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1.0 Introduction

At the December 2013 Executive Committee (ExCo) Meeting of the Hydrogen Implementing Agreement (HIA) of the International Energy Agency, whose official name is the Implementing Agreement for a Programme of Research and Development on the Production and Utilization of Hydrogen, ExCo Members voted to extend the charter for a new five year term beginning 1 March 2015 and ending 28 February 2020.

Completion of a term provides a special opportunity to plan for the next five years in compliance with IEA requirements and for the benefit of the HIA. The HIA uses a formal strategic planning process to prepare its five year Strategic Plans. The process for the 2015-2020 had two main components: a Map the Gaps exercise that involved both Operating Agents and Executive Committee (ExCo) Members; and a day-long Strategic Planning session that was conducted at the fourth quarter 2013 ExCo Meeting. The outcomes of these activities coalesce in the HIA's 2015-2020 Strategic Plan.

2.0 Perspectives on the Current Situation

2.1 HIA View on Hydrogen, our Past Contributions and our Guiding Principles

The HIA has not wavered in its vision of a hydrogen future based on a clean, sustainable energy supply of global proportions that plays a key role in all sectors of the economy. The following principles guide the Agreement:

- Hydrogen—now mainly used as a feedstock for upgrading fossil-based energy carriers—will in the future increasingly become an energy carrier itself. It is necessary to carry out the analysis, studies, research, development and outreach that will facilitate a significant role for hydrogen in the future.
- Significant use of hydrogen will contribute to the reduction of energy-linked environmental impacts, including climate change due to anthropogenic carbon emissions, mobile source emissions such as CO, NOx, SOx, and NMHC (non-methane hydrocarbons), and particulate matter.
- Hydrogen has the potential for short-, medium- and long-term applications. The steps to realize the potential for applications in appropriate time frames must be understood and implemented.
- All sustainable energy sources require conversion from their original form. Conversion to electricity and/or hydrogen will constitute two prominent and complementary options in the future.
- Hydrogen can assist in the development of renewable and sustainable energy sources by providing an effective means of storage, distribution and conversion; moreover, hydrogen can broaden the role of renewables in the supply of clean fuels for transportation, heating, back-up power, portable power and combined heat and power (CHP) or cogeneration.
- Hydrogen is an energy carrier that can be produced as a storable, clean fuel from the world's sustainable non-fossil primary energy sources—solar energy, wind energy, hydropower, biomass, geothermal, nuclear, or tidal. Hydrogen also has the unique feature that it can upgrade biomass to common liquid and gaseous hydrocarbons, thus providing a flexible, sustainable fuel.
- Hydrogen can be used as a fuel for a wide variety of end-use applications including important uses in the transportation and utility sectors.
- All countries possess some form of sustainable primary energy sources; hence, hydrogen energy technologies offer an important potential alternative to fossil fuel energy supply (in many instances to imported fuels). Utilization of hydrogen technologies can contribute to energy security, diversity and flexibility.
- Barriers, both technical and non-technical, to the introduction of hydrogen are being reduced through advances in renewable energy technologies and hydrogen systems including progress in addressing hydrogen storage and safety codes & standards concerns.

- Hydrogen energy systems have potential value for locations where a conventional energy supply infrastructure does not exist. The development of hydrogen technologies in niche applications will result in improvements and cost reductions that will lead to broader application in the future.[1]

As of mid-2014, the HIA had originated a **broad portfolio of thirty-seven (37) tasks since its creation in 1977**. Of this number, **fourteen (14) tasks were approved during the 2009-2015 term**. During this term,19 tasks were active: 15 in collaborative R,D&D; 2 in Analysis and 2 in Hydrogen Awareness, Understanding and Acceptance.

As a task-shared Agreement, the **aggregate level of effort over the 2009-2015 term is estimated at 685 person years, conservatively valued at 10.3 Million USD in monetary terms**.

While our core business remains collaborative R,D&D, the call for analysis is stronger than ever. The creation of the first HIA Analysis task was one of the key outcomes of the preceding 2009-2015 term. Today, the HIA is proud to possess the capability and experience to mount a targeted response to analytic needs in hydrogen.

The need for outreach that informs, educates and engages policymakers, media and other target audiences has grown over the 2009-2015 term. The HIA has functioned to this demand to the greatest extent possible. With the prospect of deployment and commercialization of hydrogen technology, the need for outreach in the 2015-2020 term becomes even more compelling.

2.2 IEA Outlook

In the 2004-2009 term, the HIA began a concerted effort to make the case to the IEA Secretariat for including comprehensive analysis of hydrogen in IEA analysis activities. Liaison with the IEA was reinforced in the 2009-2015 term through the creation of a subtask to our Global Analysis Task.

In 2012, the International Energy Agency's (IEA) flagship publication, ***Energy Technology Perspectives 2012 (ETP2012) – Pathways to a Clean Energy System,*** for the first time dedicated a chapter to a far-reaching examination of hydrogen (H_2) use in the future global energy mix, ***concluding that hydrogen could play an important role in a low-carbon energy system***. The transportation sector is pivotal to realizing this outcome: deployment of hydrogen powered Fuel Cell Electric Vehicles (FCEVs) at the ETP 2012 2°C Scenario analysis levels could ***reduce CO_2 emissions significantly, helping to limit average global temperature increase to 2°C, the agreed UN target***. Without Hydrogen, concludes ETP 2012, it may not be possible to eliminate fossil fuel in transport and industry in the longer term, post 2050.

The IEA is now engaged in developing a Hydrogen Roadmap. It is one in a series of 21 G8 commissioned IEA technology roadmaps intended to provide guidance to stakeholders on the technology pathways needed to achieve energy security, economic growth and environmental goals. Roadmaps aim to advance adoption of key technologies resulting in a 50% reduction in energy-related CO_2 emissions by 2050. The IEA Hydrogen Roadmap embraces the ETP 2°C Scenario (2DS). This scenario envisions technology-driven transformation across all energy sectors that affords an 80% chance of limiting average global temperature increase to 2°C. To develop the roadmap, the IEA is holding a series of three regional workshops in Europe, North America and Asia. This approach has already revealed significant variation in regional conditions and policies, which is likely to impact uptake of hydrogen. By late summer 2014, the workshops will be complete.

It bears mention that the OECD, the IEA's parent organization, is keenly interested in the future of transport and related infrastructure. In 2013, the OECD's International Futures Program (IFP) independently held a workshop entitled *Developing Infrastructure for Alternative Transports Fuels and Power-trains to 2002/2030/2050*.

[1] The guiding principles are incorporated in the 2002 HIA Handbook of Policies and Procedures. While the handbook is not a legal document, it serves as an all-purpose reference document for the HIA.

Hydrogen infrastructure was a featured topic and several HIA representatives participated[2]. The workshop focused on economic risks and developing appropriate business models for system-wide change. The resulting report concluded that "innovation in vehicle and infrastructure technology needs to be matched by innovation in the design of business models and public sector intervention" across the value chain[3].

2.3 Geographic Outlook

Across the globe, government-industry partnerships and alliances are forming to create action plans for development of infrastructure and roll-out of fuel cell vehicles.

2.3.1 Asia

The major Asian car manufacturers (Toyota, Nissan, Honda and Hyundai) are gearing up for the coming FCEV market. Many are teaming up with other automakers around the world to collaborate on bringing FCEVs to markets around the world.

At the Los Angeles Auto Show in late 2013, Honda unveiled its sleek 5-passenger FCEV Concept, the successor to the FCX Clarity that launched in 2008. The next generation, the 2016 model year, will launch in 2015 and include a >300 mile driving range. Hyundai announced plans to deliver Tucson Fuel Cell SUVs to Enterprise Rent-A-Car. The vehicle will also be available in late spring 2014 at select Hyundai dealers in Southern California.

The Japan Hydrogen Fuel Cell Demonstration (JHFC) began in 2002. The JHFC is now approaching the end of its third phase. Beginning with phase 1, this productive program has tested many combinations of production, storage and siting approaches to refueling stations. JHFC 3 is demonstrating FCEVs and buses. It has also focused on: 70mpa filling technology; low-cost H_2 station technology; high frequency operations; and total system technology. Since mid-2013 commercial HRS models have been constructed at Kaminokura, Ebina Chuo and Toyota Ecofultown. METI has a new subsidy scheme for installation of HRSs that will be implemented in the next phase, along with NEDO's Project "Hydrogen Utilization Technology Development."

Since 2011, JHFC 3 has been administered by the Research Association of Hydrogen Supply/Utilization Technology (HySUT). HySUT was created in 2009 to commercialize the hydrogen supply business and FCVs by addressing technology issues and building social/consumer awareness. HySUT has 19 companies and organizations.

Tokyo Gas created the ENE-FARM, a micro CHP (combined heat and power) energy system that utilizes a 1 kW PEM fuel cell, to serve the residential building sector, providing heat electricity and hot water. Small Ene-Farm demonstrations began in 2003 and built up to larger demonstrations that installed some 3,000 systems. The commercialization phase began in 2009. Between April 2009 and March 2013, 49,813 systems were installed. As of March 2014, NEDO reported a total of 71,000 installed systems. The Ene-Farm micro CHP extracts hydrogen from the city gas supply to generate electricity via a fuel cell. Although the hydrogen source is not renewable, this micro application is especially significant because it is contributing to development of a renewable hydrogen PEM fuel cell market using natural gas as a bridge feedstock.

In Korea, the Ministry of Education, Science and Technology (MKE) is sponsoring a ten year (2006-2016) hydrogen and fuel cell program. The Fleet program, which ended in 2013, had two phases. As of January 2012, Korea had 13 hydrogen refueling stations in operation. The Hydrogen Station Roadmap in Korea forecasts 43 station in phase 2 (~2015) and 500 stations in phase 3 (~2030). Hyundai envisions a 5 step roadmap to

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[2] Stevens, B., & Schieb, P., *Developing Infrastructure for Alternative Transport Fuels and Power-trains to 2020/2030/2050.* (Paris: Organisation for Economic Co-operation and Development (OECD), 2013), 14.
[3] Stevens, B., & Schieb, P. Ibid, p. 22.

commercialization of FCEVs. Korea has a 1 million Green Home Program that is promoting fuel cell technology. It also has a Hydrogen Town in Ulsan. The Hydrogen Energy R&D Center (HERC) performed basic and applied research on hydrogen production and storage through its 21st Century Program, which ended in 2013. The Program also has activities in hydrogen distribution for both pipelines and tube trailers, plus fuel cell activities for the local community.

The Korean Energy Management Corporation (KEMCO) was created in 1980. In 2003, KEMCO established the New and Renewable Energy (NRE) Center (NREC). "New Energy" includes hydrogen and fuel cells. Industrial participation in NRE has been growing rapidly. KETEP (Korea Institute of Energy Technology Evaluation and Planning) and the Korea Evaluation Institute of Industrial Technology (KEIT) are working on balance of plant for fuel cells with the support of Ministry of Trade, Industry and Energy (MOTIE) programs.

In 2014, Korea hosted the World Hydrogen Energy Conference (WHEC), the premier community conference, in Gwangju.

2.3.2 Europe

In 2006, the German government created the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP). Initially a 10 year program with a budget of 1.4 billion Euros for hydrogen and fuels, NIP has recently been extended to 2025. The 2025 goals include not only transport and infrastructure but also the following interest areas and targets: hydrogen production from renewables; Power to Gas (PTG) and hydrogen storage; integration of the entire energy system (electricity, gas and transport); 1500 MW installed electrolysis capacity; and 500,000 micro CHP FC units.

