginalized and low-income communities. A number of stakeholders indicated that it is also preferable to recirculate local capital within local energy economies, rather than "sending" that capital off-island to fossil fuel suppliers. It was stated that the fuel cell buses can also serve as mobile generators to provide civil defense and disaster relief to local communities in emergency situations (e.g., hurricanes). It was also mentioned that the contract between the County of Hawai'i government and the private sector partner that owns the fuel cell buses requires that the buses be available to the community for rental, when not in use. It was further noted that light-duty government agency vehicles are available to employee family members as well as employees of other county government agencies, when not in use. An initiative to make these assets available to low-income families and community members on weekends, on holidays, and at night was proposed. In general, making zero-emissions vehicles available to the community was also suggested as a way to improve public familiarity with, and acceptance of, newer technologies.

In addition to providing services to the community, it was also asserted that developing zero-emissions transportation systems can directly benefit the community by creating an industry that did not previously exist. Through the education and employment of community members, stakeholders claimed that developing systems for local sustainable energy production and consumption provides various opportunities, including: (i) new employment opportunities, (ii) decreased "brain drain" (i.e., trained/educated locals leaving for opportunities elsewhere), and (iii) a sense of community cohesion.

It was asserted that the implementation of public transportation must focus on providing access to all community members. Informing stakeholder decisions by considering societal indicators, including: (i) existing mobility of people, products, and services, (ii) community income levels, (iii) community poverty levels, (iv) the walkability and bikeability of different locations, (v) required surface infrastructure changes, and (vi) major points of onboarding/offboarding for various mobility options was suggested to be critical for providing effective service to communities, and particularly for serving underserved communities. Listening to the needs, concerns, and opinions of community members was posited to be essential.

Throughout the debate, multiple stakeholders noted that achieving a greater degree of energy independence is a common goal among many island communities. Dependence upon the importation of fossil fuels was identified as both environmentally harmful and economically problematic. It was asserted that imported fossil fuels incur a large premium (i.e., due to storage and transportation costs) and have highly volatile costs that are impacted by international economic and geopolitical realities. Domestic production of energy, particularly using renewable energy sources, was posited to be critical to improving the energy independence of island communities. The current production of renewable energy in the County of Hawai'i was purported to result in the use of approximately: (i) 17% geothermal, (ii) 14.7% wind, (iii) 4.5% biofuels, (iv) 4.1% hydroelectricity, and (v) 50% solar energy, contributing to an overall county energy usage of approximately 180 MW. It was further noted that about 18.6% of the renewable energy produced in the County of Hawai'i comes specifically from customer-sited solar panels (e.g., household rooftop solar panels). It was suggested that many islands in the South Pacific have opportunities to access several, or all, of these resources, given the development of appropriate infrastructure.

Several stakeholders posited that the mechanisms for enacting energy transitions being utilized in the County of Hawai'i may provide a useful and germane example for other island communities, particularly in the South Pacific. Several reasons were offered to support the comparability of Hawai'i county and other island communities. It was suggested that the poverty rate in Hawai'i county, which is relatively higher than the overall poverty rate of the state of Hawai'i and that of the overall United States, may make its approaches more applicable to many of the developing nations in the South Pacific. It was also suggested that the overall distribution of GHG emissions-by-sector in Pacific island communities is similar to that of Hawai'i county: 57.9% of GHG emissions produced in Hawai'i Couny were purported to be caused by the transportation sector, while Pacific islands writ large were purported to generate approximately 45% of their GHG emissions from their transportation sectors and approximately 50% of their GHG emissions from electricity generation. Some stakeholders proposed that forming partnerships between stakeholders engaged in hydrogen energy systems in Hawai'i and energy stakeholders from diverse island communities could help to facilitate the transfer of knowledge regarding potentially effective approaches for implementing energy transitions and promote the importance of supporting shifts to environmentally sustainable energy systems globally.

Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy of Tonga**

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Summary

Tonga is a Small Island Developing State (SIDS) in the South Pacific region consisting of 177 islands with an estimated population of 100,650. Its main island groups are the Tongatapu, Ha'apai, Vava'u, 'Eua, and Niuas groups. About 36 of Tonga's islands have permanent settlements, and more than 75% of the country's people live on Tongatapu, the main island, and the location of the capital, Nuku'alofa.

Tonga is highly dependent on diesel for energy and electricity generation. Overall installed capacity is 20.2 megawatt (MW) to 5.5 MW (or 27%) comes from solar photovoltaic materials (PV) and 1.3 MW (or 6.4%) comes from wind, coupled with 13.2 MW/24.68 MWh Battery Energy Storage System (BESS), soon to be completed. Most installed capacity is in Tongatapu, the main island and main grid. Further capacity is centered on separate mini-grids or household systems across many islands. In terms of renewable energy penetration, in 2021, only about 11% of electricity consumption was being met by renewables.

As highlighted by the Tonga Strategic Development Framework II, electricity is a key driving force of economic development which in turn fuels better living standards. Tonga Power Limited is the main provider of electricity, and its mission is to provide safe, reliable, affordable, and sustainable electricity services for Tonga. The Government of Tonga (GoT) has mandated that 50% of electricity requirements must be produced by renewable energy (RE) sources by 2020, 70% by 2030, and 100% by 2035, all while maintaining financial stability. Tonga is limited by its financial capability to implement this RE program by the need to cooperate with developed countries in transitioning to net zero carbon emissions.

Current realities

For Tonga as a whole, electricity consumption in 2021 was estimated at about 74 GWh with a 2.8% annual growth. The electricity grids on seven of the outer islands are currently powered by diesel generators and scattered solar home systems. Small diesel generators supply electricity to a limited number of households on the furthest most island group of Niua.

Due to the COVID-19 Pandemic in 2020, the goal of reaching 50% renewable was not achieved due to delays (i) in project implementation, ii) grant funded and public-private partnership (PPP) agreements, and (iii) the COVID closure of borders to international travelers. The Tonga Energy Road Map (TERM) 2010-2020 goal of becoming 50% renewable proved a difficult transition. The realistic barrier for most of the SIDS countries that rely on solar and wind technologies to initiate the RE transformation is the need for a grid that is both structurally sound and robust to enable a decentralized RE network. Therefore, three challenges are urgently important to address: (i) seeking grant funding for feasibility studies with various technologies being considered (ii) obtaining the funding for RE projects that generally require two-to-four years from project inception to project completion, (iii) upgrading the network to a more reliable, resilient, and robust decentralized system, and (iv) pursuing a PPP with independent power producers by way of a power purchase agreement (PPA) to accelerate the transition to RE goals.

Despite the COVID-19 Pandemic disrupting international travel for two years, including shipping logistics and, most recently, the Hunga Tonga Hunga Ha'apai Volcanic Eruption and Tsunami at the beginning of 2022, Tonga is now moving into TERMPLUS of establishing 70% renewable electricity by 2030 and ultimately 100% renewable electricity by 2035 along with goals of improved energy security, sustainable transportation and a greater emphasis on climate-resilient energy systems. TERMPLUS will build upon the projects that will be planned and implemented in the next 10 years whilst strengthening the framework foundation to support Tonga's progressive transition towards a higher penetration of renewable energy.

Tonga's energy transition is gaining acceleration with updated policy from the GoT new Energy Bill (poised to become an Act in 2022). When enacted, the Energy Bill will begin the development and adoption of Tonga's National Energy Policy including the ambitious centerpiece targets of 70% and 100% renewable electricity in 2030 and 2035 respectively. This comprehensive Energy Bill provides policy to establish coherent institutional and regulatory frameworks for coordination of the energy sector. It establishes clear national objectives as well as promotes private sector incentives and research initiatives. Given the intermittency of solar and wind, BESS is integral to the ongoing transformation to net zero carbon emission for Tonga. The current lithium-ion BESS projects only enable the march towards 50%, and possibly 70%, RE goals. This is the area in which hydrogen energy plays a key role in following together with developed country initiatives for Tonga to reach 100% RE by 2035.

Scientifically and technologically credible approaches and challenges

Tonga's current peak demand in the evening is approximately 11.5 MW. This will increase with the expansion of RE penetration, grid stability and RE spillage will become more critical and frequent given the fluctuation of energy demand and availability throughout the day, month, season, and year. The current BESS capacity consists of two funded projects under the Green Climate Fund (GCF): the first for grid stability (7.2 MW/3.8 MWh) and the second for load shifting (6 MW/20.88 MWh) on the main island of Tongatapu. In order to displace 50% of diesel generation with 50% RE penetration annually, Tonga needs at least 17.5 MW of RE (combination of solar and wind) to be funded with private sector engagement, which is currently being implemented.

In addition to the current projects that are signed and underway, there are also the other RE potential technologies that are gaining credibility for sustainability issues (e.g., bio energy, waste-to-energy) as well as technologies that are being considered on a longer timeline (e.g., Ocean Thermal Energy Conversion and wave energy for which Tonga has an abundance of natural resources). Agriculture and farming provide the biggest economic sector and therefore, a circular economy with the inclusion of bio energy can be a very significant transformation across a variety of sectors. The challenge remains of solving excess energy and grid stability challenges, which, with the advancement of green hydrogen energy technology and hydrogen fuel cells, can become an important element in the structure of Tonga's energy system.

Evidence-based options and actionable next steps

For Tonga to reach 70% RE and 100% RE by 2030 and 2035 respectively, the following generation and storage capacity will be required with the current solar and wind technology: (i) 39 MW RE with 15 MW/74 MWh of BESS for 70% RE and (ii) 170 MW RE with 20 MW/273 MWh of BESS for 100% RE. Given the TERMPLUS spans over the next 8-to-13-year energy roadmap, it is prudent to also evaluate and seek participation in developments across the globe with other technologies and determine their link to green hydrogen energy. Actions that are needed to transition to net zero carbon emission in Tonga, and potentially its neighboring SIDS, include:

1. Identify and structure policy measures, technological options, financial investments (e.g., public-private partnerships) that will provide the lowest cost of electricity to the people of Tonga.
2. Manage a strategic business continuity plan when facing international crises (e.g., pandemic or global recession).
3. Model baseload RE technology such as bio energy, waste-to-energy, wave energy that would blend with hydrogen energy to replace thermal generation that is traditionally diesel fuel.
4. Compare other technologies with the traditional solar and wind options with respect to land requirements and potential offshore generation (e.g., floating PV and wind).
5. Conduct an economic cost/benefit analysis of creating a green hydrogen circular economy with the storage of excess RE produced rather than limiting energy output during maximum conditions from solar and wind.
6. Assess the cost of BESS with respect to hydrogen fuel cells vs. the BESS currently being utilized (e.g., lithium ion, flow battery, lead acid).
7. Determine the comparative benefits of vehicle-to-grid EV and hydrogen vehicles.
8. Assess the current and projected economic feasibility of extending hydrogen energy technologies to the smaller island communities with Tongatapu being the hub.
9. Assess the most feasible approach for a multidimensional model for a clean energy investment towards a sustainably driven future.

*****A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP***

Debate 4 Summary

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. Talolakepa Fonua (see position paper above and author biographical information in the Appendix). Mr. Fonua 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 45-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. Fonua and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Fonua, 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.

At the beginning of the debate, it was stated that the government in Tonga is open to exploring possibilities for using any technology that would help meet its energy needs as well as its environmental commitments. Multiple stakeholders acknowledged that Tonga has very ambitious environmental goals for its energy system, despite the fact that SIDS generate a very small percentage of harmful global emissions. In general, stakeholders acknowledged that challenges to meeting energy needs and related societal goals in Tonga primarily pertain to financing and economics, rather than technological issues. It was asserted that any technology needs to be fully vetted and "matured," most likely by wealthy states, before being deployed in developing states. Resilience (e.g., to typical weather, natural disaster, climate change) was identified as perhaps the most critical attribute of any transitioning energy system in SIDS. Multiple stakeholders suggested that transportation sectors within SIDS may be the most practical first target for decarbonization with hydrogen-based energy technologies.

The importance of ensuring that robust economic mechanisms function to make technologies financially feasible for SIDS was discussed at length. It was noted that most, if not all, technologies for renewable energy generation currently produce energy that is significantly cheaper than energy produced by diesel (i.e., at current prices). One stakeholder argued that, once Tonga was able to produce renewable energy at a threshold price (e.g., reported to be $0.10/KWh in the County of Hawai'i) consistent with the production of hydrogen fuel at "price parity" with fossil fuels, the SIDS could begin producing hydrogen for domestic use and export.

It was suggested that identifying funding for (i) assessments of which technologies will best meet energy needs in Tonga and (ii) projects deploying new technologies in Tonga energy systems was critical. The Tonga government, it was disclosed, is engaged in and/or exploring two Power Purchase Agreements (PPA) with private sector partners, including one proposed agreement that aims to develop a 6MW solar farm. While the government of Tonga has been focused on using PPA as its approach to energy system transitions, it was proposed that providing direct financial incentives, in the form of carbon credits, to independent, private sector stakeholders would be a more impactful approach to catalyzing sustainable energy transitions, particularly for industries that are heavily impacted by private sector decisions (e.g., transportation sector). Specifically, carbon finance systems and carbon credits were suggested to be a way to encourage energy transitions in the transport sector, because private sector stakeholders will usually utilize whichever source is most lucrative (i.e., if diesel is cheaper, the private sector is unlikely to willingly use other energy sources). Conversely, it was argued that financiers (e.g., multilateral development banks), who often base decisions on "financial additionality," would not prioritize carbon finance programs and other forms of concessional finance (e.g., grants, soft loans). Programs that directly engage governments as well as the private sector were claimed to produce more substantive results than concessional finance mechanisms by mitigating early-stage financial risks.

One stakeholder claimed that some existing, well-funded financing programs for sustainable energy transitions in developing nations (e.g., through the Asian Development Bank, Australia Infrastructure Financing Partnership for the Pacific, and the International Finance Corporation) attempt to provide a financial link between governments and private sectors. There were renewed questions concerning whether existing financing programs were not receiving attention as a result of either (i) an information gap regarding awareness of existing financing programs or (ii) existing financing programs are failing to function as intended. Multiple stakeholders described the circumstances characterizing this question with the phrase "people with money (i.e., financiers) are looking for projects (i.e., energy development initiatives) and people who need projects are looking for money."

Potential options were discussed regarding how these recognized challenges may be effectively addressed (i.e., ways in which the money can be appropriately provided to beneficial projects). It was expressed that the government of Tonga emphasize proposals for projects with focus areas that are attractive to independent power producers to catalyze new energy initiatives. It was also suggested that the government of Tonga could garner interest among potential partners and financiers by identifying a specific list of government priority areas (e.g., target sectors, priority technologies or methodologies, environmental goals) as well as a list of the specific criteria (e.g., with regard to resilience, economics, energy efficiency) that new energy projects need to fulfill.

One stakeholder asserted that financiers from multilateral development communities are most likely to support proposals for structuring projects that foster competition and more optimized pricing. As an example, a recent 100 MW project supported by the Asian Development Bank and the government of Cambodia was claimed to achieve an offtake of $0.038/KWh, which was purported to be approximately 50% less expensive than previous bilaterally negotiated PPA for diesel energy in Cambodia. The methodology utilized by the County of Hawai'i to develop funding and partnerships to transition its government fleet vehicles was suggested to be an option for SIDS to consider. Elements of the County of Hawai'i methodology cited to be pertinent included the solicitation of a request for proposals to private sector bidders.

Hydrogen Production in an Islanded Energy System**

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Summary

This paper considers hydrogen production and consumption within the bounds of electricity generation. The aim is to demonstrate through a Tasmanian case study that, while energy firming from a hydroelectric system is highly advantageous for receiving total green energy supply, there are significant risks that likely limit the scalability, and therefore the economic feasibility, of a successful hydrogen production industry in an island energy system.

Tasmania has been the focus of hydrogen production globally, because it currently sustains a total renewable energy grid, leveraging a large fleet of hydroelectric power plants that can also operate as a battery (i.e., the fleet is inherently flexible for capacity requirements).

However, given the energy balance requirements of island energy systems, hydrogen production will face significant challenges accessing the underlying energy (i.e., locally available energy) at an efficient cost. It is expected that developing the supply-demand dynamics required to create efficient energy prices commiserate with hydrogen production is not possible in an island setting. Without a high penetration of variable renewable energy (e.g., wind, solar energy generation), which is usually not economic without a high degree of transmission and/or interconnection, there will not be enough "surplus" energy for uses like economic hydrogen production.

This challenge is expected to be prohibitive to the production of cost-effective hydrogen in Tasmania until (i) the technology used for hydrogen production is effective within a closed system (i.e., hydrogen production economics are sufficient with only the output of variable renewable energy forms), and (ii) broader energy grid connection is not required.

Current realities

It is key to be forthright and define the inherent characteristics of new technologies and geographies that guide the overarching principles of economic development. These characteristics will either be complementary and consistent, or conflicting and limiting.

The production and consumption of hydrogen fuel are separate industries, as is the case for almost all commodities traded globally today. Generally, it can be assumed that the benefit to specific regions producing hydrogen is substantiated by the associated economic development of the supply chains and logistics industries stimulating economic activity, while the benefit for those consuming hydrogen is the access to a green fuel source where green alternatives may be limited.

An inherent characteristic of islands is that they are isolated. Generally, we can then assume the energy system is contained to the island, with little or no interconnection (transmission between regions). It then follows that energy supply needs to be carefully considered for meeting varying levels of demand, as the absence of interconnection removes the ability to under- or over-supply locally beyond tight bounds. Energy systems on islands are generally well balanced. Inability to create new energy supplies limits demand and, therefore, economic development, while oversupply will burden consumers with inefficiently high costs.

Scientifically and technologically credible approaches and challenges

If hydrogen is to be consumed on islands as a fuel source, it can be assumed it is either: (i) a storable form of energy required for weather drought (e.g., absence of wind and solar generation), or (ii) a concentrated source of energy for islands that do not have sufficient space to accommodate enough wind and solar energy generation to meet their continuous needs.

Both rationales are considered in the context of pursuing a total green energy grid, whereas the current alternative is likely generation of grid electricity using gas or diesel fuels. In either case, hydrogen energy can play a crucial role in providing a renewable energy source when alternative forms are limited. The acceptance and adoption of hydrogen energy will likely depend upon the economics of hydrogen production, particularly with regard to achieving a financially efficient price to consumers. Notably, the production cost of hydrogen fuel is typically understood to be 90% attributable to the cost of input energy (e.g., the cost of electricity produced using fossil fuels, solar, wind).

In pursuit of a totally renewable energy grid, it is important to consider the extent to which an island system can electrify its total operations, while removing non-renewable fuels and replacement fuels (e.g., hydrogen) from its economy. This would be a separate analysis of the interaction of supply, demand response, and storage factors associated with meeting consumer energy needs within an island system. The extent to which this option is successful could reduce the total energy costs to consumers before other technologies, including those associated with hydrogen energy systems, are considered.

The following case study will focus on the production of hydrogen from an island energy system. This case study pertains to the Australian island State of Tasmania and the ability of its energy system to absorb additional demand (i.e., load) for powering hydrogen electrolyzers and associated generation requirements in the pursuit of producing hydrogen for export.

Case study for developing hydrogen energy systems in Tasmania

Like most island systems, current energy requirements in Tasmania are in balance. That is, renewable supply meets total demand in an average year, and balancing is facilitated by an interconnector. Hence, Tasmania does not need hydrogen-based energy generation to meet local demands.

The Tasmanian energy system balances at about 10.5 terawatts (TWh) of demand, which is met by 9 TWh hydro and 1.5 TWh wind generation. Assuming additional interconnection is not feasible or possible, a key requirement for any augmentation to islanded energy systems is the matching of additional load with additional supply. Financial and other hedging instruments do not account for the physical constraints. Matching new load with wind and solar is only possible in Tasmania because the state has a hydro generation fleet, allowing it to time-shift variable generation to match the needs of hydrogen production. This process is known as firming (e.g., when more wind energy is produced than the amount required by the system, the hydro fleet stops generating energy and holds the water for a later stage when the wind stops generating).

As a generally understood rule, a hydrogen production facility today needs to scale to approximately 300 megawatts (MW) in total load to approach economic feasibility. The system matching criteria can be treated as 1-to-2.5 times ratio (i.e., every 1 MW of new load requires 2.5 MW of wind). Therefore, the proposed 300 MW hydrogen development requires 750 MW of new operational wind farms. The focus here is on wind generation, as opposed to solar, because of the superior capacity factor of wind energy (i.e., wind will produce energy for an average of 40% - 50% of a day compared to 20% - 30% for solar).

For 750 MWs of wind turbines, location will make a material difference, as diversity of the wind profile would be needed to manage volatility. It should be noted that diversifying the location of the wind will affect the total price of its output as well.

Based on today's round-trip efficiency of hydrogen economics, it is understood that a delivered energy price of AUD$20/MWh is required for a plant of a 300 MW scale. Delivered energy price includes total wholesale, transmission, and retail costs.

If supplied by new wind that retains the system balance (i.e., 2.5 times the load), the cost of wind alone is expected to cost AUD$40 - $60/MWh. Wind then needs to be firmed by the hydro system, which typically comes at the opportunity cost of committing storages to the hydrogen production, instead of market-based opportunities, and therefore a firming (or time-shifting energy premium) is charged. Transmission and retail costs are then overlaid to the wholesale energy price for the total delivered cost of energy.

Under these circumstances, it is necessary to ask, "why not use the input wholesale energy directly in an electrified economy to avoid the additional costs of hydrogen?" If this is not possible, what premium above that input energy cost is acceptable for energy stored as hydrogen?

It is important to acknowledge that, until hydrogen can be produced in a flexible enough manner that its electrolyzers can operate in an off-grid variable renewable system (i.e., without grid connected changes such as transmission and retail costs), consumers will be prone to paying transmission and retail costs twice: (i) for the production of hydrogen, and (ii) for electricity generation from hydrogen.

Hydrogen economics today require a high utilization factor to achieve a large enough production volume to meet both logistical and economic hurdles. This would likely require electrolyzers to continue producing when weather droughts occur, or overnight with no solar output. As technology improves over time, the utilization factor economics are expected to improve.

Evidence-based options and actionable next steps

Fundamentally, the economics of hydrogen meet consumer requirements when it is produced by energy that is surplus to demand, which is the consequence of highly coincident variable renewable generation. These circumstances are unlikely to exist in an islanded energy system where the energy system balance is so carefully considered (e.g., the state of Tasmania in Australia). Based on the case study described above, overarching principles suggest the strategic fit for hydrogen is to either:

1. Focus hydrogen production in highly interconnected regions that accommodate a high penetration of variable renewable generation.
2. Improve the production flexibility of hydrogen energy to effectively operate in a closed system, off-grid.
3. Ensure that an energy system exceeds a particular threshold (i.e., determined based on the considerations proposed in the above case study) of renewable generation penetration prior to developing hydrogen production at scale, because implementing hydrogen production before a sufficient share of the grid has been converted to renewable energy sources (e.g., wind, solar generation) will slow the overall transition to a total renewable energy grid.

*** A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP.*

Debate 5 Summary

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. Nick Sallmann (see position paper above and author biographical information in the Appendix). Mr. Sallmann 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 45-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. Sallmann and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Sallmann, 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.

It was generally recognized that Tasmania represents an extraordinary case for energy systems, as the state currently receives 100% of its electrical grid energy from renewable energy sources. It was repeatedly stated that the Tasmanian energy system is highly resilient compared to most renewable energy systems because large-scale hydroelectric power generation and storage significantly offset intermittent renewable energy sources (e.g., wind energy, solar energy). It was suggested that the heavy reliance upon hydroelectric power in Tasmania, and the corresponding importance of water availability, may result in vulnerabilities as impacts from climate change worsen.

In Tasmania, it was posited that approximately 1 MW of hydroelectricity production is required to firm (i.e., act as a battery) 2 MW of intermittent renewable energy. Based on this assertion, it was proposed that 2 gigawatts (GW) of total hydroelectric power in Tasmania could act as a battery for 8 GW of intermittent renewable energy in mainland Australia to help phase out the persisting thermal fleet (i.e. diesel or gas-fired generation). It was repeatedly stated that Tasmanian energy stakeholders have developed close ties with partners in New Zealand, Canada, and Norway since each nation has highly developed hydroelectric power systems that are being leveraged to (i) support electricity grids in neighboring regions and (ii) provide firming of overall energy supply through hydro-storage, rather than environmentally harmful alternatives (e.g., gas peaking units). It was argued that hydroelectric power also offers grid stability and security because it uses infrastructure similar to that of coal and gas plants and can offer frequency support and ancillary services (i.e., the procuring of energy reserves that can bring the grid back into safe frequency range by balancing demand and supply).

It was claimed that the Tasmanian government is exploring opportunities for creating at least two more cables between Tasmania and Australia, which would (i) diversify the subsea cables between Tasmania and the mainland (ii) abate the active gas subsea cable and (iii) leverage almost 2 GW of hydroelectric power that would otherwise be inaccessible to Australia. It was mentioned that Australia is developing two international subsea cables (i.e., to Singapore and Malaysia). Concern was expressed that if (i) the cost was not equally shared between Australia and the foreign recipient and (ii) the resulting relationship is exclusively an export relationship (i.e., Australia exporting energy to a foreign recipient), then the associated economic burden would be excessive for a single country to bear. It was asserted that as hydroelectric power in Tasmania becomes more integrated with the Australian power grid, it would be increasingly important to communicate the purported benefits associated with hydroelectric power (e.g., frequency management, voltage support, synchronous frequency services) widely on mainland Australia and abroad.

It was suggested that many of the purported shortcomings (e.g., short range, long charge times) of battery electric-powered vehicles are not a major concern for light-duty transportation applications in Tasmania, because local transportation needs typically do not entail long-distance ground travel. It was asserted that commonly cited benefits of hydrogen energy cars (e.g., longer range, quick fueling time) are not as critical in Tasmania, so hydrogen applications for local transport may not be a priority. Regarding maritime transportation, it was argued that methanol is a more practical source for maritime fuel applications than ammonia. It was acknowledged that ammonia has certain advantages and was being studied, but that it carries risks of environmental damage.

One stakeholder contended that the technological advancements and economic factors required to effectively implement battery-electric technologies and/or hydrogen energy technologies are still too distant to be reasonably competitive against solar, wind, and hydroelectric energy in Tasmania. It was repeatedly emphasized that the downstream economics (i.e., capital costs) of hydrogen production inhibit hydrogen energy from outcompeting prices for hydroelectric power. It was argued that electrolyzers (i) are very energy-intensive (ii) have very high utilization factors, and (iii) cannot be used in a closed system and would therefore require grid firming. It was suggested that if significant amounts of energy from hydroelectric power were directed to hydrogen production facilities, then reliance upon thermal energy generation in Australia (i.e., and correspondingly, timelines for overall grid decarbonization) may be prolonged as an adverse effect of redirecting energy from the electricity grid.