The National Organisation for Hydrogen and Fuel Cells (NOW GmbH) was created to administer NIP. The Clean Energy Partnership (CEP) demonstrates hydrogen cars, buses and infrastructure. NOW created the H2 Mobility Initiative in 2009. In September 2013, an H2 Mobility Initiative comprised of Air Liquide, Daimler, Linde, OMV, Shell and Total announced an action plan for the construction of a hydrogen refueling network in Germany. The network is expected to include 100 stations in 4 years and 400 fueling stations by 2023.

HIT—Hydrogen for Infrastructure for Transport—is developing a synchronized National Implementation Plan (NIP) for the Netherlands, the Nordic countries and France. The plan features a hydrogen refueling stations (HRS) roll out along a 1000 km corridor from Rotterdam, Netherlands to Gothenburg, Sweden.

A strong environmental ethic is a pan-European attribute. The European Parliament recently approved rules for build-up of refueling points that feature hydrogen. The main measures include: minimum levels of infrastructure across Europe; EU wide standards for the infrastructure; and clear consumer information that facilitates use. The new rules are subject to adoption by the Council later in the year. The Dutch Ministry is now managing a multi-billion Euro pan-European implementation infrastructure program that includes hydrogen refueling stations. EU Directive 2009/28/EC mandates national overall targets for the share of energy renewable sources in gross final consumption by 2020.

The success of renewable energy is contributing to overcapacity in the electric grid. This situation has led to exploration of energy storage opportunities on the part of government and industry. Hydrogen is a leading candidate for energy storage. There is keen interest in the conversion of power to gas (P2G)—in particular hydrogen—for storage in the natural gas system, which has long experience with hydrogen. Among the dozen plus examples of significant P2G pilot plants is the 140 MW E.On wind farm with a 1 MW electrolyzer in Meckleburg-Vorpommern.

Inspired by Germany's example, there are national H2 Mobility initiatives across Europe in the UK, France, Scandinavia, the Netherlands, Switzerland and Portugal. All face the challenge of developing a Hydrogen Refueling Station (HRS) Network that strikes a balance between "maximizing customer convenience (and thereby Fuel Cell Electric Vehicle uptake) and minimizing the investment required." (http://www.ukh2mobility.co.uk/). In the case of the UK, it has been determined that 65 stations would provide adequate coverage for the initial network with growth to 1,150 stations by 2030. In France, stakeholders operate under the umbrella of the French Association for Hydrogen and Fuel Cells (AFHyPAC), which participates in H2 Mobility France (H2MF). The H2MF deployment plan is targeting captive fleets with the goal of deploying 800,000 vehicles and 60 refueling stations by 2030.

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a European public-private partnership supporting research, technological development and demonstration in hydrogen and fuel cells. Now in its second six-year phase, FCH 2 is funded by Horizon 2020, the new European framework program for research and innovation. Horizon 2020 is funding five Joint Technology Initiatives and four public-private partnerships at the level of €22 billion.

In 2012, car manufacturers Toyota, Nissan, Honda and Hyundai signed a Memorandum of Understanding (MOU) with organizations from Nordic countries (Denmark, Iceland, Norway and Sweden) on market introduction of fuel cell electric vehicles (FCEV) and hydrogen refueling infrastructure for the period 2014-2017. National networks in these countries have been cooperating on the Scandinavian Hydrogen Highway Partnership (SHHP) since 2006: HyNor for Norway; Hydrogen Link for Denmark; and Hydrogen Sweden.

In 2013, BMW and Toyota signed a long-term agreement to jointly develop fuel cells and collaborate on hydrogen infrastructure as well as codes and standards. They are targeting a platform for a mid-size sports vehicle. Daimler, Ford and Nissan/Renault announced a three way collaboration to develop affordable fuel cell electric vehicles (FCEVs).

In a landmark European study on drivetrains in transportation, McKinsey concluded that the **cost for developing the hydrogen infrastructure is comparable to costs for rolling out a charging infrastructure** for Battery Electric Vehicles (BET) and Plug-in Hybrid Vehicles (PHEV) ***before*** **(emphasis added) adding the cost for upgrading the power distribution network for BETs and PHEVs.**[4]

2.3.3 North America

Since the late 1970's, the U.S. Department of Energy (DOE) has had a significant research effort in hydrogen. The Hydrogen Program experienced considerable growth in the in the early 1990's. That growth accelerated substantially in 2004. Among its recent accomplishments, the DOE Program has reduced the cost of producing hydrogen from renewable and natural gas sources: hydrogen can now be produced at a cost competitive with gasoline by distributed reforming of natural gas in high volume. DOE coordinates a Hydrogen and Fuel Cell interagency task force to coordinate federal adoption of hydrogen and fuel cell technology. DOE has validated the status of the technologies by demonstrating 122 fuel cell vehicles and 16 fueling stations nationwide. Furthermore, DOE cost and performance targets are used as benchmarks around the world.

Nationwide, DOE reports rapidly growing markets for fuel cells in stationary power, specialty vehicles (such as forklifts) and portable power. As of 2009 renewable energy (including hydropower) accounted for ~10% of total primary energy production[5]. In 2013, renewable energy sources accounted for 13% of electricity generation.[6] As a result of the Energy Policy Act (EPACT) of 2005, energy corridors for infrastructure (hydrogen, gas and oil pipelines, as well as electricity transmission and distribution) have been designated on federal and tribal lands in 11 western states in order to facilitate transmission of energy supply from high resource areas in the west to high demand locations. The energy corridors are expected to positively impact production of renewable energy.

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[4] McKinsey & Company, A Portfolio of Power-Trains for Europe: A Fact-Based Analysis, 2010, p. 46.

[5] Valladares, M. d., *Hydrogen Implementing Agreement 2009 Annual Report* (Bethesda: IEA Hydrogen Implementing Agreement, 2010)

[6] "How much U.S. electricity is generated from renewable energy?", *U.S. Energy Information Administration*, Last Updated April 14, 2014, http://www.eia.gov/energy_in_brief/article/renewable_electricity.cfm.

American President Obama has begun to signal grave concern about climate change and interest in building climate change awareness in the American public. Policy support at this level, coupled with increased public awareness, could significantly improve the landscape for clean energy and hydrogen in America.

However, despite the progress, the single most important development on the American energy scene from 2009-2015 is arguably the hydraulic fracturing or "fracking" of natural gas and oil, which is typically combined with horizontal drilling. "Fracking" has turned the U.S. into a net energy exporter, assuaging some of that nation's energy security concerns.

Meanwhile, the U.S. is not alone in the fossil fuel renaissance. Canada is deeply engaged in natural gas fracking and development of oil from tar sands. R&D in hydrogen and fuel cells has been suspended at Natural Resources Canada (NRCan). To our regret, NRCan has also withdrawn from the HIA. Given Canada's leadership position in the fuel cell industry, another Canadian government organization remains involved in the sector to support Canadian business interests.

Despite the continuing opposition of much of the U.S. electric utility industry, 30 states and the District of Columbia have adopted enforceable renewable portfolio standards (RPS) or other mandated renewable capacity policies. In addition, seven other states have voluntary goals for renewable generation. These programs typically involve commitment to generation of a certain percentage of electricity from renewables.

Progress in hydrogen infrastructure development in the U.S. is evident at the state level as well. On the west coast, California passed legislation authorizing and appropriating $200 million to construct up to100 hydrogen fueling stations across the state by 2024. The program will be administered by the California Energy Commission and the funding will come from motorist payments of existing vehicle registration fees. All stations must have a minimum average daily fueling capacity of no less than 100 kg. The California Fuel Cell Partnership (CaFCP) mapped out locations in the Los Angeles and San Francisco Bay area for 68 hydrogen fueling stations, some existing or in development, and others needed.

On the east coast, Connecticut is the center of the fuel of the American fuel cell industry and the hub of the New England hydrogen cluster. The Connecticut Center for Advanced Technology (CCAT) administers the Connecticut Hydrogen-Fuel Cell Coalition, comprised of stakeholders from the fuel cell and hydrogen industry, labor and the Connecticut Clean Energy Fund.

During the 2009-2015 term, the two U.S. trade associations for fuel cells and hydrogen merged into a single organization called the Fuel Cell Hydrogen Energy Association (FCHEA) that represents the full global supply chain. Motivated by the success of H2 Mobility hydrogen infrastructure initiatives in Europe, the U.S. launched its own public-private partnership, H2 USA, in May 2013 to advance hydrogen infrastructure. FCHEA plays an active role in H2 USA. In Canada, the Canadian Hydrogen and Fuel Cell Association continued its active promotion of the hydrogen/fuel cell industry.

2.4 Energy Sector and Inter-Sectoral Outlook

2.4.1 Sectors

Hydrogen is an energy carrier with potential applications across all end-use sectors: transport, industry and buildings, as well as power (including heat and electricity). The IEA reports that in 2011 the power sector accounted for 38% of primary energy (including electricity) use. The transport sector accounted for 20%. The industry sector accounted for 25% and the building sector accounted for 18%[7]. See Table 1 for primary energy demand by sector in 2011 forecast out to 2050. Over time, the power sector is expected to grow to 42% of total demand, while the building sector shrinks to 13%. The percentage of primary energy demand for the transport and industry sectors is expected to remain constant during this period relative to total demand.

[7] *IEA Energy Technology Perspectives 2014*. (Paris: International Energy Agency (IEA), 2014), 235.

Table 1 Primary Energy Demand by Sector in 2011 with Forecast to 2050

	2011		2015		2020		2025		2030		2035		2040		2045		2050	
	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%
Buildings (residential, services, agriculture)	96,584	18%	97,727	17%	98,313	16%	96,364	16%	94,094	15%	94,053	15%	93,719	15%	92,269	14%	91,163	13%
Transport	107,557	20%	121,318	21%	123,643	21%	122,749	20%	120,369	19%	121,715	19%	125,125	20%	129,079	20%	133,714	20%
Industry	136,495	25%	150,164	26%	155,973	26%	159,192	26%	159,705	26%	161,924	26%	160,080	25%	163,032	25%	166,501	24%
Power	208,420	38%	211,846	36%	223,401	37%	236,662	38%	245,686	40%	251,849	40%	259,077	41%	272,753	42%	289,214	42%
Total	**549,056**	**100%**	**581,055**	**100%**	**601,329**	**100%**	**614,967**	**100%**	**619,853**	**100%**	**629,541**	**100%**	**638,001**	**100%**	**657,132**	**100%**	**680,592**	**100%**

In 2011, 38% of primary energy was converted to heat and electricity. Electricity is secondary energy. Both the ETP 2014 and the WEO 2013 forecast some two-thirds growth in electricity demand from 2011 to 2035[8].

Like electricity, hydrogen is secondary energy. In the future, with the uptake of hydrogen, primary energy will be converted to hydrogen. Moreover, hydrogen and electricity are complementary energy carriers: hydrogen can be converted from and back to electricity. Effectively, hydrogen can be used to store electricity. A brief introduction on hydrogen applications in end use sectors follows.

In the power sector today, hydrogen is used to make electricity for backup-power systems for uninterruptible power and emergency applications.

In industry today, hydrogen is already used extensively in numerous applications, from chemical and refining (gas and petroleum) to metallurgical, food, glass and electronics. ETP 2012 reports that today's annual hydrogen production of around 6EJ is split 50-50 between refining and chemical industries[9]. In the future, use of hydrogen could displace the oil used in chemicals and petrochemicals, and coal used in iron and steel[10]. Current research is investigating production of CO_2 free hydrogen for use in the chemicals, petrochemicals and steel-making industries. These industries have multi-billion market caps and high market potential for hydrogen. In terms of current industry energy applications, it is the fuel cell forklift for material handling that has penetrated the commercial market: more than 4,000 are being used in the U.S. alone.

In the future buildings sector, use of high temperature fuel cell micro cogeneration systems (either power or heat led) is anticipated, ideally in conjunction with a smart grid that balances heat and power supply.

In the future mass transport market, hydrogen will be converted to electrical energy in fuel cells to power the electric motor in fuel cell electric vehicles (FCEV).

2.4.2 Inter-Sectoral Synergies and Storage

Hydrogen's cross-sectoral potential and flexibility are attractive features. Today, various energy systems or "networks" with differing structures and operating conditions serve each of the sectors discussed in 2.4. These networks are not typically interconnected. To some degree, the networks and the sectors they serve are all subject to global concerns about carbon emissions, efficiency, cost and security of supply. These concerns may facilitate changes resulting in intersectoral synergies that transform networks and affect the greater energy system.

Hydrogen can serve as a bridge to exploit synergies and connect networks that serve diverse applications in all energy sectors. It can disrupt the logic of conventional systems and networks, breaking the "spell" of the immutability of incumbent technology. In Europe, for example, there is already recognition that the electric

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8 van der Hoeven, Maria. "How We Must Build the Electric Future." *The Journal of the International Energy* Agency 2nd quarter 2014: 3. http://www.iea.org/ieaenergy/.

9 *IEA Energy Technology Perspectives 2012* (Paris: International Energy Agency (IEA), 2012), 235.

10 IEA, Ibid., p. 258.

power and transport sectors could be a "single stream."[11] Moreover, energy networks can be connected within centralized and distributed (including on-site) systems that may vary widely in size and scale. The interconnection of energy networks enhances the flexibility of the greater energy system.

Consider some of the energy system's dynamics, starting with the power sector and moving into the transport sector (still almost exclusively fueled by oil), and storage. By 2013, wind power deployment approached 300 Gigawatts, more than double its 2008 level.[12] Onshore wind experienced 27% average annual growth over the past decade and solar photovoltaic (PV) grew at an annual average of 42% with large (75%) reductions in costs in some countries over a three year period.[13] This growth increased the supply of renewable electricity. Renewable electricity may be fed into the electrical grid, but it can also be converted to hydrogen via electrolysis and then used for transport fuel and heating in buildings.

Furthermore, hydrogen can be stored in the natural gas grid. If stored in the natural gas grid, hydrogen could be used for combined heat and power for the building sector and even re-fed into the electric grid after conversion to electricity via fuel cells or gas turbines. This creates synergies between the electric network and gas network.

Underground caverns can also be used for hydrogen storage. **Storage in effect optimizes the H_2 value chain**. Large-scale hydrogen energy storage could help enable use of high levels of variable renewable energy. As costs decrease and technology matures, the potential for hydrogen to enable decoupling of electricity supply and demand on a short term (minute to weekly) basis could provide the flexibility needed to maximize the integration of variable renewable sources of energy in the greater system.

Low-carbon hydrogen from renewable sources of energy or fossil fuels in combination with carbon capture and storage (CCS) can be mixed with natural gas for use in conventional heating and power applications. In the transport sector, deployment of fuel cell electric vehicles (FCEV) ranging from longer range cars to trucks could clearly create a large and important demand for hydrogen. Hydrogen supply for the mass transport market may come from different feedstocks, sectors and intersectoral synergy. Hydrogen production from renewables for the transport market has already been mentioned. Tri-generation that produces heat, power and hydrogen from natural gas or biogas, may also provide low cost hydrogen for vehicles. Furthermore, there is significant potential for value-added from successful hydrogen applications (such as fuel cell forklifts, fuel cells for backup power systems, combined heat and power), as they help to create synergies that inure to the benefit of infrastructure development for the mass transport market.

2.5 Challenges, Opportunities and Barriers

Many nations and companies have blueprints or roadmaps for the adoption and penetration of hydrogen technologies. The IEA is now working on a Hydrogen Roadmap in collaboration with the HIA, as discussed in section 2.2. This roadmap, like other IEA Roadmaps, will be subject to periodic revision. Such revisions are a "best" practice. In the case of the IEA Hydrogen Roadmap, the likelihood of revision is compounded by the variation in the current condition of major world regions. These variations are expected to contribute to a geographically fragmented "transition" to significant hydrogen utilization. At this time, there is no single coherent vision for the transition. **There is not expected to be a single pathway given the differences in the policy and regulatory framework, market and utility networks around the world. Whatever the case, the climate change challenge unequivocally functions as a universal driver for adoption of hydrogen technology.** Many of the challenges, opportunities and barriers discussed here—notably climate change—will impact but survive the HIA's 2015-2020 term.

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[11] Friedman, R., *IEA Hydrogen Roadmap Role of PEM Technology in Energy Storage.* (for internal use only), 2014 January 28.
[12] *IEA Wind Power Technology Roadmap 2013* (Paris: International Energy Agency (IEA), 2013), 5.
[13] *IEA Energy Technology Perspectives 2012* (Paris: International Energy Agency (IEA), 2012), 59.

Lack of understanding about hydrogen's potential value as an energy vector is a barrier to advancement. Greater clarity about this key topic is expected to come with analysis and time. Analysis will be both a challenge and an opportunity in the HIA's 2015-2020 term and beyond. To borrow from the HIA's 2009-2015 Strategic Plan, there remains **a Hydrogen Information Gap that that needs to be filled with coherent and balanced information, providing a clearer picture of hydrogen R&D needs and the future of hydrogen in the economy."**[14] Fortunately, because the HIA recognized this need and made an effort to develop analytic capability during the last term, it is positioned to respond to this challenge. Various kinds of analysis will be needed. They include support for IEA work in the ETP and WEO as well as other technical, marketing and policy related work.

Over time, the availability, cost, sustainability and security related challenges to hydrogen supply will continue to create opportunities for short and long-term research in hydrogen production from renewables, fossil fuel and nuclear. As for solid storage, the research challenge is not new. While research in gaseous and liquid storage has made serious progress, these forms of storage remain topics of research interest as well. What is new is the intense interest and effort devoted to investigation of large-scale storage, whether geological or in the gas system. Storage in the gas system is variously referred to as power to gas (P2G)/hydrogen/fuel. Storage of renewable energy in the gas system offers the potential for power balancing in the electric grid.

Hydrogen faces technical challenges that vary from sector to sector. Transport is the mass market opportunity for hydrogen. It includes fuel cell electric vehicles (FCEVs) for passenger cars and fleets as well as buses. In the transport sector, the HIA has stated that "all hydrogen delivery options are feasible—there are no technical issues that cannot be overcome … The transport challenges are not so much technical as they are policy, regulatory and business-related…the best practical and economic combination depends on specific national, regional and local situation, especially in the pre-commercial phase. First movers in hydrogen distribution and refuelling stations must pay attention to the existing industrial hydrogen infrastructure, energy mix, energy prices, safety and regulation…"[15]

Both renovation and new construction offer opportunities in the building sector, as demonstrated by the Japanese commercialization of 70,000+ ~1kW "Ene-Farm" PEM fuel cell systems that provide power, heat and hot water in a combined heat and power (CHP) system. The example of forklifts in the industrial sector offers a good model for niche markets in the industrial and other sectors. The forklift story demonstrates that there is opportunity in niche markets where a business case for hydrogen can be made. Success with the forklift and residential CHP systems, along with back-up and uninterruptible power applications, enhance the case for development of the hydrogen refueling station infrastructure.

There are already new opportunities for conversion technology. One critical example is the electrolyzer, which is needed in various sizes. Serious work in electrolyzer scale-up is underway. In 2013, a 1 MW system was installed at 140 MW E.ON wind farm in northeastern Germany. Key challenges associated with the electrolyzer and conversion technologies are efficiency and cost-reduction.

Resistance from many incumbent energy leaders is expected to continue and even increase in some cases. For example, spurred by the success in North America, the oil and gas industries are pursuing hydraulic fracturing outside North America. This is happening despite widespread community concerns and sometimes flat-out opposition for environmental reasons. At some point in the not too distant future, more empirical evidence about the impacts of fracking may be available. Until that time, the practice of fracking could be a challenge to all clean energy, including hydrogen. While renewables have been widely embraced in Europe and incorporated in the business strategy of European electric utilities, American utilities continue their 30-year resistance to net

[14] *Hydrogen Implementing Agreement Strategic Planning 2009-2014* (Bethesda: IEA Hydrogen Implementing Agreement, 2009), 52.
[15] Weeda, M., *Hydrogen Refuelling Stations and Role of Utilization Rates: Key Messages and Issues* (for internal use only), 2013, July 10.

metering. Such opposition served as a barrier to market entry for renewables in the past and remains a serious challenge today.

Efforts to mitigate climate change will continue to target the power and transport sectors, affording opportunities for hydrogen. As mentioned, renewable energy is already transforming the European power sector. It is poised to stimulate innovation in energy storage as well. The potential for a large-scale storage solution is expected to enable a new hydrogen value chain. This could be a real win-win opportunity not just for hydrogen but also for the gas industry.

Common to all these examples is the need for infrastructure that will support the operation of hydrogen technology in different applications and sectors. This is a challenge. In fact, whether technical, policy, regulatory or business-related, there is more than one type of infrastructure challenge. First, there are intra-sector challenges, such as how to develop a refueling infrastructure. Second, there are inter-sectoral challenges as connections are established between formerly independent energy sectors such as transport and power. Meeting intra-sectoral and inter-sectoral challenges and opportunities to integrate the energy infrastructure will create synergies that enable the hydrogen vector and transform the energy system. While this is a manifestly complex undertaking, the good news is that the cost of generation far exceeds the cost of infrastructure (perhaps by a factor of ten or more), so it makes sound economic and business sense optimize infrastructure.[16]

3.0 Strategic Direction

The essential elements of the 2009-2015 HIA Strategic Framework—mission, vision, strategy, themes and portfolios—continue to be relevant. Therefore, they have been retained for the new term. These elements are depicted in the molecule diagram in Figure 1.

In addition, the basic Strategic Framework has been enlarged to incorporate overarching objectives and theme-specific priorities for the 2015-2020 term. These new strategic elements were developed in view of current conditions and the anticipated challenges of the new term. They are expressly intended to sharpen our strategic direction and facilitate implementation of our work program in support of the HIA Vision and Mission.

The ensemble of elements in the 2015-2020 strategic framework is discussed below.

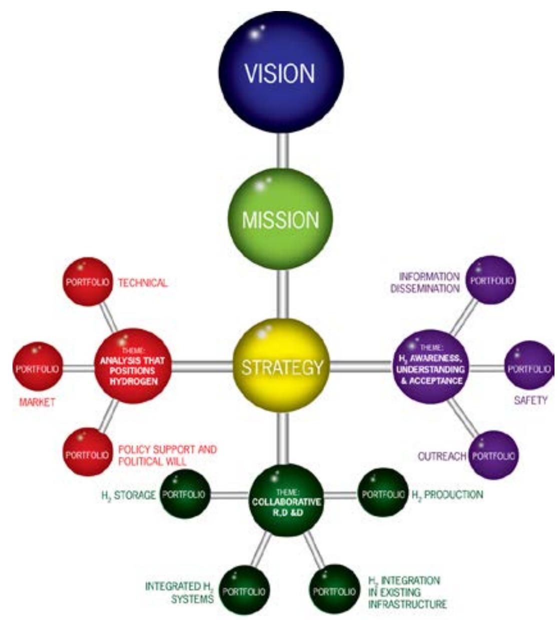


Figure 1 HIA Strategic Framework: Molecule Diagram

[16] Kramer, G. J., *Shell's presentation at the HIA 69th ExCo Meeting* (for internal use only), 2013, December 3.

3.1 Strategic Framework: Vision, Mission, Strategy, and Overarching Objectives for 2015-2020

As stated, the essential elements of the 2015-2020 Strategic Framework—Vision, Mission and Strategy—remain unchanged from the preceding term.