To produce economically viable hydrogen for exportation from Tasmania, it was posited that the requisite scale of production would necessitate at least 300 MW of energy input from local renewable energy sources. It was suggested that wind energy would be the primary energy source and most relevant benchmark for assessing the economic viability of hydrogen production in Tasmania, as wind energy provides the cheapest renewable electricity available within the state. It was further noted that projections for viably producing hydrogen energy under this model of analysis are also influenced by the Tasmanian government's priority to expand/develop Tasmanian wind farms. It was repeatedly mentioned that Tasmania has proposed projects to export renewable energy. However, because Tasmania has a relatively even energy demand-supply balance, any novel project would need to match the additional energy load for producing exportable hydrogen energy. It was posited that a wind farm would need to produce approximately 2.5 times the output, in megawatts, of the energy consumed by the hydrogen plant, assuming that wind energy has a capacity factor of 40%. It was suggested that hydroelectric power plants could absorb wind energy when it exceeds the requirements of the hydrogen plant and could buttress the hydrogen plant when wind energy is not as abundant, thereby firming the hydrogen load.

While it was noted that water consumption is integral to the electrolysis process for green hydrogen production, it was contended that the quantity of water necessary would not negatively affect hydroelectric power in Tasmania. However, it was repeatedly stated that the water supply could be seriously affected if Tasmania were to become a significant food-producing area due to the irrigation necessary for the growing crops and other agricultural products. It was suggested that water conservation would be fundamental to leveraging solar and wind resources to achieve a green electricity grid in mainland Australia. It was argued that while hydroelectric power generation is regarded by some as a cause of negative impacts on the environment (e.g., the alteration of natural habitats by damming water resources, the decomposition of environmental matter in hydroelectric power storage, producing methane), the urgency of implementing climate change action and the emissions-reduction benefits provided by hydroelectric power generation far outweigh the negative aspects. It was also acknowledged that hydroelectric power does not require the damming of large rivers and that significant amounts of hydroelectric power can be generated in smaller rivers or creeks while causing less intense local ecological impacts.

Archipelagos: Perspectives on Energy Challenges, Priorities, and Opportunities for Hydrogen Energy in Indonesia **

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Summary

Our window to respond to climate change is narrowing. Decarbonizing the energy sector is essential for Indonesia to become a net-zero economy by 2060. It is not an easy process. As an archipelagic country, Indonesia needs to utilize all available technology suitable for each region. A combination of clean energy sources, (e.g., solar photovoltaic (PV)), needs to be developed and accompanied by other flexible energy counterparts. This synergy brings reliable, affordable, and sustainable electricity to all. As the highest energy content by weight, hydrogen holds great potential to be the ultimate energy carrier, replacing any fossil fuels. However, to be widely and commercially adopted as an energy carrier, there are many collective efforts to be done, particularly focusing on: (i) improving the energy efficiency of hydrogen production, (ii) reducing the production cost, (iii) preparing hydrogen distribution networks either using pipelines or over the road, (iv) and developing technology to lessen the well-to-wheel carbon emission of hydrogen production.

Current realities

The Intergovernmental Panel on Climate Change (IPCC) recently released a new report mentioning that our opportunities to respond to climate change are narrowing. Scientists have warned that our earth's condition is on a "Red Alert", meaning that we need to act immediately to reduce our greenhouse gas (GHG) emissions. Failing to respond to climate change will bring catastrophic impacts to our energy conditions, especially in altering our energy generation potential and energy needs. More extreme weather will increase our cooling demand due to extreme heat waves, and the average temperature will get higher. On the other hand, our variable renewable energy generation, prone to challenges based on weather conditions, will also be affected, such as hydropower, solar PV, and wind generation. In response, Indonesia is revising its National Energy General Plan to accommodate Indonesia's vision to become a net-zero economy by 2060. This effort is essential, considering the energy sector will be the main GHG emitter in the coming years.

The energy sector in Indonesia accounted for 39% of total GHG emissions in 2019, primarily due to electricity generation. Coal still acts as the main primary energy source, contributing to 37.62% of the total primary energy supply in 2021. Oil is the second most used energy source, accounting for 33.40% of the total primary energy supply (Figure 1). Even though Indonesia is gaining traction to develop renewable energy with a supply increase of 11.6% year over year growth, its share of the total primary energy supply is still low, at 12.16%.

As the largest archipelagic country in the world, Indonesia has more than 17 thousand islands that collectively span 5,100 km. This geographical condition makes the development of major power grids a formidable challenge. As a result, many smaller or isolated grid systems are formed with high electricity generation costs due to the utilization of diesel power plants. According to the National Electricity Plan (RUPTL) 2021-2030, more than 5,200 Diesel Power Plants are distributed across 2,130 locations in Indonesia, with a total installed capacity of 4.863 GW. Aside from emitting many GHG emissions, the high penetration of diesel power plants also causes a burden on the finances of the State Electricity Company (PLN). Furthermore, the current high oil price does not appear to be decreasing soon, and this condition indicates that Indonesia needs to prioritize the development of renewable energy in these smaller grid systems to replace the existing diesel power plants.

To solve the energy trilemma, renewable energy power plants must be able to generate reliable, affordable, and sustainable power. This is no longer a concern in terms of the second and third elements. As for reliability, it is essential to address this issue, particularly in a small grid system with limited energy sources. Variable renewable energy (VRE) sources heavily affected by weather conditions, such as solar PV and wind, are most effective when paired with flexible energy sources. Two examples of energy sources that can be dispatched flexibly to balance the grid are hydroelectric and geothermal power plants.

The other option is to use an energy storage system. The pump-hydroelectric system (PHES) is the most extensive energy storage in the world, but on the other hand, using PHES in a microgrid system is not technically or financially feasible. This is where hydrogen fuel cells come into play, bringing reliable generation for VRE. The question is how to make hydrogen economically feasible as a flexible energy carrier to support Indonesia's clean energy initiative.

Scientifically and technologically credible approaches and challenges

In 2022, the PLN devised a de-dieselization strategy to convert those diesel power plants into renewable energy sources. The first phase of this strategy used a combination of solar PV power plants with energy storage systems. The excess supply of solar PV electricity generation can be converted to produce hydrogen energy using electrolysis. This hydrogen produced from renewable energy is usually called Green Hydrogen. Hydrogen's potential to be used for energy is massive, considering its higher energy density compared to lithium-ion batteries, a common small-scale energy storage system.

There are some drawbacks to producing hydrogen from electrolysis, especially in its efficiency rate and cost of production. To produce 1 kilogram of hydrogen, a fully efficient electrolysis plant would consume 39 kWh of power, yet a typical electrolysis plant would require between 45-50 kWh/kg hydrogen, or an efficiency rate between 60-80%. This number can be increased if the bubble produced in the electrolyte is further reduced by limiting the contact between anode/cathode with electrolyte. The production cost of Green Hydrogen is between $3/kg and $6.55/kg (European Commission, 2020).

A cheaper option, and also a more efficient way, to produce hydrogen is through steam-methane reforming. The vast majority of the world's commercial hydrogen, around 95% of total hydrogen production, is generated using steam-methane reforming, despite growing concerns about its environmental impact, considering almost 7 kg of carbon dioxide is produced per 1 kg of hydrogen. The solution is to implement a carbon capture, utilization, and storage (CCUS) process to reduce emissions. The hydrogen produced through this method is called Blue Hydrogen. This process normally requires a large-scale plant to reach economies of scale. The hydrogen produced is mostly used for either petroleum refining or fertilizer production, but has not yet been applied as an energy storage system. Aside from the economies of scale aspect, using hydrogen as an energy carrier in a microgrid system has another challenge, especially in ensuring the infrastructure for distributing both natural gas and hydrogen.

For decarbonizing the local/micro grid system in Indonesia, the next option is to use energy sources from local areas, such as waste and biomass. Gasification by using these feedstocks can produce hydrogen, carbon monoxide, and carbon dioxide. The carbon monoxide then can be further processed using a water-gas shift-reaction to form carbon dioxide and more hydrogen. Even though the efficiency will not be as high with large-scale steam-methane reforming plants, this method can be applied to many regions in Indonesia. Installation of carbon capture and utilization plants can be developed to support the net-zero emission initiative. In Japan, the carbon emission from waste incineration plants is recovered and then sold for algae cultivation, which later can be sold as materials for cosmetic and dietary supplements.

Of all the previous energy sources to produce hydrogen, most of them, aside from solar PV and wind, must consider their feedstock availability. Ensuring the feedstock will be increasingly critical if the area is remote. Another option is to use nuclear energy, although it is a sensitive subject for the public. Nuclear energy has merit, especially in producing hydrogen through its excess heat. Instead of using electricity, methane can be decomposed into carbon and hydrogen using a method called methane pyrolysis. The temperature required for this process ranges between 500-700°C if using nickel catalysts. These temperatures are within the range of reactor outlet temperatures. More than half of Small Modular Reactors currently reviewed by the Canadian Nuclear Safety Commission will generate high heat, with a capacity as low as 5 Megawatt electric (MWe) (i.e., a suitable capacity for a local/micro grid system). Although carbon is still produced in this process, it is pure solid carbon that is significantly simpler to be captured and to be utilized for other applications. Moreover, because the heat required for this process is considered a by-product of electricity generation, and this process uses the lowest energy input to generate hydrogen, the production cost can be competitive with the steam-methane reforming.

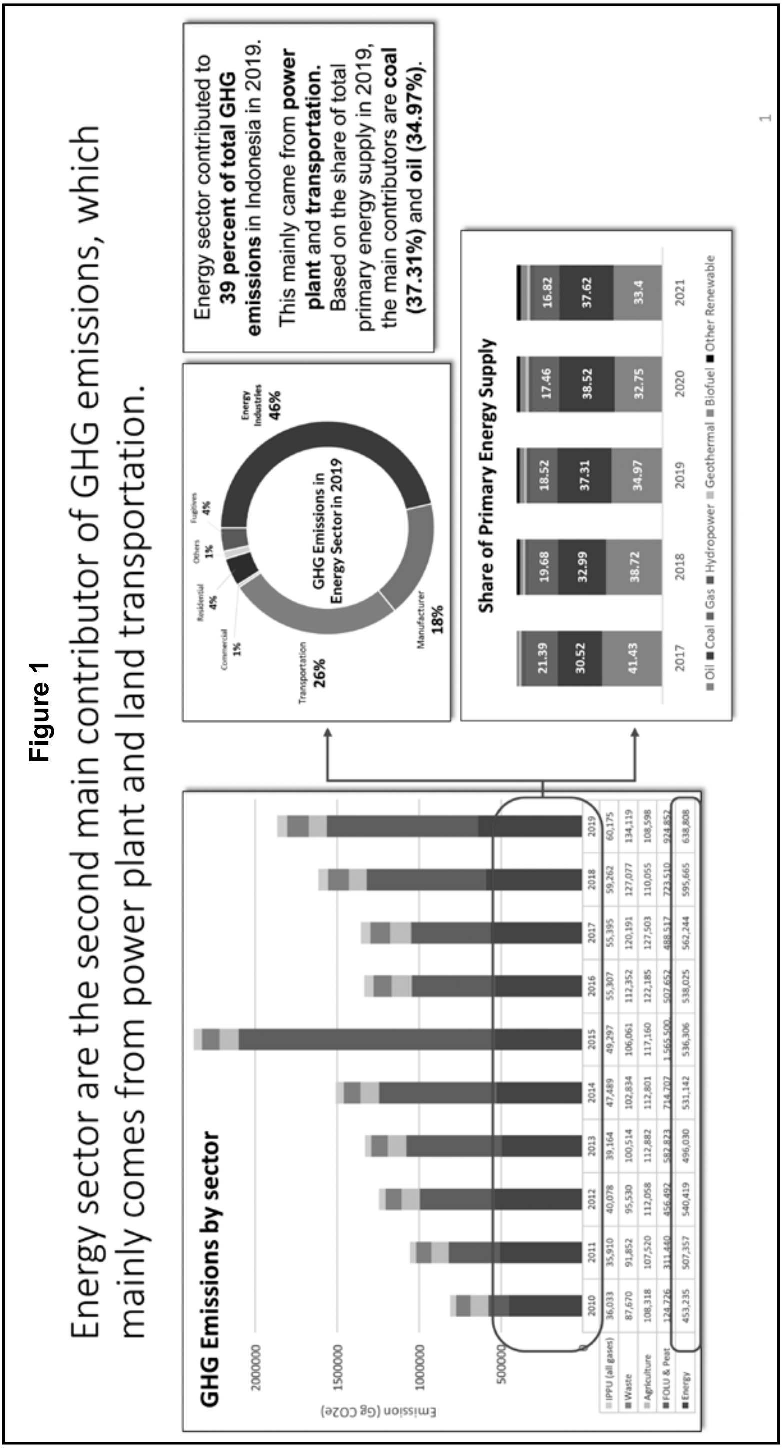
Evidence-based options and actionable next steps

Hydrogen energy holds great potential to be used as an energy carrier in the electricity and transportation sector. However, for it to be used commercially in Indonesia, several actions need to be done, as follows:

- Continue to invest public and private funds in research to develop and improve hydrogen production efficiency and well-to-wheel emissions, particularly in electrolysis, gasification, and methane pyrolysis. These programs need to also focus on a small-scale balance of plants so that the result can be widely applied across regions in Indonesia.
- Implement the PLN de-dieselization program with any available technology options, as long as the proposed technology can reliably provide electricity with cheaper costs and cleaner emissions.
- Utilize mechanisms within government and financial institutions to mobilize more resources and provide more incentives for clean energy development by issuing green/sustainability bonds, implementing more blended financing schemes, and developing a mandatory carbon market.
- Identify the potential hydrogen production processes for various regions of Indonesia, within the public and private sectors, while also preparing the distribution infrastructure, either via pipelines or over the road in cryogenic liquid tankers or gaseous tube trailers.

- Kick-start the nuclear energy program in Indonesia, by accelerating the government's fulfillment of the IAEA (International Atomic Energy Agency) recommendation for Indonesia, which is creating a nuclear energy program implementation organization, increasing stakeholder engagement, and issuing a formal statement on "Go Nuclear." A combination of a small-modular reactor with hydrogen co-production can be a great solution to become a net-zero economy for both electricity and transportation sectors.

** ***A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP***


Energy sector are the second main contributor of GHG emissions, which mainly comes from power plant and land transportation.
GHG Emissions by sector
Emission (Gg CO2e)
2000000
1500000
1000000
500000
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
IPPU (all gases) 36,033 35,910 40,078 39,164 47,489 49,297 55,307 55,395 59,262 60,175
Waste 87,670 91,852 95,530 100,514 102,834 106,061 112,352 120,191 127,077 134,119
Agriculture 108,318 107,520 112,058 112,882 112,801 117,160 122,185 127,503 110,055 108,598
FOLU & Peat 174,726 311,440 456,492 582,823 714,707 1,565,500 507,652 488,517 723,510 924,852
Energy 453,235 507,357 540,419 496,030 531,142 536,306 538,025 562,244 595,665 638,808
GHG Emissions in Energy Sector in 2019
Energy Industries 46%
Manufacturer 18%
Transportation 26%
Commercial 1%
Residential 4%
Others 1%
Fugitives 4%
Energy sector contributed to 39 percent of total GHG emissions in Indonesia in 2019.
This mainly came from power plant and transportation. Based on the share of total primary energy supply in 2019, the main contributors are coal (37.31%) and oil (34.97%).
Share of Primary Energy Supply
2017 21.39 30.52 41.43
2018 19.68 32.99 38.72
2019 18.52 37.31 34.97
2020 17.46 38.52 32.75
2021 16.82 37.62 33.4
Oil Coal Gas Hydropower Geothermal Biofuel Other Renewable
1
Figure 1

Debate 6 Summary

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 Dr. Bambang Brodjonegoro (see position paper above and author biographical information in the Appendix). Dr. Brodjonegoro 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 45-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 Dr. Brodjonegoro and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Dr. Brodjonegoro, 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.

It was generally recognized that Indonesia has a unique set of challenges and characteristics that define its energy system, many of which stem from the fact that Indonesia is the largest archipelagic nation in the world, comprising approximately 17,000 islands. It was stressed that meeting the energy needs of Indonesia requires an understanding that energy infrastructure in Indonesia could not be developed in the same way as nations with similar size land areas (e.g., Mexico, Sudan, Libya) because of its archipelagic nature. It was noted that the rapid development of the Indonesian energy system has resulted in a highly decentralized energy grid that is not interconnected. Consequently, the Indonesian energy system was initially dominated by diesel power plants, and then increasingly by coal power plants, both of which were developed through the Indonesian electricity company Perusahaan Listrik Negara (PLN), and dispersed throughout the archipelago. It was repeatedly asserted that among the most significant factors driving the expansion of non-renewable energy sources (e.g., coal, diesel) were (i) their affordability to consumers, (ii) the ease of their transport from areas where they were obtained, and (iii) the highly reliable nature of diesel and coal technology. It was claimed that certain regions of Indonesia (e.g., Kalimantan) have only recently developed large-scale power grids since the energy needs across different communities have historically been met through isolated small grids and microgrids.

Indonesia purportedly developed diesel and coal power plants, in part, because the effects on the climate were not fully understood. It was posited several times that the imbalance of energy demand and resources throughout Indonesia is a central problem to solve, with a particular emphasis on developing methods for inter-island distribution of energy. It was suggested several times that if hydrogen were to be produced in Indonesia, it would have to be done in concert with the development of microgrids and small grids to ensure the affordability of energy to local consumers. It was also repeatedly mentioned that one of the most feasible options for energy alternatives in Indonesia could be the integration of biomass and waste management processes with existing microgrids and small grids. It was asserted that the richness of biodiversity in Indonesia would provide a source of potential feedstock for biomass. Stakeholders claimed that, if hydrogen production were linked to small power plants, baseload electricity could be directly linked to local communities at close to $0 per kw. It was strongly suggested that developing hydrogen distribution networks within Indonesia would be a necessary logistical step before green ammonia could be utilized from foreign markets. However, concern was expressed that carbon markets would need to be fully compensated for the reductions in coal power plant emissions for the importation of green ammonia to be economically feasible.

With the aid of development institutions and the Indonesian Ministry of Energy, it was noted that important progress has been made in developing power plants that combine batteries, renewable energy, and hydrogen. However, it was claimed that in certain areas (e.g., East Nusantara, which has ample geothermal resources), it would be critical to implement effective distribution networks, because the demand for energy is likely to remain very low in that particular region. It was stated that submarine cables are being used in Indonesia to distribute energy, particularly from Java to Bali and from Java to Madura. It was suggested several times that solar development on the island of Sumba could play a vital role in electricity distribution for Indonesia, and that submarine cables were expected to play an integral role in distribution networks. More generally, it was contended that submarine cables could bring electricity from regions rich in renewable energy resources (e.g., Eastern Indonesia) to energy-poor regions. Concern was expressed regarding the dependency on international submarine cables since deterioration at any point along the cable could take extended periods of time to resolve and would compromise the energy supply for all regions upstream of the cable. It was posited that Indonesia would need to identify renewable energy hubs and energy-poor areas, then construct cables domestically between those areas before international submarine cables were rolled out.

Solar panels are a reasonable renewable energy alternative, but concern was expressed over the cost of batteries and the fact that effective electricity generation from solar for certain regions of Indonesia would only be 4 hours per day. Despite this, it was reiterated that the 2060 Indonesian zero-emission energy objectives state that the composition of primary energy would be dominated by solar panels. It was also noted several times that the second most important source of energy is anticipated to be pump-storage hydropower. It was asserted that the development of pump-storage hydropower would also be an option for repurposing mining sites that are no longer in use. It was mentioned repeatedly that pump-storage hydropower would have to be feasible from business and public budget perspectives to be effectively implemented in Indonesia. Additionally, it was stated that large-scale pump-storage hydropower is currently being developed to meet the energy needs of Java.

The debate focused specifically on Kalimantan because of the decision by the Indonesian government to move its capital city to Nusantara. Multiple people suggested that the planned city of Nusantara offers Indonesia a unique opportunity to develop a modern energy grid powered by zero-carbon and renewable energy. It was asserted that even though Kalimantan is rich in coal resources, it does not have an abundance of coal power plants because there exists a demand-supply imbalance between widely dispersed energy demands and energy resources. It was noted that Kalimantan continues to rely heavily on diesel power plants. The development of a large hydropower plant in North Kalimantan has the potential to be a major renewable energy source for the region as a whole, but particularly for the new capital city in East Kalimantan. It was posited that smaller-scale hydropower or nuclear plants could help provide energy to the more isolated portions of Kalimantan, but that an interconnected grid would be an ideal solution.

The Future of Fiji Energy Systems: Supporting the Transition of Achieving Fiji's SDG7 and NDC Targets by 2030**

Mr. Inia D. Saula
Principal Planning Analyst, Department of Policy & Planning, Ministry of Infrastructure and Transport, Government of Fiji

Summary

The Fiji government has made significant commitments to advance Fiji energy systems and meet targets laid out by the United Nations (UN) Sustainable Development Goal (SDG) 7 and the Paris Agreement. Actions taken to improve the environmental sustainability (e.g., utilization of renewable energy, improvement of energy intensity) of Fiji energy systems need to simultaneously ensure that they are resilient to climate change impacts (e.g., natural disasters) and address critical energy needs (e.g., provide universal access to electricity, provide universal access to clean cooking options). Reducing and replacing the reliance on imported fossil fuels, which account for one-third of Fiji's energy, with domestically produced renewable energies is a key target. To do this, government policies and stakeholder decisions need to (i) ramp-up renewable power, (ii) promote access to clean cooking stoves, (iii) embrace multi-sectoral approaches to improving energy efficiency in residential, commercial and transport sectors, and (iv) reduce emissions in the transport sector while improving energy efficiency. While existing and emerging hydrogen energy technologies may be capable of contributing to the fulfillment of these needs, particularly in the transport sector, hydrogen is not currently considered an immediate priority, because Fiji does not currently have the infrastructure to adopt hydrogen technologies. If hydrogen were to contribute to Fiji's energy transition, significant investment in infrastructure would likely need to be committed by private sector oil companies.

Current realities

Fiji consists of 332 islands, nearly one-third of which are inhabited and are populated by diverse peoples. Fiji is heavily reliant on fossil fuels in meeting the energy demand of its growing population and on advancements of technology, especially within growing industries. In Fiji, indigenous energy sources are limited to biomass, hydroelectricity (hydro), wind, and solar. Hydro has been the main source of energy since the commissioning of the Monasavu Hydro Scheme in 1983 and Nadarivatu hydro in 2012. Energy Fiji Limited (EFL) is the sole provider of grid-based electricity in Fiji, with 51% of shares held by the government, 44% held by the Japanese company Chugoku Electric Power and 5% held by citizens of Fiji. EFL operates five grid systems in Fiji.

Fiji Embracing SDG 7 Targets and National Determined Contribution (NDC) Targets
Fiji is embracing the SDG Roadmap in the path to transform its energy sector towards achieving the SDG7 targets and our commitment to the Paris Agreement by 2030. The SDG Roadmap presents options, in terms of technologies and strategies, for the sector. The document also identifies gaps and the support needed from international stakeholders to achieve the SDG7, objectives: (i) ensure universal access to affordable, reliable and modern energy services, (ii) substantially increase the share of renewable energy in the global energy mix, and (iii) double the global rate of improvement of energy efficiency. Our National Development Plan (NDP) and NDC Roadmap mandate that we provide all Fijians with access to modern energy services and reduce carbon emissions by 30% by 2030. A 20% reduction is possible through a 100% renewable share in the power sector, while a further 10% can be realised with economy-wide energy efficiency measures. While good progress has been made in the energy sector, more is required through enabling tools and policy frameworks to achieve all SDG7 targets.

Our energy transition pathway presents multiple challenges for policymakers. Vulnerability to the threats of natural disaster and climate change, oil price volatility, and small market size, each coupled with the unprecedented impacts of the COVID-19 pandemic, pose great challenges to the sector and the economy at large. Fuel imports represent approximately one-third of Fiji's total import bill, or over one-billion Fijian Dollars. Fossil fuel imports also have enormous economic, environmental, and social impacts on ordinary Fijians, and this proportion is expected to increase if alternative means of benign energy are not utilized. A large proportion of mineral fuel imported in Fiji is used for transportation, electricity generation, and home economics. The greatest impacts are felt by communities in rural and remote areas where supply chain issues contribute to added costs and supply inconsistency, leaving people exposed to issues of energy insecurity and unaffordability on a daily basis. Despite many interventions by the Fiji Government (e.g., fuel price control), the increasing international market price of fossil fuels is inadvertently passed down to Fijian consumers, exacerbating hardships faced by some of Fiji's most vulnerable people. Therefore, key aims need to include diversification of power generation, with a focus on sustainable indigenous sources (i.e., solar and hydro), and a reduction of the reliance on imported petroleum fuel.

Scientifically and technologically credible approaches and challenges

Achieving Fiji's SDG7 and NDC targets by 2030

Universal access to electricity: An estimated 20,243 Fiji residents, particularly in rural, maritime islands and informal settlements, lack electricity access. NEXTSTEP analysis indicates that mini/off-grid systems technologies (e.g., solar mini-grid and solar home systems) are the appropriate technologies for these communities, based on the technology's cost-effectiveness and climate resiliency.

Universal access to clean cooking: In 2018, 51% of the population in Fiji still depend on unclean cooking fuel, exposing them to poor indoor air quality and associated negative health impacts. Trends indicate that 28% of Fiji's population will not have access to clean cooking by 2030. NEXSTEP analysis suggests that electric cooking stoves and liquified petroleum gas (LPG) stoves may provide better alternatives as long-term solutions.

Renewable energy: In 2018, Fiji's share of renewable energy in its total final energy consumption (TFEC) was 9.4% (including biomass) or 11.4% (without biomass). Based on current policies, the share of renewable energy is projected to increase to 14% by 2030, due to the projected expansion of renewable electricity for power grids, as described by the current power expansion plan for 2020-2030, which is expected to increase the share of RE-based grid generation from 59% of electricity in 2018 to 71% in 2030. In the SDG scenario, the share of renewable energy is further improved to 14.5% of TFEC in 2030.

Energy efficiency: Fiji's energy intensity declined at an average annual rate of 2.22% between 1990 and 2010. A doubling of the 1990-2010 improvement rate is required to achieve the SDG 7.3 target, corresponding to an average annual rate of 4.44% between 2018 and 2030 (i.e., a projected 1.80 MJ/USD in 2030). NEXSTEP analysis suggests that Fiji's energy intensity target should be aligned with the global target of 2.9% annual improvement. This corresponds to a 2030 energy intensity target of 2.18 MJ/USD.

Important Policy Directions

Ramping up of renewable power capacity is cost-effective and contributes to both climate and sustainability objectives. Renewable power has become cheaper than conventional fossil fuel-based generation. Least-cost optimization analysis suggests that an early ramp-up of renewable power generation and reduction of fossil-fuel-based generation to a minimum would provide a larger financial benefit and pave the path towards a 100% renewable power goal by 2036.

Promotion of electric cooking stoves and LPG stoves as long-term solutions to achieving universal clean cooking access. The choice between electric cooking stoves and LPG stoves is dependent on a household's power supply capacity.

Implementation of this programme will cost the Government of Fiji US$2.4 million to US$3.4 million to achieve universal access to clean fuels and technologies for cooking by 2030.