Vision

The HIA vision for a hydrogen future is one based on a clean, sustainable energy supply of global proportions that plays a key role in all sectors of the economy.

Mission

Accelerate hydrogen implementation and widespread utilization to optimize environmental protection, improve energy security and promote economic development internationally while establishing the HIA as a premier global resource for expertise in hydrogen.

Strategy

Facilitate, coordinate and maintain innovative, research, development and demonstration activities through international cooperation and information exchange.

Overarching Objectives

The HIA has adopted the following overarching objectives for the period 2015-2020:

- Broaden the perspective on the transformative role of H_2 by articulating and communicating its functions and value as a highly flexible energy vector and energy carrier capable of serving as a weapon against climate change in an integrated future multi-sector energy system.
- Strengthen analysis activities with a special focus on IEA analysis & publications and the competitive global energy technology environment.
- Focus on the development and implementation of the H_2 infrastructure, highlighting storage, safety and cost reduction.
- Raise the profile of the HIA, enhancing its reputation for excellence in R&D and analysis while underscoring its importance as a forum for information exchange.
- Formulate messages derived from HIA technical and analytic activities guide in order to guide and inform IEA's policy making activities.
- Foster productivity and progress through growth in membership, closer relationships and cooperation with other H_2 organizations, as well as a broader business orientation.
- Cultivate and deepen industry participation at the task and ExCo levels.

3.2 Strategic Framework: Themes and Portfolios for 2015-2020

For the period 2015-2020, the HIA has reaffirmed the three current themes of its strategic framework. The three themes are:

- **Collaborative R,D&D**

  That advances hydrogen science and technology

- **Analysis that Positions Hydrogen**

  For technical progress and optimization

  For market preparation and deployment

  For support in political decision-making

- **Hydrogen Awareness, Understanding and Acceptance**

  That fosters technology diffusion and commercialization

The portfolios defined for each theme during the previous period have likewise been retained for the 2015-2020 term. The portfolios associated with each theme are listed below:

Collaborative R,D&D	Analysis that Positions H_2	H_2 Awareness, Understanding and Acceptance
▪ Hydrogen Production	▪ Technical	▪ Information Dissemination
▪ Hydrogen Storage	▪ Market	▪ Safety
▪ Integrated Hydrogen Systems	▪ Support for Political Decision-Making	▪ Outreach
▪ Hydrogen Integration in Existing Infrastructure		

3.3 Priorities for 2015-2020

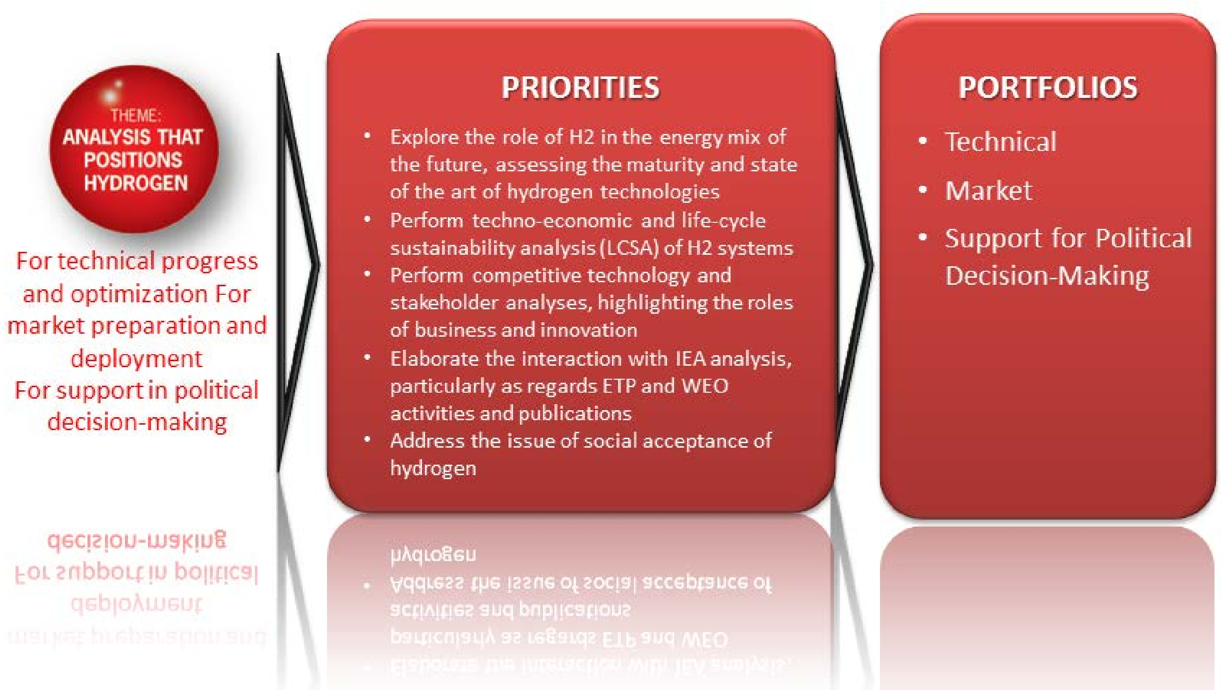
In order to define its activities for the five-year period 2015-2020, the HIA has identified priorities for each theme. There is no rank order to the priorities. The HIA will utilize the collective priorities to influence and inform research content for each theme and its associated portfolios.

3.3.1 Collaborative R,D&D

Collaborative R,D&D remains the HIA's core business.

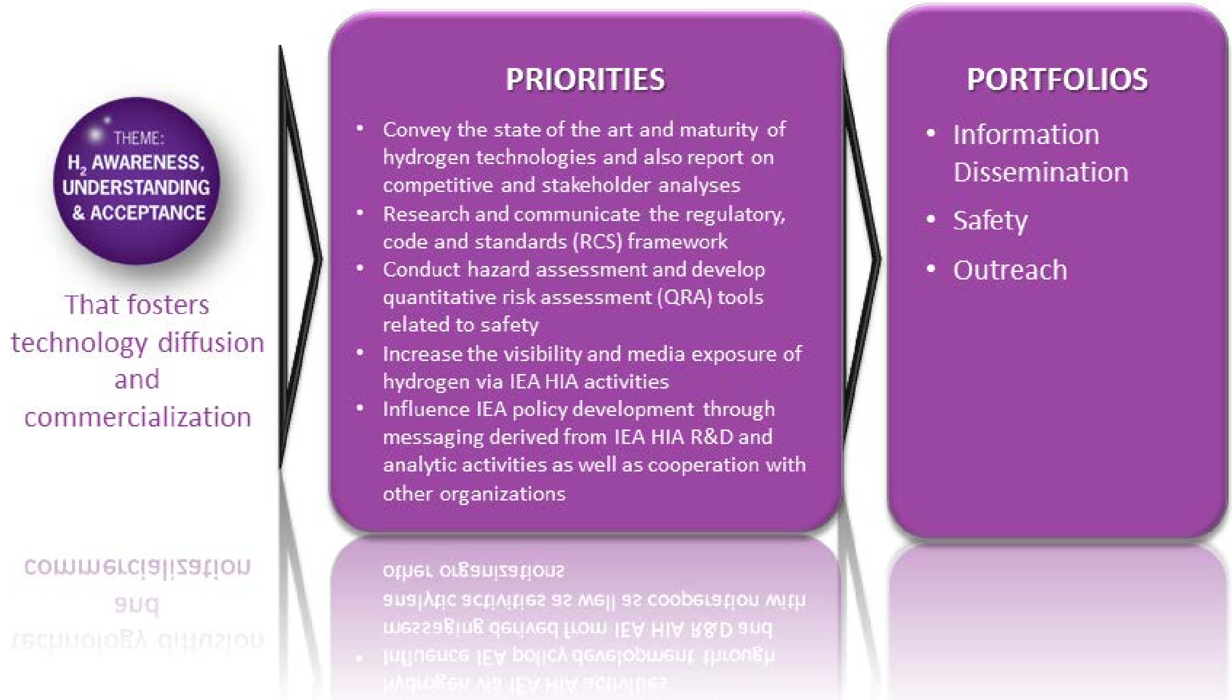
3.3.2 Analysis

With the growing need for analysis, the HIA is intent on addressing topics of interest and developing system analysis capabilities to the greatest extent possible.



3.3.3 Awareness, Understanding and Acceptance

The HIA aims to promote the diffusion and commercialization of hydrogen by educating stakeholders about its cross-sectoral applications and system-wide value.



3.4 Correspondence of the HIA Themes and Portfolios with IEA CERT and REWP Strategies and Overarching HIA Objectives

For the 2015-2020 term, the HIA has adopted overarching objectives that correspond with current CERT objectives and REWP functions from their respective Strategic Plans. The CERT objectives and REWP functions appear in italics in the left column of Table 2 above the pertinent HIA overarching objectives. The HIA Themes and Portfolios that correspond with particular CERT objectives, REWP functions and overarching HIA objectives are found in the right column. The purpose of mapping this relationship is to illustrate the correspondence between the IEA and HIA values and their expression in key elements of the HIA strategic framework. In general, it bears mention that these connections find further expression and reinforcement at the operational level in the work proposed program, which is discussed in Section 4.2. The reader is invited to review Table 2 with a view to the strategic connections between the IEA bodies and the HIA. It may be helpful to point out a couple examples.

Both the CERT and REWP strongly encourage analysis and policy guidance. Policy guidance aimed at the IEA is particularly welcome. For its part, the HIA has articulated overarching objectives to formulate messages derived from our technical and analytic activities to inform the IEA and to strengthen our analysis activities, notably IEA analysis. These activities will be carried out under the HIA's analysis theme. One of the CERT objectives is to "engage with selected countries and relevant organizations". The corresponding HIA objective is to "Foster productivity and effectiveness through growth in membership, closer relationships and cooperation with other H_2 organizations, and a broader business orientation," which will be carried out under the Awareness, Understanding and Acceptance theme.

Table 2 Correspondence of HIA Themes and Portfolios with IEA CERT Objectives and REWP Functions

<table>
<tr><th>CERT Objectives and HIA Overarching Objectives</th><th>HIA Themes and Portfolios</th></tr>
<tr><td>Enhance and expand analysis to provide strategic energy technology policy guidance
Formulate messages derived from technical and analytic activities that guide and inform IEA's policy making activities
Strengthen analysis activities with a special focus on IEA analysis & publications and the competitive global energy technology environment in the context of business and innovation.</td><td>Analysis Theme
▪ Technical
▪ Market
▪ Support for Political Decision-Making</td></tr>
<tr><td>Engage with selected countries and relevant organizations
Cultivate and deepen industry participation at the task and ExCo levels
Foster productivity and progress through growth in membership, closer relationships and cooperation with other H_2 organizations, and a broader business orientation</td><td>H_2 Awareness, Understanding and Acceptance (AUA)Theme
▪ Information Dissemination
▪ Safety
▪ Outreach</td></tr>
<tr><td rowspan="2">Strengthen the energy technology network
Foster productivity and effectiveness through growth in membership, closer relationships and cooperation with other H_2 organizations, and a broader business orientation.</td><td>Collaborative R, D&D Theme
▪ Hydrogen Production
▪ Hydrogen Storage
▪ Integrated Hydrogen Systems
▪ Hydrogen Integration in Existing Infrastructure</td></tr>
<tr><td>Analysis Theme
▪ Technical Analysis</td></tr>
<tr><td rowspan="2">Encourage financing of clean energy technologies
Broaden the perspective on the transformative role of H_2 by articulating and communicating its functions and value as a highly flexible energy vector and energy carrier capable of serving as a weapon against climate change in an integrated future multi-sector (power/ electricity, heat, transport and storage) energy system</td><td>Analysis Theme
▪ Market
▪ Support for Political Decision-Making</td></tr>
<tr><td>H_2 Awareness, Understanding and Acceptance Theme
▪ Information Dissemination
▪ Safety
▪ Outreach</td></tr>
</table>