A multisectoral approach should be taken to realise energy efficiency improvement potential. Ample energy saving opportunities can be found in the residential, commercial and transport sectors. Policies including the establishment of an appliance minimum energy performance standard (MEPS) and a labelling scheme as well as the codification of building codes need to be considered in order to leverage the energy reduction potential while providing positive financial gains.

Transport sector energy efficiency measures are the key to achieving substantial energy savings and emissions reduction. The transport sector has the highest share of energy demand, largely relying on imported oil products. Progressive transport policies, including minimum fuel economy standards and measures to rapidly increase the share of hybrid vehicles, needs to be considered in order to reach the SDG energy efficiency and NDC conditional targets, while enhancing energy independence. Policies to facilitate the significant reduction of emissions from maritime transport are also needed.

Opportunities and Challenges for Hydrogen Energy

Most Pacific islands, including Fiji, depend heavily on transportation (land and sea) to move both cargo and people. It is very important to consider hydrogen energy for the future because it is clean, can be produced locally, and can have zero emissions. Fiji's transport sector consumes the highest quantity of mineral fuels, effectively making it the most pollutant sector in-terms of CO2 emissions to the environment. Fiji and the pacific islands do not have appropriate infrastructure to accept the introduction of hydrogen energy. It's a very new subject to talk about and more awareness is needed for public acceptance in terms of its advantages in achieving zero emission targets. Fiji and any other islands in the Pacific will depend on oil companies (e.g., Total Energy, Mobil, Shell) to build the infrastructure, as a large scale of investment is required. Such developments would be similar to companies' current arrangements for the supply of mineral fuels. Fiji's government can consider ways to provide an enabling environment for stakeholder (e.g., oil companies) investment in hydrogen energy and infrastructure through policy support and incentives.

Evidence-based options and actionable next steps

Based on the challenges, goals, and policy directions described above, Fiji's government aims to expand and diversify domestic renewable energy production and improve energy intensity indicators, while providing its people with accessible electricity, clean cooking options, and adequate transportation. Actionable next steps required to achieve this include:

1. Ensure universal access to affordable, reliable and modern energy services.
2. Substantially increase the share of renewable energy in the global energy mix.
3. Reduce carbon emissions in Fiji by 30% by 2030 by establishing a 100% renewable power sector and implementing economy-wide energy efficiency measures.
4. Reduce reliance on fossil fuel importation by diversifying forms of domestic power generation within Fiji.
5. Implement programs to provide Fiji citizens with electric and LPG cookstoves.
6. Utilize policies and incentives that create an enabling environment for stakeholders (e.g., oil companies) to invest in energy infrastructure for new technologies.
7. Utilize minimum fuel economy standards and measures that can rapidly increase the share of hybrid vehicles in Fiji.
8. Develop policies that significantly reduce emissions from maritime transport.
9. Implement options (e.g., minimum energy performance standard (MEPS), labelling schemes, building codes) that can also provide positive financial gains.
10. Foster multi-sectoral approaches to transitions in Fiji energy systems.

*** A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP.*

Debate 7 Summary

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. Inia Saula (see position paper above and author biographical information in the Appendix). Mr. Saula was unable to attend the scheduled debate of his position paper. However, participants, including other authors, engaged in discussions regarding the views conveyed by Mr. Saula's position paper throughout the 45-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. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Saula, 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.

Fiji is an archipelago in the South Pacific comprising about 300 islands of which 110 are inhabited. It was noted that 55% of Fiji's total energy is produced via hydropower. The remaining energy needs are obtained from tunnel generation, a source that is intended to be decreased. Fiji has committed to meet the goals set by the United Nations Sustainable Development Goal and the Paris Agreement by the year 2030. To increase the percentage use of renewable energy, it was broadly recognized that the biggest challenges were obtaining available land for use with renewable energy sources (i.e., wind and solar) and the funding required for installing the appropriate infrastructure. The funding options identified by numerous stakeholders for supporting renewable energy infrastructure, consistent with the limited availability of land found on island communities, uniformly relied on international partnerships focused on existing resources held by the respective island themselves (e.g., exclusive economic zones (EEZ)) These issues were discussed in detail.

Due to the scarcity of land for renewable energy production,using solar and wind on many islands such as Fiji, it was broadly understood that Fiji needs to explore other options that would increase its renewable energy generation without further land restrictions. Even for the land available for solar- and wind-based energy production, it was noted that effectively addressing traditional/customary land right issues (i.e., multiple claims to land ownership and/or usage) remain significant barriers to implementing renewable energy infrastructures. These land right challenges often involve competing claims from private companies, historically vested individuals or groups, and government entities. It was suggested by multiple stakeholders that utilizing floating or roof top solar would help minimize the impact of land restriction challenges and allow for the total renewable energy generation to increase. Fiji has signed an agreement with the International Finance Corporation to allocate megawatt solar on the grid as an approach to making solar a practical option. However, policies and regulations would need to be put in place to facilitate such an expansion of solar energy production to adjust to the amount of solar energy produced through private companies. Different stakeholders highlighted specific issues within lower income areas on islands regarding affordable solar rooftop options. The relevance of these issues for Fiji was used to illustrate the complexity of different approaches designed to overcome the challenges emerging from limited availability of land.

Since it was noted that achieving a functioning renewable energy system for Fiji may be especially reliant on the implementation of floating or rooftop solar energy production, it was suggested that utility companies using electricity offer a financial incentive for hosting rooftop solar panels on the homes of their customers. Currently, Fiji utilizes solar energy production for 200 MW of energy from the main island with 20 MW of energy utilized from secluded rooftop solar. It was strongly asserted that Fiji would need to incorporate storage infrastructure on its islands due to the production of excess energy that would be obtained from the introduction of new floating and/or rooftop solar. Furthermore, it was stated that utilizing the high potential of floating and/or rooftop solar energy production would offer the possibility of using pump hydroelectric systems, options for which there are currently many opportunities on the islands of Fiji.

Throughout the debate, the implementation and production of hydrogen energy was repeatedly discussed as potentially one of the main renewable energy generation sources on the islands of Fiji. As solar energy is currently the main renewable energy source being explored in Fiji, several stakeholders suggested utilizing solar energy to convert hydrogen gas to liquid fuel hydrogen would significantly improve marine and/or vehicle travel. There were also suggestions that hydrogen-based energy could be used for cooking fuel or heating water.

Separately, a detailed discussion ensued concerning the benefits for Fiji to explore opportunities to use its accessible geothermal energy to produce hydrogen-based energy. Among the significant challenges of using geothermal energy are the initial investments in geothermal exploration throughout a wide geographical region. The related challenges of efficiently distributing the resultant energy from the sites of production to specific communities is an equally difficult task. The absence of sufficient funding was identified as the main obstacle to conducting this effort in Fiji. It was stated that Fiji could increase infrastructure funding by selling renewable energy generation systems and utilizing battery energy storage that supports the subsequent implementation of infrastructure needed to expand its renewable energy generation on more Fijian islands.

Economic Viability Considerations for Green Hydrogen in New Zealand**

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Summary

Green hydrogen (produced via electrolysis from renewable electricity) is proposed for use in various applications. Green hydrogen production costs need to fall significantly for it to become an economic alternative to fossil fuels or competing clean energy technologies.

This paper proposes that if hydrogen demand emerges in New Zealand, the development of hydrogen production infrastructure will depend on three key factors: (i) availability of low-cost and high-capacity factor renewable electricity, (ii) level of demand that justifies scale production, and (iii) sunk infrastructure that permits adaptation for hydrogen, imports, and distribution.

New Zealand is a useful test case to consider the economic viability of hydrogen production and use. New Zealand has a high level of development and good quality road infrastructure. It has a high urbanisation but low population density with large distances between towns. These are favourable conditions for hydrogen-powered heavy vehicles compared to battery electric. New Zealand also has good hydro, wind, and geothermal renewable sources and moderate solar resources. Coupled with good electricity infrastructure, this means New Zealand could be a low-cost production centre. If global trade in hydrogen emerges, and other countries are lower-cost, New Zealand ports could adapt to import the fuel.

Current realities

Hydrogen produced via electrolysis from renewable electricity (i.e., green hydrogen) is an alternative to fossil fuels. It does not have widespread use as an energy source in the Pacific region, other than in subsidized pilot projects in New Zealand and Australia. Green hydrogen currently has significantly higher production costs than hydrogen produced from fossil fuels (i.e., so-called “blue” or “brown” hydrogen). Nevertheless, multinational technology firms, investors, and governments are betting on the fuel becoming an economic clean energy alternative for some uses. This is because of forecast lower cost electricity, reductions in electrolyzer capital costs, and improvements in electrolysis technology.

The use cases for green hydrogen fall into three broad categories: (i) transportation, (ii) electricity system services (ESS), and (iii) heating/industrial applications. For New Zealand, the key possible uses are transportation and ESS, because except for one steel mill, New Zealand mostly lacks the heavy industry of Europe, North America, and Asia where hydrogen is proposed as a decarbonisation option for industry.

Scientifically and technologically credible approaches and challenges

Demand for hydrogen in New Zealand will determine the level of supply. The cost of hydrogen production depends on scale and access to low-cost , high-capacity electricity. Depending on how transportation costs evolve, importing the fuel rather than domestic production may be justified.

Demand in New Zealand is most certain in transport applications where the key advantage of hydrogen compared to battery electric energy is the high energy-to-weight ratio (i.e., energy storage density). It is a better option for heavy transportation uses such as large freight loads, specialty industrial or logistics vehicles, and for some buses. Significant use of hydrogen is more likely in New Zealand due to large distances between cities, primary production locations, and ports and where heavy vehicle transportation is estimated to use 5,505 tonnes per annum by 2030, 122,286 tonnes by 2040, and overall comprise 0.11% and 2.64% of the total energy demand in those respective years. However, this also depends on prices of substitute fuels and technologies such as biodiesel and battery electric technology. Hydrogen could emerge as a viable energy source for shipping or aviation, depending on the emergence of alternative fuels and development of technology. These latter options may be some time away.

In ESS, stored hydrogen and fuel cell generation could be a clean approach to firming variable renewable generation, especially for intra-day firming or longer time-scales. However, the costs of alternative technologies appear lower at this stage. These include small- and large-scale batteries, generators fuelled by biofuels, or pumped hydropower at grid-scale.

The future viability of green hydrogen use depends on hydrogen production costs and the costs of transporting hydrogen to the point of use. Currently, green hydrogen production is cheaper at scale. Production via electrolysis plants above 100 megawatt (MW) capacity maximizes economies of scale. While most forecasts expect hydrogen electrolysis costs to fall over time, the benefits of scale are unlikely to change significantly. Further, low-cost electricity is critical to overall production costs. A 20% fall in electricity costs leads to an estimated US$0.40 drop in total hydrogen cost per kilogram. Maximizing the usage of the electrolyzer also lowers overall production costs significantly. This means that renewable energy generation plants with higher capacity factors will tend to lower total hydrogen production costs. A 20% increase in capacity factor of the electrolyzer leads to an estimated US$0.15-US$0.20 drop in total hydrogen cost per kilogram, point illustrated in Figure 1.

These three key production cost components mean that certain other countries are likely to emerge as the lowest cost producers of hydrogen. The best solar resources are in North Africa, Southwest Africa, the Middle East, Australia, and northern Chile, according to the World Bank's ESMAP atlas. However, even in these countries, solar energy has an absolute maximum capacity factor of 45%. This means an electrolyzer powered exclusively by captive solar power could only run less than half the time. Therefore, hydrogen production in locations that have very low-cost, high-capacity solar, or can combine solar or wind energy and another firm source of renewable electricity, like hydro or geothermal, will tend to have the lowest production costs overall. New Zealand has a good combination of low-cost wind and hydro renewable energy, but there are competing demands for renewable electricity in the wider economy. Some locations have sunk electricity generation and transmission infrastructure and could have excess capacity in the future as current uses of the power depart the market. For instance, investors are currently evaluating New Zealand hydrogen production for export opportunities for a large-scale plant near an existing harbour with transmission infrastructure from a 600 MW hydroelectric plant that currently supplies an aluminium smelter. Furthermore, as the electricity generation system moves to meet the government's commitment to 100% renewable [1] by 2035, renewable resources may be overbuilt, resulting in very low marginal cost electricity at certain times.

Domestically produced hydrogen also needs to be transported to the point of use. Lower cost scale production can be negated if the trucking or pipeline distribution costs to the point of use exceed smaller scale distributed hydrogen production at the point of use. Since New Zealand is approaching 100% renewable electricity, it is possible that centralized, at-scale production of hydrogen can be located on the national electricity grid and near the point of major use (e.g., in urban areas). Because electricity transmission and distribution costs are far lower than hydrogen transport costs, the location of the plant becomes important.

Importing or domestic production?

Transporting hydrogen is complex and global trade is in its infancy. Significant technical challenges to regular compression or liquification remain and new infrastructure investment at ports is required. Modelling by Castalia suggests that loading and shipping costs comprise at least 15% to 20% of the total landed cost of hydrogen, provided both scale volumes are imported and existing port infrastructure is converted. Therefore, domestic production costs need to be at least within this 15% to 20% band of the world price in the long-term to justify domestic production.

New Zealand production costs will probably fall within the band, provided excess renewable power is available. In some locations, exports may even be possible. If New Zealand is ultimately not cost competitive, then it could accept imports at the existing large ports that can be easily converted. These are also located in or adjacent to major cities where the hydrogen will be used. For instance, major ports are all hubs for heavy transport vehicles, so imported hydrogen could immediately be consumed at the port.

Evidence-based options and actionable next steps

Green hydrogen production is a justifiable use of renewable electricity for heavy vehicle fuel and policy settings to enable and needs to be accelerated. Given uncertainty about hydrogen transportation options and global cost competitiveness, policy makers need to keep options open for local production. This could be centralised or localised, depending on where demand is located.

1. Identify and invest in sites with good access to low-cost power, electricity infrastructure, and proximity to ports to provide options for: (i) future production for export, and/or sale to heavy vehicle users, and (ii) potential for import terminal use if overseas producers are lower cost.
2. Focus New Zealand government policies on key niches, (e.g., technical development of hydrogen in aviation or marine transport), rather than trying to aim for lowest-cost global production.

References

[1] The government has committed to a 100 percent renewable electricity grid "in a normal hydrological year," recognising that in some years the hydro resources are not able to meet demand due to lack of rainfall, typically in winter.

** ***A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP.***

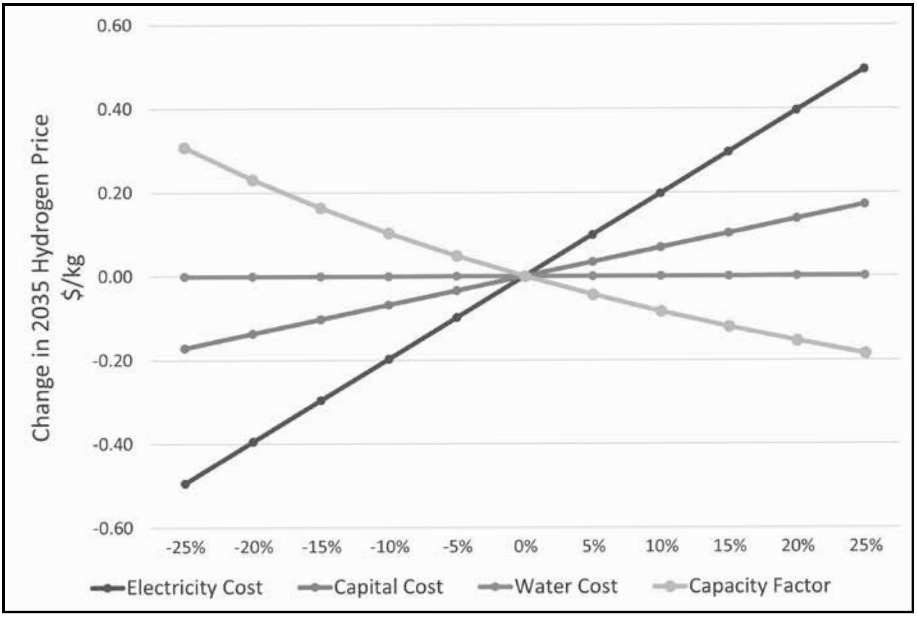

Figure 1. Sensitivity of hydrogen production costs at scale to changes in input costs

Debate 8 Summary

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. Andreas Heuser (see position paper above and author biographical information in the Appendix). Mr. Heuser 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 45-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. Heuser and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Heuser, 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.

A common theme that was carried throughout the debate was the emphasis of the unique position of New Zealand as a test case of the economic viability of hydrogen-based energy. It was posited that the robust renewable energy resources (e.g., wind, solar, hydropower, geothermal) that are available in New Zealand, as well as the current production of renewable electricity, could allow the nation to become a low-cost hydrogen energy production center.

The consideration of trade-offs between centralized and decentralized hydrogen-based energy production was contended by several stakeholders, and it was stated that this comparison is especially pertinent in New Zealand given its population distribution (i.e., densely populated urban areas and large distances between cities). Centralized, large-scale hydrogen-based energy production as an export-only opportunity due to its lower production cost was generally supported, but it was recognized that significant distribution costs would accompany isolated production. Decentralized hydrogen-based energy production was supported by several stakeholders due to the reduction of transportation cost and availability to end users. It was additionally noted that decentralized production rested on the underlying assumption that grid electricity would be used, given that New Zealand is moving towards a 100% renewable energy grid.

In regard to the viability of hydrogen energy in small island communities, it was suggested the importance of captive energy sources (e.g., power generation companies) producing hydrogen-based energy. It was strongly suggested that entities that are producing energy and controlling their own electricity prices need to be carefully considered to be hydrogen-based energy producers. A stakeholder asserted that this model is applicable to the geothermal energy potential in New Zealand and geothermal plants could act as baseload power for green hydrogen-based energy production. New Zealand is purportedly developing a business model based on "demand-response" for producing hydrogen-based energy via geothermal energy, the production of which would be curtailed when demand for electricity on the grid is high.

As there are many possible sectoral applications of hydrogen-based energy, there was a focus on vehicular applications in New Zealand. When considering light-duty vehicular and transit applications (e.g., passenger vehicles, transit buses) versus heavy-duty (e.g., long-haul trucking) applications, there was a general consensus on greater emissions reduction and economic viability for heavy-duty applications, although positive cases were posited for both. It was asserted that for development of light-duty applications of hydrogen-based energy, electrification of the transportation sector would require major grid expansion at enormous financial cost, an infrastructure program that needs to be coupled with a significant increase in demand for hydrogen-fueled vehicles. It was suggested that hydrogen powered transit buses could provide a solution to night time peak loads, when renewable power generation (e.g., solar, wind) may be at lower output levels. The behavioral switch from fueling a transit bus with diesel to fueling it with hydrogen is likely associated with less need for public re-education than that associated with battery-related changes in vehicular applications of hydrogen fuel.

Despite concerns specifically related to light-duty vehicular applications of hydrogen fuel, there was a general consensus that heavy-duty, long-haul applications could provide an avenue of decarbonisation and pollution reduction. According to the Ministry of Transport, approximately 27% of New Zealand's fossil fuel use in the transportation sector comes from heavy-duty, long-haul applications. It was strongly suggested that when considering a transition to the hydrogen-based energy economy, efficiency must remain the strategic focus. Trucking operations in the ports of California were given as an example and it was stated that 1 kg of hydrogen fuel displaces approximately 2.5 gallons of diesel fuel when in transit in these areas. It was then posited that weighing this lower operational cost with the higher capital cost of using hydrogen fuel in place of diesel fuel needs to be an important focus moving forward in the energy transition of vehicular applications.

Heavy-duty transportation vehicles generally exist in fleets, controlled by central entities, and involve travel between multiple hubs in a specific region. Several stakeholders suggested that these existing fleets of heavy-duty vehicles leaving from and returning to central hubs could act as an entry point for introducing hydrogen-based energy technology. A trash collection system in Hawai'i was given as an example of an existing hub network with centrally controlled truck fleets, all of which visit different locations in the region, but return to one central hub. It was posited that the creation of centralized refueling stations at fixed-traffic hubs (i.e., waste management centers, truck depots, ports) could potentially reduce the cost of hydrogen fuel distribution. Furthermore, it was strongly suggested that having these centralized refueling hubs positioned at major ports would foster a platform for global trade of hydrogen-based energy by allowing imported hydrogen energy to be directly available to the consumer. It was additionally suggested that these centralized production hubs positioned at ports could provide an opportunity for renewable ammonia production and exportation.

How Our Ocean Can Save Our Planet **

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Summary

The conventional wisdom is that the fight against climate change will be won or lost in the Asia-Pacific. This conventional wisdom suffers from "sea blindness" as the real opportunity lies within the "big ocean states." The fundamental areas of opportunity for climate action are the Exclusive Economic Zones (EEZ) of the Indo-Pacific countries.

Current realities

The renewable resources on earth far exceed those of fossil fuels (i.e., coal, oil, and natural gas (CONG)), which themselves were formed over geologic times from a combination of solar energy, biomass, and geothermal energy. The CONG are energy carriers but are commonly referred to as "primary fuels." The solar radiation received on the earth exceeds total annual global energy consumption by a factor of greater than 5,000, which is complemented by biomass, geothermal, hydropower, ocean energy, and wind (Abbott, 2010). The abundance of clean energy resources is overlooked systematically to the detriment of planetary and human health.

Effectively harnessing and utilizing renewable energy (RE) at the gigawatt (GW) and terawatt (TW) scale requires bulk energy storage as well as long-term time- and location-shifting of output energy for storage. Other than pumped hydropower storage, which is limited by the availability of environmentally and socially acceptable sites, no other economically viable and physically scalable energy solutions currently exist today except hydrogen. Hydrogen is emerging as a scalable and flexible alternative to other energy options, especially because it can be stored indefinitely. Using hydrogen to produce chemicals that can be transported in bulk, as is the case for CONG and refined petroleum products, can make it a versatile energy vector for decarbonization of hard-to-abate sectors.

The global hydrogen market today is about 100 million tons per year (Abbott, 2010) more than 95% of which is produced from fossil fuels (e.g., steam methane reformation (SMR) of natural gas). Almost all of this "grey" hydrogen is produced on-site for fertilizer production and petroleum refining operations and its cost of production is dependent upon natural gas prices which are set in regional markets rather than global markets. As of late February to early March 2022, the cost of grey hydrogen in Europe was estimated to be about $10/kg due to natural gas price increases. "Green" hydrogen production via electrolysis of water is possible with off-the-shelf technology at a current cost of around $5/kg.

Electrolyzers, which are inherently modular, provide critical opportunities for scalability. As factory mass production ramps up, unit costs will decline, resulting in a lower cost of production of hydrogen and oxygen. Achieving a cost of $2/kg for hydrogen production from electrolysis (Abbott, 2010) currently requires an electricity input cost of less than $0.02/kilowatt-hour (kWh). Hydrogen production from solar and other RE will be constrained by the willingness to pay premiums until sufficient scale drives the cost down to the $2/kg tipping point.

Governments can facilitate market evolution through regulatory requirements such as advanced market commitments (AMCs) wherein specific industries would be required to buy green hydrogen at market prices; however, regulated industries can be expected to demand price support for an interim period until price parity is achieved ($2/kg). Experience from other RE programs (e.g., solar and biofuels) can inform policymaking and roadmaps for hydrogen markets.

Several well-established business models can inform green hydrogen development, inter alia: (i) the current government practice of issuing deep-sea fishing licenses to foreign fleets through which governments make space available in their EEZ, for a fee, and limit the amount that can be taken on an annual basis, (ii) existing offshore oil and gas development models wherein governments make space available in their EEZ, for a fee, and production is not guaranteed, so development risk is borne almost exclusively by oil and gas operating companies, (iii) traditional LNG export project models that are anchored by long-term offtake agreements with a price formula linked to crude oil prices (i.e., compared to a traditional RE power purchase agreement, which has a fixed price per kilowatt-hour), and (iv) the model of the solar parks program, pioneered in India and replicated in many other developing countries which has been very successful in mobilizing GW-scale investment. The India program was based on the philosophy of "go big and go fast" to create a virtuous cycle of cost reductions as deployment scaled up.

Scientifically and technologically credible approaches and challenges

Early experience in Europe (particularly the North Sea) indicates that GW-scale green hydrogen development is possible without piloting at kW and MW scales if the following conditions are present: (i) a transparent and predictable regulatory framework is in place to enable program development and investments, (ii) governments facilitate GW-scale site availability based on prior experience in the offshore petroleum and offshore wind industries, and (iii) hydrogen customers are in proximity to the production centers. The North Sea hydrogen development also suggests that the traditional petroleum industry sees a pathway to corporate transformation and reinvention in the hydrogen business, but only if GW-scale development opportunities are available for investment.

The presence of renewable resources everywhere is an inherently democratic phenomenon, and commercializing RE to Hydrogen using "Power to X" business models implies that the traditional fossil fuel business will be disintermediated and democratized.

The New Ocean Economy (NOE) is shorthand for a broad spectrum of activities to monetize the value of marine natural capital and build a twenty-first-century ocean economy. A key operating principle of the NOE is that "developing" country governments will lead development by maximizing the use of local entrepreneurship, brainpower, and natural capital, and engage with external partners as necessary to conduct research and development for commercialization, scale-up and eventual export of new products made from renewable resources. Using the principle of carried embedded equity, governments can make regulatory and physical space available in the EEZ in exchange for owning a share of any new proprietary technologies and intellectual property developed via NOE activities. The countries of the Pacific may have limited domestic financial resources but have access to multilateral development banks and multinational companies seeking to commercialize and scale up. Offshore solar and wind projects can be developed in the Pacific, but stand-alone monolithic projects developed around power purchase agreements will not facilitate NOE development. Since offshore wind is a mature industry, governments can lead a more ambitious program employing lessons learned from offshore oil and gas, offshore wind, LNG exports, and solar park development. The Asian Development Bank ADB and its development partners can assist governments in pursuing "power to X" with offshore RE, incorporating lessons learned from the U.S. rigs-to-reefs program to integrate the creation of natural capital into the offshore RE development. The potential for RE to Hydrogen in ADB developing member countries with EEZ is minimally five times greater than today's global hydrogen market: using 1% of the EEZ of these countries can generate 500 million tons of hydrogen per year (i.e., with a power density of 50 MW/km2, running at 16% capacity utilization factor, converted at 50 MWh electricity per ton of hydrogen). At the target price of $2/kg, this could be a $1 trillion/year industry.

The most critical step for green hydrogen production in the Pacific is for governments to make space available in their EEZ for development. The next step is to identify buyers, primarily in developed countries, to secure long-term, offtake agreements at an agreed price formula. The ADB has been working on such a technical assistance (TA) project for Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services (MARES). The TA is exploring the linkages between four related areas: (i) marine energy (offshore solar, wind, tidal energy, etc.), coupled with the production of hydrogen and other value-added products (power to X), (ii) cultivated reefs, (iii) restoration of ocean health through regenerative aquaculture, and (iv) ecotourism. The opportunities for the creation of both economic and natural capital are significant and have been demonstrated in locations in Hawai'i and the Shetland Islands. MARES is predicated on the abundance of offshore RE resources which are difficult to monetize via projects constructed around electric power purchase agreements.