***REWP Functions* and HIA Overarching Objectives**	
Provide a member states' platform for information exchange and discussion Raise the profile of the HIA, enhancing its reputation for excellence in R&D and analysis while underscoring its importance as a forum for information exchange.	H_2 Awareness, Understanding and Acceptance Theme ▪ Information Dissemination ▪ Outreach
Give guidance to IEA secretariat Strengthen analysis activities with a special focus on IEA analysis & publications and the competitive global energy technology environment in the context of business and innovation.	Analysis Theme ▪ Market ▪ Technical ▪ Support for Political Decision-Making
	H_2 Awareness, Understanding and Acceptance Theme ▪ Information Dissemination ▪ Outreach
Review and add value to IEA's Multilateral Technology Initiatives Broaden the perspective on the transformative role of H_2 by articulating and communicating its functions and value as a highly flexible energy vector and energy carrier capable of serving as a weapon against climate change in an integrated future multi-sector (power/ electricity, heat, transport and storage) energy system Foster productivity and effectiveness through growth in membership, closer relationships and cooperation with other H_2 organizations, and a broader business orientation. Cultivate and deepen industry participation at the task and ExCo levels. Focus on the development and implementation of the H_2 infrastructure, highlighting storage, safety and cost reduction	Collaborative R, D&D Theme ▪ Integrated Hydrogen Systems ▪ Hydrogen Integration in Existing Infrastructure
	Analysis Theme ▪ Technical ▪ Market ▪ Support for Political Decision-Making
	H_2 Awareness, Understanding and Acceptance Theme ▪ Information Dissemination ▪ Safety ▪ Outreach
Enhance the impact of IEA's work Formulate messages derived from technical and analytic activities that guide and inform IEA's policy making activities.	Analysis Theme ▪ Technical ▪ Market ▪ Support for Political Decision-Making
	H_2 Awareness, Understanding and Acceptance Theme ▪ Information Dissemination ▪ Safety ▪ Outreach

4.0 Scope

4.1 Portfolio Planning: Rationales and Content

This section presents the HIA's planning rationales by theme and portfolio. The portfolio rationales discuss content that is either a part of the ongoing work program or already targeted for consideration. During the 2015-2020 five year term the HIA will continue to define new activities in keeping with the priorities for each theme. For the new term the HIA will continue its tradition of creating well-defined tasks that address specific R&D needs harmonized to the greatest extent possible with needs identified by the international stakeholder community.

For ready reference, the priorities for each theme appear in a box in that theme's rationale section. At the end of each theme's rationale discussion, a table maps the theme's priorities with its portfolios and the activities defined as of this writing.

THEME: COLLABORATIVE R,D &D

4.1.1 Collaborative R&D

Collaborative R,D&D is the HIA's central function. While HIA R,D&D activities have been predominantly mid-long term in nature, often in the fundamental or basic science category, the HIA has instituted more near-midterm applied R,D&D activities over the past 10 years. Applied technology activities reflect the evolution of the technology and the readiness of the marketplace. During the new term, the HIA will seek increasing cooperation with international hydrogen reference groups, such as its strategic allies IPHE and the FCH JU. As in the past, the HIA will engage other IEA Agreements in its R&D activities wherever possible. Regular information exchange already takes place with the AFC IA. The HIA also expects to continue ongoing cooperation with the EUWP's Transport Contact Group and its IA members and the new EUWP Industry Group. Periodic cooperation with RETD is expected as well as closer interaction with SOLAR PACES.

PORTFOLIOS

- H2 Production
- H2 Storage
- Integrated H2 Systems
- H2 Integration in Existing Infrastructure

PRIORITIES

- Investigate development, deployment and delivery challenges and risks pertinent to hydrogen safety and infrastructure
- Pursue research on hydrogen production from renewable energy
- Explore power to hydrogen (P2H; power to gas - P2G; power to fuel), examining the potential for storage of intermittent renewable power sources in the natural gas grid for energy balancing
- Continue research on solid storage of hydrogen
- Research hydrogen production via reforming and gasification

Production Portfolio

Over its lifetime, the HIA has initiated more tasks in production than in any other area. A diversity of feedstocks enriches the potential hydrogen supply, presenting numerous research possibilities. These possibilities include both fundamental (long term) and applied (near-mid-term) research. Our applied research is typically non-competitive in nature.

Production of hydrogen from renewable resources is a priority for the 2015-2020 term. **The growth of renewables is in fact a major opportunity for hydrogen in the near future.** In Europe, especially, the focus on renewables is intensifying in terms of both policy and installed capacity.

The need for continued innovation in renewables spurred creation of the **Renewable Hydrogen Production** task. This task aims to establish a network of international experts who will scan the globe performing secondary research in **critical technologies that affect renewable hydrogen pathways**. While this task is indicative of an increasing emphasis on applied research, it also includes longer term and fundamental research. The task will provide the ExCo with **state of the art information in three subjects/subtasks: renewable electrolysis, photoelectrochemical water splitting and solar-thermochemical water splitting**. Likely research areas include thermodynamics, catalysis, membranes/separations, metrics and standards and techno-economic analysis.

Production from renewables encompasses various conversion technologies, notably electrolysis, which may be particularly valuable in the early phases of transition to a hydrogen infrastructure. Building on the work of its Task 23 predecessor, Task 33 – Local Hydrogen Supply for Energy Applications is evaluating the merits of various pathways for local supply, whether for transport or stationary uses, using a systems approach. The conversion technology featured in Task 33 is the electrolyser. However, work continues on fuel requirements and feedstock options involving reformer technology. This task may include emerging technologies such as catalytic heat-exchange reactors. Given the **positive market prospects for on-site supply of hydrogen, distributed energy and the evolution of a broader hydrogen infrastructure, industry participation plays a**

large role in this task. On completion of its current three year term, Task 33 is likely to be extended as-is or revised to further reflect commercial opportunities across technology and market segments. Fast-tracking deployment of on-site reformers and electroyzers for market introduction and penetration is likely to become an issue. This may entail collateral research investigating CO_2 capture technology onsite.

Closer cooperation with the IEA AFC may occur on electrolyzer technology and perhaps high temperature fuel cells. The HIA has a systems perspective on electroylzers while the AFC is more focused on technology components. Integration of different methods of high temperature hydrogen production and further investigation of promising high temperature processes and methods were identified as gaps in the 2015-2020 strategic planning process. They may emerge as research topics during this term.

The increase in installed capacity of fluctuating renewable energy—particularly wind—is creating opportunities for energy balancing and storage in the electric power sector, as is fairly well understood. But these opportunities extend beyond the electric power sector to the gas industry, which is interested in storage of hydrogen in the gas system. For many reasons, the **Power to Hydrogen/Gas** task topic is an R&D priority. The P2G task is expected to investigate its systemic aspects. In fact, P2G has many dimensions so this task can legitimately be considered part of several R,D&D portfolios. It is discussed here as part of the production portfolio because electrolysis is used to produce hydrogen. In addition, The Power to Hydrogen/Gas/Fuel Task can also be considered part of the Storage and H_2 integration in Existing Infrastructure portfolios.

Biohydrogen offers considerable promise. It is mostly a longer term proposition, but there are near-mid-term "applied" research possibilities. Biohydrogen combines photosynthesis and anaerobic digestion. Biohydrogen can be made from dark fermentation as well as biological electrochemical (microbial/enzymatic), light-driven (for algae cultivation) and bio-inspired processes. There has been progress in development and innovation of photobioreactor design, including the first purely industrial scale-up of a biohydrogen facility at the Sapporo Brewery in Brazil, in partnership with Petrobras. The current biohydrogen task, Task 21, nears completion. In the new term, **a new biohydrogen task entitled Biological Hydrogen for Energy and Environment will pursue basic and applied research with greater emphasis on economic and social conditions**.

In waterphotolysis, materials research is of continued interest, as are design and development of the actual photoelectrochemical (PEC) devices. Development of a working model is highly desirable. Task 26, Advanced Materials for Waterphotolysis, focused exclusively on materials. The new renewables task expects to include secondary research on photoelectrochemical water splitting. A dedicated future waterphotolysis task might either continue the advanced materials track or combine it with research on devices.

Production of hydrogen from gasification of biomass and reforming, particularly natural gas reforming, continues to of great interest and is, in fact, **a priority for this term**. Biomass to hydrogen processes, thermo-chemical (gasification and pyrolysis-based) and biological processes, are near-midterm options of interest for further research.

Carbon capture and storage (CCS) and pre-combustion decarbonization were cited in the 2009-2015 Strategic Plan as topics for future research. However, they were noted as a gap in the recent strategic planning process so they are included in the 2015-2020 Strategic Plan.

Storage Portfolio

Hydrogen can be stored in gaseous, liquid and solid forms. Today, gaseous and liquid storage are commercially available, although research is underway to improve both options and reduce their costs. Despite the status and merits of compressed and liquid storage, solid storage is viewed as an attractive future hydrogen storage solution for transport and stationary applications for reasons of volumetric density and safety. While the HIA's storage research includes activities in liquid storage, the greatest need for research is in solid storage. Therefore, solid storage is the focus of our activities. Continuation of research in solid storage is a priority for the 2015-2020 term.

Solid storage faces challenges in gravimetric density and hydrogen uptake, as well as release under moderate conditions. There are several promising categories of solid storage for hydrogen, such as magnesium-based materials, complex hydrides and imide/amides. Research on these groups is underway in Task 32. **Task 32 researches materials and systems for use in stationary, mobile and portable applications and electrochemical storage**. It encompasses reversible metal hydrides, regeneration hydrogen storage materials, chemical hydrides, nanoporous materials and rechargeable organic liquids and solids. Hydrides are under investigation for heat storage in solar thermal plants. Physisorption in metal organic frameworks (MOFs) for use in cryo-tank systems and borohydrides for Na-ion conductors in batteries are the subject of investigation as well.

Task 32 spans the research continuum from fundamental to applied activities. Since most of the work is of a longer term nature it is very likely that the task will be extended after the 2016 completion of the present term. As storage systems meet technical targets, increasing emphasis on applied research and interface with conventional resource chains is anticipated. For example, an optimization study on solid storage for stationary and mobile applications, identified as gap in strategic planning, could elaborate the present work. This evolution is not, however, expected to supplant the ongoing need for fundamental research in hydrogen storage.

Through a **power to gas/hydrogen/fuel** task, prospects for large scale hydrogen storage will be investigated. As previously explained, hydrogen storage has become an attractive prospect, motivated by the increased (and still increasing) installed capacity of wind coupled and correlated with the increasing curtailment of wind energy. Given its flexibility advantage, hydrogen could be an ideal storage medium, particularly when intermittent generation exceeds demand, creating a demand for storage. (Stored hydrogen can then be used to reproduce electricity using fuel cells or gas turbines.) While **the focus of the research is expected to be on storage in the gas system, underground storage in aquifers, depleted gas fields or caverns (salt mine, hard rock mine) may also be studied**.

Integrated Hydrogen Systems Portfolio

This portfolio addresses system integration, the bringing together of component subsystems. As the new term begins, there are two tasks in this portfolio: Task 29 – Distributed and Community Hydrogen (DISCO H2); and Task 33 – Local H2 Supply for Energy Applications. **Task 29, DISCO H2, is investigating distributed systems in urban, rural/remote/island and industrial communities**. This research provides an opportunity to compare and contrast system integration needs under various conditions. DISCO H2 intends to develop models for each community type that will contain guidelines for system integration. **Task 33 is developing norms for small-scale reformers and electrolyzers in order to harmonize industrialization and commercialization**. This activity will contribute to improvement of system integration. It will also contribute to standardization of technical components and systems, which is key to driving down costs and thereby enhancing market prospects. Both of these tasks respond to the 2015-2020 priority to "investigate development, deployment and delivery challenges and risks pertinent to hydrogen safety and infrastructure."

Market introduction and penetration will require optimized, well-integrated systems. During the 20150-2020 term, cost reduction in componentry and efficiency improvements in system integration will be of increasing concern. Hydrogen production from renewables, conversion (electrolyzers) and hydrogen fueling station equipment (for storage and compression) will be important targets for cost reduction. In addition to research, information exchange on these subjects will support the marketing process.

Hydrogen Integration in Existing Infrastructure Portfolio

As the HIA reported during the first IEA Hydrogen Roadmap Workshop in July 2013, "All hydrogen delivery options are technically feasible – there are no technical issues that cannot be overcome."[17] This is good news. Integration of hydrogen in the existing infrastructure is underway in leading nations (Germany, Japan and Korea) and organizations (such as the European H2 Mobilities and H2 USA), in combination with other global efforts, notably those of the HIA. This is also good news. However, it is clear that there will be many and varied challenges in transforming the infrastructure to integrate hydrogen. The current infrastructure includes not only generation, transmission, distribution and storage of electric power but also heat. **Investigating infrastructure related development, deployment and delivery challenges and risks is a priority for this term.** Through **Task 28 – Infrastructure, the HIA has already begun to look at the development and deployment of the refueling infrastructure.** There are many variables to be considered – the existing industrial hydrogen infrastructure, the energy mix, energy prices, safety regulations -- especially in the pre-commercial phase. Furthermore, standardization is key to driving down the cost of hydrogen refuelling stations. This will require consistent and harmonised regulations, codes and standards (RCS), along with standardisation of technical components and systems.

In the new term, the HIA expects to continue this work and further address the market and behavioral aspects of how to bring hydrogen to the customer. In the event that there is no immediate successor to Task 28, the **HIA may form an industry roundtable to preserve the industrial network** created in that task. Issues that merit investigation include:

- The tension and trade-offs between swift maximum market coverage (with many small stations) in early markets and the investment need for rapid optimization of the hydrogen refueling station (HRS) business case (with fewer but strategically placed stations of as large a capacity as possible)
- Effective strategies for increasing the capacity utilization of HRS
- Whether or not to combine hydrogen with conventional filling stations, securing locations with sufficient space for future expansion of capacity
- Proof of hardware reliability (compressors, hoses nozzles, seals) under conditions of intensive practical use
- Suitable method for periodic inspection and certification of the accuracy of hydrogen meters, which is necessary to be able to sell hydrogen to customers
- Cost-effective monitoring method to be able to demonstrate that the quality of dispensed hydrogen complies with applicable quality standards

Task 29, DISCO H2, already mentioned in the Integrated Hydrogen Systems portfolio, is likewise a part of the portfolio on hydrogen integration in the existing infrastructure. While this task focuses predominantly on stationary applications, it is also looking at potential benefits for transportation. DISCO H2 also aims to progress the optimization and replication of hydrogen – especially "green" hydrogen – within distributed and community energy systems. Resources permitting, **Task 29 would like to turn its three community models (urban, remote-rural and industrial) into easy-to-use handbooks to facilitate development.** The HIA would further **like to undertake training based on these handbooks**. There is a further possibility, again resources and industry permitting, that the HIA might be able to cooperate on this endeavor with the IEA Division on International Partnerships and Initiatives.

[17] Weeda, M. Op.cit. (for internal use only), 2013, July 10.

Task 33 is studying barriers and opportunities for local hydrogen energy supply in existing and future energy markets. This effort is also critical to integrating hydrogen in the existing infrastructure. The need for research in this area is expected to continue beyond its 2016 tenure. In the event that the task is neither extended nor immediately succeeded, industry participation in this area may be preserved through creation of a formally constituted industry roundtable. The roundtable will be charged with moving forward at a lower activity level than that involved in a typical task.

The Marine sector is expected to open up in the coming term as an appealing target for exploration. A proposal for a task on hydrogen in the maritime sector has already been presented. The objective of the proposed task is to foster smarter, greener, safer shipping through research and use of hydrogen and fuel cells in marine systems. Use of hydrogen and fuel cells in maritime applications is expected to have multiple benefits, starting with reduced fuel consumption, emissions, noise, vibration and maintenance requirements. The proposed task would create an expert group to evaluate technology, identify technological barriers and create a project database.

Table 3 synthesizes the Collaborative R,D&D rationale in a table. The table maps the priorities for the R&D theme in the left column to the tasks and activities defined for each of the four R&D portfolios.

Table 3 Relationship of Collaborative RD&D Priorities to Tasks in Each RD&D Portfolio

Collaborative R&D	Portfolios under the Collaborative R&D theme			
PRIORITIES	**H_2 Production**	**H_2 Storage**	**Integrated H_2 Systems**	**H_2 Integration in Existing Infrastructure**
Investigate development, deployment and delivery challenges and risks pertinent to hydrogen safety and infrastructure	Task 33, Local H2 Supply for Energy Applications; Task 29, Distributed and Community Hydrogen (DISCO H2)		Task 33, Local H2 Supply for Energy Applications; Task 29, Distributed and Community Hydrogen (DISCO H2)	Task 28, Large Scale H2 Delivery Infrastructure; Task 29, Distributed and Community Hydrogen (DISCO H2)
Pursue research on hydrogen production from renewable energy	Task 21, BioHydrogen & successor Task 34, Biological H2 for Energy and Environment; Task 35 on Renewable Hydrogen production(renewable electrolysis; Photo-electrochemical water splitting; and Solar-thermochemical water)			
Explore power to hydrogen (power to gas –P2G; power to fuel), examining the potential for storage of intermittent renewable power sources in the natural gas grid for energy balancing	Task 21, BioHydrogen & successor task; Task 35 on Renewable Hydrogen production(renewable electrolysis; Photo-electrochemical water splitting; and Solar-thermochemical water)	Task 33, Local H2 Supply for Energy Applications; Task 32, H2 Based Energy Storage		Power to Hydrogen (P2H; power gas – P2G; power to fuel) Task
Continue research on solid storage of hydrogen		Task 31, Hydrogen Safety		New Safety Task
Research hydrogen production via reforming and gasification	Possible successor to Task 26, Advanced Materials for WaterPhotolysis		Task 33, Local H2 Supply for Energy Applications	Task 33, Local H2 Supply for Energy Applications

THEME: ANALYSIS THAT POSITIONS HYDROGEN

4.1.2 Analysis

PRIORITIES

- Explore the role of H2 in the energy mix of the future, assessing the maturity and state of the art of hydrogen technologies
- Perform techno-economic and life-cycle sustainability analysis (LCSA) of H2 systems
- Perform competitive technology and stakeholder analyses, highlighting the roles of business and innovation
- Elaborate the interaction with IEA analysis, particularly as regards ETP and WEO activities and publications
- Address the issue of social acceptance of hydrogen

PORTFOLIOS

- Technical
- Market
- Support for Political Decision-Making

The HIA anticipates a growing demand for hydrogen analysis. Responding to this demand is expected to be one of the central challenges of the 2015-2020 term. Section 2.5 Challenges, Opportunities and Barriers clearly states that "Lack of understanding about hydrogen's potential value as an energy vector is a barrier to advancement." Furthermore, analysis is needed "to fill the hydrogen information gap with coherent and balanced information, providing a clearer picture of hydrogen R&D needs and the future of hydrogen in the economy." This will require continuous cooperation with the IEA to overcome possible misunderstanding. In reality, while the HIA's analysis efforts are vitally important, they face internal resource constraints as the HIA must first address its core business, R,D&D and also respond to the need for action under the Awareness, Understanding and Acceptance theme.

The HIA first adopted Analysis as one of the three themes in its strategic framework for the predecessor 2009-2015 term. **Task 30 – Global Hydrogen Analysis expressly endeavored to build up a body of systems analysis expertise**. It succeeded in this undertaking, and the HIA now joins the IEA and the OECD as an authoritative source of energy analysis.

For the 2015-2020 term, the HIA has affirmed the continuing importance of Analysis as both a theme and an overarching objective, in keeping with the CERT's #1 2012-2016 objective to "enhance and expand analysis to provide strategic energy technology policy guidance." Therefore, the HIA will endeavor to strengthen the Agreement's analysis activities with a **special focus on IEA analysis and publications as well as the competitive global business environment**. These activities will occur in the framework of a dedicated analysis task; other tasks will also have the opportunity to contribute to various IEA analysis efforts. The IEA Hydrogen Roadmap is a prime example of the special HIA cooperation with the IEA. Task 28, Infrastructure, has already contributed significantly to roadmap development. The ExCo and Secretariat in fact hosted the North American roadmap workshop. **ExCo and tasks alike will continue to contribute to preparation and elaboration of the IEA Hydrogen Roadmap.**

Moreover, the tasks may also include techno-analysis and other analysis topics within their respective scopes of work.

If the HIA resources were to expand, increasing our capacity, the HIA would consider alternative approaches to analytic studies including shorter-term studies. Under current resource conditions the HIA plans to continue cooperation with analytic efforts of allied organizations. These include sister IAs (such as the RETD) and non-IEA organizations, such as the JU FCH and IAEA, with which development of an MOU is underway.

One of the enduring challenges for hydrogen has been the lack of understanding of hydrogen's flexibility and its larger role as an energy "vector" rather than an energy "technology(ies)". So compelling is this issue that it has become the subject of the overarching HIA objective to "Broaden the perspective on the transformative role of H_2 by articulating and communicating its functions and value as a highly flexible energy vector and energy carrier capable of serving as a weapon against climate change in an integrated future multi-sector energy system." This issue cross-cuts all three analytic portfolios: technical, market, and public policy/political will. **During the 2015-2020 term analysis activities will spotlight this cross-cutting issue**.

The 2015-2020 priorities for the Analysis theme will further guide the analysis activities undertaken during this term. While expectations for the technical and market portfolios are discussed separately in the following sections, it is evident that many of their respective issues are closely linked. Consequently, such issues are likely to be addressed from both technical and market perspectives.

Technical Portfolio

The Analysis theme's technical portfolio seeks to promote advancement and optimization of the technology. One 2015-2020 analysis priorities directs the HIA to "explore the role of H_2 in the energy mix of the future, assessing the maturity and state of the art of hydrogen technologies." **The HIA already monitors Technology Readiness Levels (TRLs) on a task basis for inclusion in the annual report, but additional work in this area is anticipated**. Further research on H_2 from CO_2 free sources is also forecast. The HIA is also **targeting development of expertise in risk analysis for deployment of hydrogen refueling stations.** As discussed in the analysis introduction, the HIA will continue to be involved in the IEA Hydrogen Roadmap effort in order to optimize not only the Hydrogen Roadmap but all related outcomes. The IEA Roadmap might be the topic of an ExCo Workshop.

After completing the information dissemination process and End of Task Workshop for Task 30, **follow-on work directly associated with Task 30 activities may take place on Subtask B: Hydrogen Technology Database**. Such work is likely to take the form of technical and economic updates to the database and companion handbook designed to facilitate system analysis on regionally differentiated resources (and reserves), energy requirements and costs.

The Task 30 successor analysis task is expected to feature Life Cycle Sustainability Analysis (LCSA). LCSA will entail cost, economic and environmental analysis as well as consideration of social factors contributing to sustainability and better understanding of technology. This methodology compares technologies, so it will expand understanding of the relative technical merit and technology costs of hydrogen technology on a competitive basis.