Evidence-based options and actionable next steps

The international landscape for energy and biosphere regeneration has changed markedly since February 2022. Energy prices are responding to the uncertainty of carbon markets and international security volatility. Crude oil prices can be expected to remain volatile and natural gas prices can be expected to remain elevated for the foreseeable future. The MARES activities of ADB are providing a knowledge base and planning tools for "big ocean states" to effectively use their EEZ to produce RE with demonstrated technology.

National governments, ADB, and other development partners can help Pacific countries with the following specific steps:

1. Lead the development of investment programs with firm government commitments to use a small fraction of the EEZ for MARES operations.
2. Provide offshore resource analyses and mapping.
3. Develop marine spatial planning for the identification of areas for development (i.e., project identification).
4. Provide technical assistance for deal structuring including securing long-term offtake commitments from buyers to anchor project financing.
5. Tender projects to crowd in commercial investment.
6. Expand financial assistance for investment and implementation, including carbon finance and possibly the creation of tradable natural capital credits.

References

[1] Abbott, D. 2010. Keeping the Energy Debate Clean: How Do We Supply the World's Energy Needs? *Proceedings of the IEEE*.

***** A position paper prepared for presentation at the Institute on Science for Global Policy (ISGP) conference on Island Community Priorities (ICP) within the Global Pathways to Hydrogen Energy Futures (GPHEF) program, organized and convened by the ISGP***

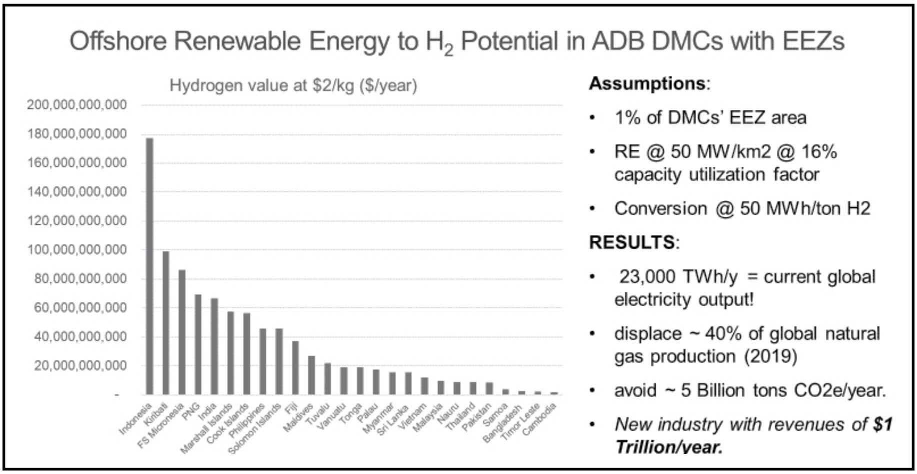

Figure 1. Marine solar to hydrogen potential in developing Asia and the Pacific

Debate 9 Summary

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. Dan Millison (see position paper above and author biographical information in the Appendix). Mr. Millison 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 45-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. Millison and participants. Given the not-for-attribution format of the debate, the views comprising this summary do not necessarily represent the views of Mr. Millison, 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 explored the opportunities and challenges of utilizing the EEZs of island nations to produce green hydrogen. It was broadly recognized that the most effective way to achieve a least-cost scenario for hydrogen production would be to commit to scaling (e.g., large-scale solar panel projects in India and Cambodia, and the North Sea where gigawatt-scale offshore wind is being converted to hydrogen and sold in existing markets). Developing offshore renewable energy projects was also considered to be an opportunity for island nations to establish more control over their EEZs. Stakeholders noted that island nations often have expansive EEZs, particularly in comparison to their landmass, where various renewable energy sources can be accessed. It was suggested that infrastructure used for offshore renewable projects (e.g., offshore wind, offshore solar, ocean thermal energy conversion) could also be coupled with monitoring and surveillance equipment (e.g., drones, microsatellites) that will allow island nations to better regulate the remote areas of their EEZs.

The traditional liquefied natural gas (LNG) export business was offered as a parallel for understanding the potential of offshore renewable energy generation, as the untapped potential of offshore renewable energy resources was suggested to be analogous to "stranded" gas fields. Additionally, some important differences were noted, including that: offshore renewable energy resources (i) do not require any drilling, (ii) do not produce spills or blowouts, and (iii) do not deplete reserves, unlike a natural gas field. It was asserted that when paired with regenerative aquaculture, offshore renewable energy infrastructure can contribute to the direct sequestration of carbon, much in the same way that mangroves naturally sequester carbon. It was noted that the limitations of coastline length and access to the intertidal zone indicate that mangroves alone cannot sequester carbon dioxide from seawater at the scale deemed necessary by the Intergovernmental Panel on Climate Change. It was argued that offshore infrastructure projects could simultaneously contribute to this carbon sequestration. Power purchase agreement structures were argued to be ineffective funding mechanisms for anchoring, structuring, and financing offshore renewable energy projects at the scale required to successfully avert global carbon emissions tipping points. Rather, it was advised that Small Island Developing States can lease portions of their EEZ space to private sector renewable energy producers to sell the converted hydrogen into existing markets, similarly to some existing practices for international fishing licenses.

Particular attention was given to how United Nations (UN) Sustainable Development Goal 14 would be addressed through offshore renewable energy infrastructure. It was noted that conventional pollution is compromising the ocean ecosystem's ability to absorb carbon dioxide emissions going into the atmosphere. Stakeholders also emphasized that the shortage of oxygen in our atmosphere is a serious problem that needs to be addressed, as approximately half of our atmospheric oxygen comes from the ocean.

Stakeholders identified the facilitation of trading in carbon credits as an important mechanism to help reduce the capital costs associated with developing offshore renewable resources, particularly for developing island nations. Governments were identified as having a key role in structuring these initial offshore renewable energy projects, but eventually, assets/responsibilities could be auctioned off to responsible private sector companies, similar to a reverse Build-Operate-Transfer (BOT) project. With respect to financial additionality, it was suggested that the wholesale cost of energy production with diesel, based on current crude oil prices, was estimated at $0.60-$0.70/KWh, while gigawatt-scale solar projects facilitated by the ADB in Tonga and Cambodia reportedly yielded offtake prices of $0.11/KWh and $0.038/KWh, respectively. Consequently, it was posited that justifying financial additionality or concessional financing would be extremely difficult, assuming the identified pricing scenarios. Nevertheless, if calcium carbonate growth was promoted on the metal substrates composing offshore renewable infrastructure, it was claimed that an estimated 0.44 tons of carbon dioxide could be sequestered. Crucially, however, carbon market experts reportedly have not yet provided a real-world estimate for how much that amount of carbon dioxide would be worth in a carbon finance market. Stakeholders recommended that the creation of a new, tradable credit based on "natural capital" rather than a carbon credit, would be most effective. While criticisms that Reduce Emissions From Deforestation and Forest Degradation" (REDD+) became a fount of phantom carbon credits were noted, it was suggested that REDD+ is a "natural capital" program that can serve as a model for carbon sequestration on offshore infrastructure. It was argued that the natural capital generated from the calcium carbonate on offshore infrastructure could be developed as a credit for blue carbon systems.

All of the projections in the debated paper were made assuming 1% of EEZ area usage and gross revenues. It was estimated that seaweed production could be sold at $250/ton, understanding that some developing countries produced it at approximately $15/ton or less. It was suggested that even with figures in gross revenue, such seaweed production would be an extremely profitable enterprise and provide a second stream of revenue for offshore energy projects. The projections also assume a $2/kg revenue for hydrogen, which was claimed to require electricity input costs of $0.02/KWh or less. Stakeholders recognized that the initial projects will not likely receive electricity input costs at $0.02/KWh, but suggested that this price could be realistically achieved, once the project scale reaches 1,000 MW of renewable energy.

Throughout the debate, stakeholders further inquired how the revenue figures in the paper were calculated. It was posited that a megawatt of solar installed anywhere between the Tropic of Cancer and the Tropic of Capricorn would produce approximately 1,400 MWh/yr. The cases of the Maldives, Jamaica, and Tonga were offered as examples of islands that would fall under that criteria. For renewable wind resources, it was hypothesized that if the wind speed was estimated at more than 6 meters/second, a megawatt would produce energy eight hours a day for 350 days a year, assuming real-world conditions. If Ocean Thermal Energy Conversion (OTEC) were to be used in specific sites, it was posited that a typical geothermal power plant with high-temperature steam would be a reasonable comparison for OTEC and that a megawatt of geothermal could yield 7,000 – 8,000 Megawatt hours per year.

Workforce development was a common topic of concern for stakeholders. It was defended that the current human capacity and human resources that exist on island communities globally would be sufficient to undertake most aspects of the theoretical offshore renewable energy projects. The specific example of growing reefs using an electrolytic mineral accretion system was asserted to be possible with unskilled and semiskilled labor, citing completed projects using local labor in both Indonesia and the Philippines. The design and construction of solar and wind farms were recognized as a component that (i) required more skilled labor than the regenerative marine aquaculture features and (ii) was more labor intensive. The clean energy industry in the U.S. was cited as an example of substantial job creation, as the renewable energy sector in the U.S. has reportedly outgrown the non-renewable energy sector, in terms of job growth. Stakeholders emphasized that job growth is inherent in the energy transition, but could be significantly greater if the full potential of the EEZs are realized. Understanding that marine life will grow on offshore renewable infrastructure, it was agreed that the opportunities offered by regenerative marine aquaculture could provide quality employment with high compensation for semiskilled and unskilled labor.

The historical case of the island of Nauru was proffered as a pertinent example of how the absence of an equitable revenue-sharing arrangement can lead to an unequal distribution of economic gains from natural resource development. This example was given importance, as the key decision-making power of central governments was argued to be increasingly important for infrastructure built far from shorelines. It was emphasized that this must not exclude traditional landowners and that governments are responsible for ensuring that (i) traditional landowners and ownership are respected and (ii) the economic rewards of offshore renewable energy resources are equitably distributed. The latter point was specifically underscored based on the suggestion that the added value of converting hydrogen to ammonia or methanol for sale into existing international supply chains (e.g., growing seaweed, seafood production) could potentially create a $1 trillion/year industry in the Pacific. It was added that this estimate only includes smaller Pacific islands, reaching a total population of approximately 10 million people. Of the larger countries examined, it was noted that Indonesia has the largest EEZ and therefore holds great potential for offshore renewable energy resources. Additionally, Indonesia has an active rigs-to-reef program off the coast of East Kalimantan, where two to three production platforms will be left in the water as reefs. This was cited as a notable opportunity for Indonesia to expand these projects, particularly since these areas are important scuba diving destinations.

Stakeholders also discussed whether offshore nuclear energy would be a profitable and feasible project. It was suggested that nuclear power generation within vessels for maritime propulsion may be an opportunity, as the price of onshore nuclear energy is not currently competitive with onshore solar energy. Rather, it was posited that the International Maritime Organization (IMO) regulations for cleaner shipping have paved the way for nuclear-powered marine vessels. It was emphasized that, based on fuel prices for common marine transportation fuels (e.g., heavy fuel oil, low sulfur, diesel), nuclear propulsion would be competing with the energy price of approximately $0.60-$0.70/KWh, rather than the $0.05/KW price of onshore solar electricity generation. Furthermore, because IMO regulations are mandatory, as opposed to UN Framework Convention on Climate Change regulations, stakeholders agreed that they will be much more effective at achieving real-world solutions to energy transitions.

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 Global Pathways for Hydrogen Energy Futures (GPHEF) program. Funding from the Hawai'i Natural Energy Institute at the University of Hawai'i, Manoa, Hawai'i Electric, Hawai'i Electric Industries, HEI Charitable Foundation, Hawai'i Gas, and the Ulupono Initiative was used in conjunction with ISGP resources to organize and convene the ISGP-GPHEF conference, Island Community Priorities (ICP). The conference was conducted on an internet format June 23-26, 2022, from Skaneateles, New York. Other contributions aided the ISGP in preparing the material presented in this report, including the nine position papers prepared by invited subject-matter experts and the related not-for-attribution summaries of the views presented in the discussions, critical debates, and caucuses that ensued.

The ISGP greatly appreciates the willingness of the more than 280 individuals in the scientific, governmental, public advocacy, and private sector communities who agreed to be interviewed by the ISGP staff as they prepared and organized the content of this GPHEF-ICP conference. Of special significance were the efforts of those invited by the ISGP to present their views concerning the energy needs and priorities of island communities throughout the Asia Pacific region as well as the scientific and economic options for using hydrogen-based energy. Their willingness to engage regulators, policy makers, scientists, and private sector stakeholders in the vigorous debates and caucuses that comprise all ISGP conferences was especially noteworthy and appreciated. The biographies of the nine authors of the position papers used in the debates, and the not-for-attribution summaries of the respective debates are provided in this ISGP book.

The success of every ISGP conference critically depends on the active engagement of all invited participants in the often-intense debates and probing caucuses that 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 public and private sector policies that span regulatory, public messaging, and business decisions. The ISGP is greatly indebted to all participants.

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 focused on addressing many of the most important scientific, technological, and societal questions of our time. Their brief biographical backgrounds are presented in this book.

The energetic, highly professional interviewing and writing skills of the ISGP staff were essential to not only organizing and structuring the conference itself, but also to recording the often-diverse views and perspectives expressed in the critical debates and caucuses as the areas of consensus and actionable next steps. The biographies of the ISGP staff are provided in this report.

In general, ISGP receives financial support from U.S. government agencies and departments and from unrestricted gifts and donation from private-sector entities and philanthropic organizations and individuals. In the specific case of the GPHEF-ICP program and conference, in addition to the funding noted above, general financial support was provided to the ISGP by philanthropic donations from Mr. Edward and Ms. Jill Bessey, Dr. David Moran, Amb. Thomas Pickering, and Dr. George and Ms. Charlene Atkinson. The ISGP expresses its sincere appreciation to all these individuals.

Dr. George H. Atkinson
Founder and Executive Director
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July 3, 2022

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Bambang Brodjonegoro is the Lead Co-Chair of T20 Indonesia and the former Indonesian Minister of Finance (2014-2016). Following his role as Minister of Finance, he was also appointed Minister of National Development Planning (2016-2019) and Minister of Research and Technology/Head of National Research and Innovation Agency (2019 – 2021). Currently, Prof. Brodjonegoro is the President Commissioner/Independent Commissioner at several companies in Indonesia. Prof. Brodjonegoro also acts as the Head of the Economic Empowerment Agency, Indonesia Chamber of Commerce, and The Indonesia Forum Foundation. Prof. Brodjonegoro finished his Ph.D in Urban and Regional Planning form the University of Illinois, Urbana-Champaign, and has been actively teaching at the University of Indonesia.

PRESENTER: Jack Brouwer, Ph.D, Professor, Mechanical and Aerospace Engineering, Civil and Environmental Engineering, Chemical and Biomolecular Engineering, University of California, Irvine; Director: National Fuel Cell Research Center, Advanced Power and Energy Program

Jack Brouwer is an energy system dynamics expert with research interests in renewable energy systems; dynamic simulation and control; energy system thermodynamics, design, and integration; electrochemical conversion devices and systems such as fuel cells, electrolyzers and batteries; hydrogen production, storage and conversion systems; hydrogen transmission, distribution, and dispensing; and electrochemical reactions with concurrent heat, mass and momentum transfer. Prof. Brouwer obtained his M.S. and B.S. in Mechanical Engineering from University of California, Irvine, and his Ph.D. in Mechanical Engineering at the Massachusetts Institute of Technology (MIT).

CO-AUTHOR: Setitaia Chen, BEng, MIPENZ, Former CEO, Project Manager of the Outer Island Renewable Energy Project, Tonga Power Limited, Kingdom of Tonga

Setitaia Chen has been involved in the Power Utility Industry for more than 17 years having gained extensive experience in New Zealand before migrating back to Tonga in September 2012. Mr. Chen is Tonga Power Limited's former Chief Executive Officer having been the General Manager of Operations and Network Design & Planning Manager. He commenced his professional career working for Electrix NZ as a Transmission Line Engineer, leading into Project Management. His involvement with projects spans a wide range of applications including network upgrades, rehabilitation, restoration, solar and wind farms, and battery energy storage systems. Mr. Chen has a Bachelor of Engineering, Electrical and Electronics Engineering from the Auckland University of Technology.

PRESENTER, CO-AUTHOR: Talolakepa Fonua, Acting Manager-Strategic & Business Development Unit, Tonga Power Limited, Lakalakaimonu Multi-Utilities, Tonga

Talolakepa Fonua has worked in power generation on operations and maintenance of both diesel and renewable energy plants and has designed and constructed distribution network infrastructure to be more resilient and safe for end users. Mr. Fonua also implements engineering perspectives on network fault and operations. He has four years of experience developing new strategies and initiatives for Tonga Power Limited to achieve its transition to 70% and 100% renewable energy targets.

PRESENTER: Andreas Heuser, LL.M, LL.B, B.A., Managing Director, Castalia

Andreas Heuser is qualified in law and economics and is highly experienced in Asia-Pacific hydrogen projects and economic and financial projects in the energy sector. He is an expert on analyzing the impact of new energy technology in national and global markets. He is leading Castalia's project for Asian Infrastructure Development Bank to develop a hydrogen investment strategy for the bank. He is also leading Castalia's work to develop hydrogen scenarios for the New Zealand natural gas industry. He recently concluded a project for the New Zealand government to develop scenarios for hydrogen demand, supply, and infrastructure. This involves identifying barriers to hydrogen sector development, including regulation. Other hydrogen project experience includes commercial advisory to Ports of Auckland to develop New Zealand's first co-located hydrogen electrolysis and dispensing project. Mr. Heuser has considerable experience in market analysis studies for commercial clients. In 2021 he developed a modeling tool for New Zealand's largest fuel company, forecasting fuel demand and electric vehicle (EV) uptake to show the emissions impacts. This informed its financial planning, stock market investor relations communications, investment decisions, and long-term strategy in response to Climate Change Commission and government policies.

PRESENTER: Simona Kilei, B.Sc., Director, Department of Energy, Government of Tuvalu

Simona Kilei has been with the Department of Energy in the Government of Tuvalu for three years and is leading the national transition to renewable energy.

PRESENTER: Dan Millison, M.S., B.A., Consultant, Sustainable Development and Climate Change Department, Asian Development Bank; Manager, Transcendergy, LLC

Dan Millison is the Manager of Transcendergy L.L.C., a private consultancy established in 2008. He has 35+ years professional experience, including 20+ years working on sustainable infrastructure investment programs. As a consultant and former project officer with Asian Development Bank (ADB), he helped mobilize well over $10 billion USD in investments, including more than $1 Billion in co-financing from the Clean Technology Fund, Scaling up Renewable Energy Program, and the Green Climate Fund, in clean energy, sustainable transport, and other climate friendly technology. Mr. Millison is currently supporting ADB's programs for innovative, high impact technology in energy sector and climate change operations as well as the technical assistance program for Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services (MARES). He has an undergraduate degree in Geological Sciences and a master's degree in Civil Engineering, both from Northwestern University in the U.S.

CO-AUTHOR: Issa Moffett, M.S., Zero Emissions Specialist, County of Hawai'i, Department of Research and Development (R&D)

Issa Moffett is a passionate Transportation-Energy Geographer. They has worked two AmeriCorps VISTA terms as a Renewable Energy Coordinator for the County of Hawai'i for electrification of transportation, increasing efficiency of building systems, and broadband/digital equity. Previously, Moffett's professional experience has been centered on the public health sector, connecting communities with Safe Routes to School with the Health Planning Council of Northeast Florida as well as social-justice planning for equitable walking, biking, and transit-oriented communities for municipalities.

PRESENTER, CO-AUTHOR: Riley Saito, B.B.A., Energy Specialist, County of Hawai'i

Riley Saito has worked with the County of Hawai'i, Research and Development Department as the Energy Specialist for close to four years and has served the department as Deputy Director. His projects are focused on reducing importation of fossil fuel as an energy source and replacing it with on-island generation of green hydrogen. This work leads with diversity, equity and inclusion while advancing the quality of life for the community. Following graduation from the University of Hawai'i at Manoa with a business degree from the School of Travel Industry Management, Mr. Saito's tourism management career spanned 16 years with Hyatt Hotels. In 1994, he worked his way up to Vice President and Corporate Controller over 10 years with Mauna Lani Resort and spearheaded the first commercially financed photovoltaic (PV) system in 1998. By 2003, the resort had approximately 1 megawatt of PV systems in operation. In 2004, he joined SunPower Corporation and worked for over a decade to shape Hawai'i's clean energy future through legislative action, policy, and business development initiatives. He started a renewable energy consulting business before joining the County.

PRESENTER: Nick Sallman, Head of Strategy, Hydro Tasmania

Nick Sallmann has more than 15 years of experience in tracking Australia's key economic drivers and forecasting impacts across multiple industry sectors. He currently is Head of Strategy & Commercial Development at Hydro Tasmania and has been concentrating on the energy sector for the last five years, with a focus on ensuring the most effective and efficient transition to a total renewable energy across Australia. Mr. Sallmann has been guiding Hydro Tasmania's engagement with new and emerging technologies as the State of Tasmania embarks on continued state-wide development that meets a certifiably green energy supply. Before beginning a career in economic analysis spanning finance, telecommunications, and new technologies, Mr. Sallmann received a bachelor's degree from Monash University in Economics and Business Law.

AUTHOR: Inia D. Saula, Energy Officer, Secretariat of Pacific Community (SPC), Nabua, Suva, Fiji

Inia Saula has worked with Fiji Bureau of Statistics (FBS) for the Household Income and Expenditure Survey and was also involved in digitizing census boundaries in Fiji. He joined the Fiji Land Information System (FLIS) as the Computer System Administrator working on the freehold and state land in Fiji. In addition, Mr. Saula joined the Fiji Department of Energy where he managed the Renewable Energy

Development Programme (REDP). He has over 16 years of work experience in energy statistics, solar mini-grid installation, biogas programs, installation of wind, tidal, solar and hydropower monitoring stations and management of the Energy Conservation and Efficiency (ECE) Programme. Currently, Mr. Saula is the Energy Officer for the Secretariat of Pacific Community (SPC), and provides technical advice and manages the energy statistics data compilation and reporting for 22 members of Pacific Island Countries (PIC).

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. He 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 recently the 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

Dr. Tom 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 a number of 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). His most recent books are *Reducing Uncertainty: Intelligence Analysis and National Security(Stanford, 2011), The New Great Game: China and South and Central Asia in the Era of Reform*, editor (Stanford, 2016), *Uneasy Partnerships: China and Japan, the Koreas, and Russia in the Era of Reform,* editor(Stanford, 2017), and *Fateful Decisions: Choices that Will Shape China's Future*, edited with Jean C. Oi (Stanford, 2020).

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, Maryland, 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) 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, including important human and animal pathogens, 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. She also worked with the FBI and 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 Maryland Women's Hall of Fame. She is a member of the National Academy of Medicine, and in 2019, she became President-Elect of the American Association for the Advancement of Science (AAAS) and served as President from 2020 – 2021.

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 is currently serving 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 advises 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 is also Co-Chair of the Transatlantic Taskforce on Development with Gunilla Carlsson, the Swedish Minister for International Development Cooperation. He also is 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. 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 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 of 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.

Mr. 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 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 an 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. 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.

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, 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 also was 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

Dr. Mike Buch

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 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 H. Atkinson, Ph.D, Founder and Executive Director

The professional career of Dr. Atkinson spans several diverse arenas including academic responsibilities for teaching, scientific research, grant preparation, and administration within university communities, duties as the Founder and Chief Executive Officer of Innovative Laser Corp. that designed high sensitivity laser sensors for the semiconductor industry, and public service as a science and technology adviser within the U.S. government. His U.S. government activities crossed different agencies and departments and included service as the Science and Technology Adviser to the Secretaries of State Colin Powell and Condoleezza Rice. His recent efforts, facilitating the use of credible scientific understanding in the formulation and implementation of governmental, private sector, and societal policies worldwide, are reflected in his launching of the Institute on Science for Global Policy (ISGP). Dr. Atkinson is an Emeritus Professor of Chemistry, Biochemistry, and Optical Sciences at the University of Arizona. He has been recognized for his teaching (Outstanding Teacher at the University of Arizona; Distinguished Alumni Award, Indiana University; Honorary Doctorate and MacArthur Award, Eckerd College) and research (Senior Alexander Humboldt Award and Senior Fulbright Fellow, Germany; Senior SERC Awards at the Royal Institution of Great Britain and Oxford University, U.K; Lady Davis Professorships at Hebrew University and the Technion, Israel; Distinguished Visiting Professor, University of Tokyo, Japan; Distinguished Professor Award, University of California, Irvine). He was elected in 2014 President of the Sigma XI, The Scientific Research Society.

Euphemia Anderson, B.S., Senior Fellow

Ms. Anderson is a recent graduate of 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 interests for sustainable development and the intersection of science and business ignited during her internship with the Sustainable Economies Program at Manomet, a non-profit headquartered in Massachusetts, where she worked directly with businesses and communities on practices that enhanced their economic viability and quality of life 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 special interest in climate change mitigation, renewable energy, and small business sustainability.

Katie Durante, B.A., Senior Fellow
Ms. Durante is a recent graduate of Eckerd College, where she received a double B.A. in Biology, with a focus in Ecology, and Environmental Studies. Her interests in land management and environmental education stems from her internship at Boyd Hill, a nature preserve in Saint Petersburg, Florida. There she was able to effectively remove invasive species and become 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, B.S., Senior Fellow
Mr. Fitzpatrick recently graduated with Honors from Eckerd College, where he received a B.S. in Biology, as well as a second major in International Relations & Global Affairs. At Eckerd, he was a Ford Apprentice Scholar, and investigated the efficacy of intercropping in agriculture. He also worked as a cell biology research assistant, studying C. elegans as model genetic organisms for 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 hopes to become a biological researcher, using scientific communication to bridge the gap between research and policy. He takes special interest in the fields of food security and sustainability, global health, climate change, ecology, biodiversity, and genomics.

Adam Greco, Adjunct 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 original members and current Vice President of the Florida John Quincy Adams Society, the university's largest club dedicated to the exploration of International Relations as a field. Mr. Greco simultaneously has been the Undersecretary General for Crisis Committees with the University of Florida Model United Nations team, granting him the opportunity to attend conferences in locations such as Washington D.C. and San Francisco. Mr. Greco holds a special passion for developmental economics, geopolitical affairs, action against climate change, and sustainability.

Mattia Anfosso Lembo, Fellow
Mr. Mattia 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 fully 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, drought. Mr. Anfosso Lembo ultimately hopes to work at the United Nations in order 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. Mr. Anfosso Lembo is fluent in Italian, English and has a good working knowledge of French.

Jennifer Boice, M.B.A, Financial Manager
Ms. Boice worked for 25 years in the newspaper industry, 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 also was 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. She has worked with the Institute on Science for Global Policy since 2010 in a variety of positions.

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.

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:

- *Science and Governance: 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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