The Annual Report will continue to include information on the maturity and state of the art of technologies. Other opportunities to exploit this information will be explored. In a related vein, the development of status reports on leading stakeholders and relevant global expertise—**stakeholder analyses—will be investigated**. Hydrogen from CO_2 free sources is another attractive area of investigation.

In keeping with the overarching objective to focus on the **development and implementation of the H_2 infrastructure**, the HIA will address this topic in the new term through a **successor task to Task 28 and/or an industry roundtable devoted to targeted infrastructure issues.**

Market Portfolio

This portfolio speaks to the business case for hydrogen, which includes social and consumer acceptance. It speaks directly to the role of hydrogen in the energy mix. The market perspective on several important topics is expected to complement the technical analysis of these topics.

Follow-on efforts directly associated with Task 30 activities may build on **Subtask A Global Hydrogen Resource Study**. Such work would use the Global Pathways Analysis Tool (GPAT) to deepen understanding of a potential future interregional hydrogen trading scheme. A successor task in Life-Cycle Sustainability Analysis (LCSA) would expand the market view. As repeatedly stated, ongoing cooperation with IEA Analysis is an overarching priority for the HIA.

How to bring hydrogen to the customer is one of the key questions for the near future. It is already being addressed in **Task 33 – Local Hydrogen Supply for Energy Applications** and **Task 29 – Distributed and Community Hydrogen (DISCO H2)**. On completion of its current term, Task 33 is likely to be extended to continue with its current scope of work. It would also be valuable to update the electrolyser database developed by predecessor Task 23, On-Site Supply of Hydrogen. Task 29 might seek to continue its work through development of a handbook on its community models, followed by training.

With respect to new market portfolio activities, **analysis of global leaders and relevant expertise—a stakeholder analysis—is expected to better equip the HIA to understand the global marketplace**. Collecting and assessing lessons learned from country leaders such as Germany, Japan and Korea will be key to formulating strategy for different places and phases of hydrogen technology adoption. As well, periodic assessment of gaps and barriers in the deployment process would facilitate HIA efforts to encourage market penetration.

The **Power to Hydrogen/Power to Gas (P2G)/Power to Fuel task currently in definition is expected to examine relevant market impacts as well as technical concerns, requiring the integration of economics and marketing expertise**. This task will examine the **full hydrogen value chain**, including opportunities for arbitrage.

In addition to storage of hydrogen in the gas grid, other potential market analysis topics include the regional, country and international impacts of integrated gas and electricity projects on infrastructure and market design. Further, a study on financial mechanisms that facilitate integration of hydrogen into renewable energy funding flows has been identified as a topic of keen interest.

The **development of an infrastructure risk analysis capability to support deployment of hydrogen infrastructure** has already been cited as an area of analytic interest for the technical portfolio. This **subject is likewise a topic of interest for the marketing portfolio**. To facilitate such analysis, **the HIA may put a system in place to track the development of hydrogen refueling stations**. Such information is presently available in different forms from various sources that use disparate standards to identify and categorize hydrogen refueling stations. The HIA system would attempt to standardize descriptions for comparison purposes.

Likewise crucial for infrastructure development are the Regulations, Codes and Standards and Safety. These topics are expected to be the subject of the successor safety task.

Support for Public Policy/Political Will Portfolio

More than ever, the **IEA** – at the Working Party and CERT levels as well as in the Secretariat – **is concerned with the formulation and communication of policy advice for decisionmakers**. The IEA is especially but not exclusively concerned with outreach to IEA Member and Partner countries. The IEA clearly views **outreach to non-Member countries as a high priority**.

Articulating the role of hydrogen in the energy mix is an overarching HIA objective for the new term. For policymakers whose influence is needed to support hydrogen deployment, clarity about its features and benefits is requisite to success. The HIA has identified a few areas of exceptional importance to hydrogen public policy analysis: 1) hydrogen and competitive technologies; 2) cost information; 3) a critical stakeholder analysis; and 4) regulations, codes and standards (RCS) and safety. Hydrogen safety and RCS are actually mission critical to accelerating the uptake of hydrogen technologies. Analysis of relevant expertise in other countries will contribute to understanding the context and capacity for advancing hydrogen technology around the world. Analysis of costs and competitive technologies could be very persuasive.

As part of the public policy portfolio effort, the Secretariat will work to **assure development of policy messages reflecting all aspects of the HIA work program at both the task and ExCo levels**. This includes analysis of findings and conclusions from the technical and market portfolio analyses. Where resources permit, these messages may be developed into short briefs or even position papers.

Table 4 synthesizes the Analysis theme narrative rationale in tabular format. The table maps the priorities for the Analysis theme in the left column to the tasks and activities defined for each of the three Analysis portfolios.

Table 4 Relationship of Analysis Priorities to Tasks and Activities in Each Analysis Portfolio

Analysis	Portfolios under the Analysis theme		
PRIORITIES	**Technical**	**Market**	**Support for Political Decision-Making**
Explore the role of H_2 in the energy mix of the future, assessing the maturity and state of the art of hydrogen technologies	Task 30 – Global H2 Systems Analysis: Subtask A – Global H2 Resources; Subtask B – H2 Data Base;	Task 30 – Global H2 Systems Analysis: Subtask A – Global H2 Resources	Messages developed from all tasks and portfolios; plus briefs and Position Papers
Perform techno-economic and life-cycle sustainability analysis (LCSA) of H_2 systems	Task 36 – Life Cycle Sustainability Assessment (LCSA)	Task 29, Distributed and Community Hydrogen (DISCO H2) Task 36 – Life Cycle Sustainability Assessment (LCES)	Task 36 – Life Cycle Sustainability Assessment (LCES)
Perform competitive technology and stakeholder analyses, highlighting the roles of business and innovation	Development of IEA H2 Roadmap underway	Task 28, Large Scale Hydrogen Delivery Infrastructure; Task 33, Local H2 Supply for Energy Applications	
Elaborate the interaction with IEA analysis, particularly as regards ETP and WEO activities and publications	Task 30 – Global H2 Systems Analysis: Subtask C – Interaction with IEA analytics		
Address the issue of social acceptance of hydrogen		Task 31, Hydrogen Safety	Messages developed from all tasks and portfolios; plus briefs and Position Papers from

THEME: H_2 AWARENESS, UNDERSTANDING & ACCEPTANCE

4.1.3 Awareness, Understanding and Acceptance

PRIORITIES

- Convey the state of the art and maturity of hydrogen technologies and also report on competitive and stakeholder analyses
- Research and communicate the regulatory, code and standards (RCS) framework
- Conduct hazard assessment and develop quantitative risk assessment (QRA) tools related to safety
- Increase the visibility and media exposure of hydrogen via IEA HIA activities
- Influence IEA policy development through messaging derived from IEA HIA R&D and analytic activities as well as cooperation with other organizations

As the timing for commercialization draws nearer, the need to build awareness, understanding and acceptance (AUA) of hydrogen increases. During the 2015-2020 term this need must be balanced against the demands associated with the Collaborative R,D&D and Analysis themes. The AUA theme comprises three portfolios: Information Dissemination, Outreach and Safety. The first two portfolios, Information Dissemination and Outreach, are managed by the Secretariat. Safety, the third portfolio, is organized as a task.

PORTFOLIOS

- Information Dissemination
- Safety
- Outreach

Information Dissemination Portfolio

Information Dissemination is a vital component of building awareness, understanding and acceptance of hydrogen. This function is managed by the Secretariat at the ExCo level. At the task level, these activities involve the active cooperation of experts and their Operating Agents. Basic HIA information products include the HIA Annual Reports, technical and special reports, as well as outreach materials, including our Executive Summary, bi-annual newsletter and brochures. With few exceptions, these materials are posted on the website and on the HIA Facebook page (https://www.facebook.com/pages/IEA-Hydrogen-Implementing-Agreement/10150140248900527). To an increasing extent, the information products will contain messages for policy and decision makers.

Every effort is make to adequately disseminate information about HIA activities, products and outcomes. There are several target audiences, chief among which are HIA Members, IEA members and the IEA itself. Regular receipt of information is one of the benefits of membership in the HIA; it is also a benefit of belonging to the IEA Technology Network.

Channels and platforms for information dissemination include: the HIA website, electronic and print publication, conferences/events, and End-of-Task workshops. The End-of-Task Workshops were initiated in the previous term; their use will be emphasized in the new term. In the new term, the HIA aims to build awareness of hydrogen and the HIA brand by increasing its media exposure and its government relations presence.

Content-wise, the HIA will disseminate information about the progress and activities of its tasks, including reports about the maturity of hydrogen technologies. Other topics of interest include: how to bring hydrogen to the customer; how to increase the share of renewable hydrogen; RCS and safety. The **newsletter** already has a space for the hydrogen and fuel cell marketplace. The renovated website HIA will feature this report as well.

Outreach Portfolio

Outreach activities go beyond information dissemination to build awareness, understanding and acceptance of hydrogen among various publics. Outreach activities are also intended to "engage" target publics in the HIA.

As in the past, Outreach begins with **"internal" efforts to engage the IEA at the Secretariat, Working Party and CERT levels**. The HIA anticipates regular opportunities for participation and presentation at IEA events and conferences. We also look to deepen cooperation with Paris regarding the WEO and ETP reports. The HIA also expects to have more opportunities for cooperation with the OECD.

Externally, the HIA expects that the ExCo-Secretariat **will continue to make presentations at conferences and other events to multiple market sectors: hydrogen; renewables/sustainable and conventional energy**. Such efforts are meant to appeal to both IEA Member and IEA non-Member countries, as well as to industry. Industry participation has grown over the past 10 years. Continued growth in industry participation is expected in the 2015-2020 term. During the 2009-2015 term, the HIA began to recruit Sponsor Members. Membership expansion is an overarching priority for the 2015-2020 term, so this will include both Sponsor Members as well as Contracting Parties.

The HIA will also target its outreach efforts at three other groups: the media, policy/infrastructure decision makers, and other key international hydrogen reference groups. Media engagement is intended to facilitate the visibility of hydrogen and the HIA. Interaction with policy/infrastructure decisionmakers is intended to foster deployment of hydrogen technology. Outreach to other key international hydrogen reference groups—such as our strategic allies, the IPHE and the FCH JU—is intended to promote mutually beneficial cooperation that advances hydrogen. Such cooperation leverages the investments of all parties.

Otherwise, the HIA's outreach efforts will encompass the topics of interest already discussed in information dissemination. Outreach on safety and regulations, codes and standards supplement the list of outreach issues.

In parallel, it is expected that **HIA tasks will reach out to interested audiences globally through participation in conferences and events, as well as organization of task meetings in conjunction with relevant** conferences/events. The **HIA tasks are typically the vanguard in industry recruiting activities**, identifying and facilitating industry participation and Sponsor member accession.

As well, the **HIA will continue to award its Individual and Project Prizes on an alternating basis**. The prizes are awarded for RD&D characterized by technical excellence and harmony in international cooperation that contributes to the understanding and advancement of basic and applied hydrogen science.

Safety

The slogan "safety first!" has universal meaning and appeal that cross-cuts industries and societal segments. Safety is a high priority at the HIA. While safety considerations cross-cut all HIA portfolios, they are the exclusive focus of the Safety portfolio. In broad terms, the HIA safety portfolio aims to advance the hydrogen safety knowledge base. The **development of science-based and risk-informed regulations, codes and standards (RCS), aided by the use of qualitative and quantitative risk assessment (QRA) and supported by harm and risk criteria**, have been used and will continue to be used by the HIA to **inform the requirements in RCS**. Furthermore, the development of safety knowledge tools and resources will continue to play a pivotal role in educating and informing stakeholders in the hydrogen and fuel cell communities. Similarly, on-line resources such as data bases and interactive tools will play an expanding role as a hydrogen safety resource. The **refinement of a "simplified" hazard assessment engineering toolkit of validated tools will contribute to the education process**.

In addition to a continuing focus on resources and best practices, new safety topics may be introduced in the 2015-2020 term as the definition of a new safety task is completed. Promising topics may complement ongoing or completed tasks. For example, in keeping with our emphasis on renewables, the **safety of hydrogen generation from renewable sources such as integrated wind turbines/electrolyzers or solar-photovoltaics/electrolyzer systems might be explored**. **Consistent with the focus on infrastructure, potential hydrogen safety topics include transport in trucks, trailers, pipelines, etc. as well as safety in stationary sites such as hydrogen fueling stations. With respect to new applications, the safety of hydrogen storage and delivery systems in unmanned aerial vehicles (UAV) and underwater unmanned vehicles (UUV)** is intriguing. In terms of hydrogen production from novel systems, the safety of partial hydrogenation of aviation fuels may be of interest. Following on Task 25 – High Temperature Production of Hydrogen, the safety of hydrogen generation from advanced nuclear reactors integrated with chemical cycles may also be of interest.

It is anticipated that the activities and results of the new task will in due time be the subject of an "End of Task Workshop," per HIA protocol. Ideally, the new task will also have an interest in producing an "End of Task Workshop" in Europe for the recently completed Task 31 and its predecessor, Task 19. This workshop would be the second of two workshops to celebrate and communicate the outcomes of Task 31. The first Task 31 End of Task Workshop was held in its North America. It was a great success. To date, while circumstances have precluded production of the European workshop, a new target date has been set for spring 2015.

Table 5 synthesizes the AUA theme narrative rationale in tabular format. The table maps the priorities for the AUA theme in the left column to the tasks and activities defined for each of the three AUA portfolios.

Table 5 Relationship of Awareness, Understanding and Acceptance (AUA) Priorities to Tasks and Activities in Each AUA Portfolio

Awareness, Understanding and Acceptance	Portfolios under the Awareness, Understanding and Acceptance theme		
PRIORITIES	**Information Dissemination**	**Safety**	**Outreach**
Convey the state of the art and maturity of hydrogen technologies and also report on competitive and stakeholder analyses	An element of Outreach Program managed by Secretariat.		
Research and communicate the regulatory, code and standards (RCS) framework		Task 31, Hydrogen Safety; End-of-Task Workshop of Task 31	
Conduct hazard assessment and develop quantitative research assessment (QRA) tools related to safety		Task 31, Hydrogen Safety; End-of-Task Workshop of Task 31	
Increase the visibility and media exposure of hydrogen via HIA activities	An element of Outreach Program managed by Secretariat; HIA Individual and Project		Participation and presentation at IEA events and conference; Recruiting of Sponsor Members; HIA Individual and Project Prizes
Influence IEA policy development through messaging derived from HIA R&D and analytic activities as well as cooperation with other organizations.	An element of Outreach Program managed by Secretariat		Task 30 – Global H2 Systems Analysis: Subtask C – Interaction with IEA analytics; Participate in EUWP Transport Contact Group and industry Strategy Group

4.2 Proposed Work Program

Appendix A combines the strategic framework discussed in Section 3.0 with the scope of work discussed in Section 4.1. This combination of strategic and operational elements results in a proposed Work Program for 2015-2020. The proposed Work Program in Appendix A is organized by theme and portfolio, key issues, approach in place in 2014, and proposed/potential approach for the new term. It is further broken into fundamental research, applied research, and crosscutting issues.

The proposed Work Program serves as a point of departure for the new term. The Work Program will continue to evolve based on the overarching objectives and priorities the 2015-2020 term as well as research results and outcomes, and ExCo member interests.

Table 6 below, Work Program Timeline, establishes a tentative timeline for 2015-2020 tasks and activities, excepting activities covered in the information dissemination and outreach portfolios connected with the Hydrogen Awareness, Understanding and Acceptance theme.

As the 2009-2015 term draws to a close, Task 28 and Task 30 are completing. Task 30's successor analysis task, Task 36 - Life Cycle Sustainability Assessment (LCES), was approved at the 70th ExCo Meeting in June 2014 and will kick-off in early 2015. It is not yet clear whether Task 28 will have an immediate follow-on task or create an industry roundtable instead. Task 21's successor, Task 34 – Biological Hydrogen Energy and Environment was also approved at the 70th ExCo Meeting in June 2014. Task 35 – Renewable Hydrogen Production, a new task with a broad scope and innovative approach, was likewise approved at the 70th ExCo Meeting. Three current tasks (Task 29 – DISCO H2, Task 32 – Storage and Task 33 – Local Hydrogen Supply for Energy Applications) will continue into the 2015-2020 term. On their completion during the 2015-2020 term, Task 32 and Task 33 are likely to receive extensions or create successor tasks to continue similar work. Task 29 may elaborate new work based on its outcomes. Two other tasks are now in definition—the Power to Gas/Hydrogen/Fuel task and the marine sector task. They, too, may receive approval coincident with or shortly after the start of the new term.

Table 6 Proposed Work Program Timeline

	Mid 2014	2015	2016	2017	2018	2019	Early 2020
Task 21: BioHydrogen							
Successor Task 34: Biological H2 for Energy and Environment							
Task 28: Large Scale H2 Delivery Infrastructure							
Successor: task or industry roundtable							
Task 29: DISCO H2							
Successor: Training							
Task 30: Global H2 Systems Analysis							
Successor Task 36: Life Cycle Sustainability Analysis (LCSA)							
Successor: Other Analysis							
Successor: Power to Hydrogen (P2H; Power to Gas-P2G; Power to Fuel)							
Task 31: Safety Successor							
Task 32: H2 Based Energy Storage							
Successor:							
Task 33: Local H2 Supply for Energy Applications							
Successor:							
New Task 35: Super Renewables Task							
New Task: Marine Sector							

LEGEND

Current — Extension or Successor — New

4.3 Participation

One of the overarching objectives for the 2015-2020 period is to "Cultivate and deepen industry participation at the task and ExCo levels." During the 2015-2020 term, industry expert participation is expected to grow. Furthermore, the role of industry may expand as industry participants assume leadership roles as Operating Agents and Sub-Task leaders. Moreover, in cases where work in a particular task with significant industry participation has concluded, the HIA would like to retain industry interest, preserving the opportunity for participation. The proposed solution in such cases is to create an industry roundtable(s) organized by topics. This vehicle would combine some of the organizational features of the HIA task structure (recognition, purpose) with the flexibility of an ad-hoc group capable of responding to issues as they develop.

4.4 Membership

The HIA will continue its membership recruiting efforts with respect to Contracting Parties, and undertake a systematic approach to Sponsor Member recruiting with the support and cooperation of Contracting Parties. The ExCo has periodically affirmed the importance of having Members who participate actively in the Agreement. This has always applied to Contracting Parties and now applies to Sponsor Members as well.

The following sections deal with Contracting Parties and Sponsor Members. Please refer also to Section11 – Outreach to IEA non-Member countries for more information on the HIA's approach to membership.

4.4.1 Contracting Parties

Prospective Contracting Parties fall into three categories: IEA member countries, IEA partner countries and non-IEA members. Prospective Contracting Parties in the IEA member country category are Austria, Belgium, Hungary, Poland and Turkey. (Canada, Belgium and Turkey are actually candidates for reaccession.) Prospective Contracting Parties among IEA partner countries are the BRICS nations: Brazil, Russia, India, China and South Africa. There is optimism about the successful conclusion of China's accession process, which has been underway for some time.

The HIA will remain in contact with interested non-IEA Member countries such as Mexico and Argentina. Elsewhere, particularly in Asia where interest in hydrogen is growing, the HIA will put a recruiting strategy in place.

4.4.2 Sponsor Members

During the 2015-2020 term, the HIA will seek sponsor members that meet the criteria of willingness and ability to participate in the HIA ExCo and tasks. According to the policy framework formulated in the previous term, the eligible sponsor categories are: public-private partnerships, industry, associations (with a technical focus) and non-federated groups.

5.0 Management Requirements

As in the past, the HIA will endeavor to comply with all IEA management requirements on a timely and complete basis.

Changes and/or improvements contemplated with regard to specific requirements are discussed below.

5.1 ExCo Meetings

According to the HIA ExCo Meeting Design plan, the HIA holds in-person ExCo Meetings approximately every eight (8) months. The second ExCo Meeting in even years is a webinar meeting consisting of multiple sessions. Webinars are also used to address specific issues of interest. During this term, the HIA intends to continuously improve the technical quality of these webinar meetings to enhance participation opportunities.

5.2 Annual Reports

Beginning with the 2014 Annual Report, which is slated to include both member and task updates, publication in hard copy (as well as in electronic format) will resume budget permitting. Thereafter, publication in hard copy will continue for editions containing both task and member updates.

Irrespective of mode of publication, the Annual Report will place increasing emphasis on messages for policy- and decisionmakers. These messages will be developed through the work program at the task level and also by the ExCo.

5.3 Legal Text

The HIA Legal Text will undergo review during this term to determine whether and what updates are in order.

5.4. HIA Handbook

The HIA Handbook will undergo selective revision on a section-by-section basis to reflect current operations and best practices.

5.5 Internal Information Dissemination

In 2014, the HIA introduced the ~monthly "Manager's Message." This report brings the ExCo and Operating Agents up to date on key HIA and Secretariat activities of the previous month. The HIA believes the benefits of this regular internal report exceed its costs. The HIA has a consistently high activity level, so two ExCo Meetings/year are insufficient to communicate progress. The Manager's Message updates the ExCo and OAs on a more timely basis, allowing for feedback and reflection that enriches ExCo discussions and informs ExCo decisions.

5.6 HIA Office Space

In 2014, the HIA moved to another office on the campus of the Federation of Associations for Experimental Biology (FASEB) in Bethesda, MD USA, tripling its space at a minimal increase in cost. Although the HIA's space requirements are modest, the new office will more efficiently accommodate current Secretariat staffing while also allowing space for expansion.

5.7 HIA Secretariat

No changes are contemplated in the HIA Secretariat.

The intern program instituted in the 2009-2015 term to support Secretariat activities has been successful. Despite the short duration of their tenures, the interns have made a genuine contribution to the HIA. The HIA has built a solid relationship with the University of Maryland School of Public Policy. The University has been very pleased with this training opportunity for its students. As the term comes to a close, it is possible that the HIA will be able to place its first post-doctoral fellow as an expert in our new analysis task.

6.0 Contribution to Technology Evolution/Progress

During the 2015-2020 term, the HIA plans to contribute to evolution of the technology though activities in fundamental and applied research, as well as analysis. The nature of the contributions is broadly articulated in the Strategic Framework; the particulars are then discussed in the Section 4.0 Scope.

As has been stated, R,D&D is the core HIA business. Priorities for Collaborative R,D&D reinforce the HIA emphasis on research in renewables and other forms of production as well as solid storage, infrastructure development and safety. In general, **the HIA approach is to pursue continuous improvement in technology evolution as topics of interest** emerge through task activities and direct introduction by ExCo members. In some cases—hydrogen storage for example—this takes the form **of enhancing understanding through fundamental research**, as in Task 32 – Hydrogen-Based Energy Storage. In the case of applied research it often means **following and influencing improvements in components and system integration**, as in the case of reformers and electrolysers for distributed generation that are the subject of Task 33 – Local H2 Supply for Energy Applications. In still other cases it means **addressing the consequences and outcomes of successful R&D and/or deployment**. In this instance the Power to gas/hydrogen task is a good example, since the impetus for the task involves the increase of installed capacity of wind energy that might be optimized through large scale storage. HIA discussions about technology evolution will occur in the context of overarching objectives and theme specific priorities for 2015-2020.

On completion of tasks, an end of task workshop will be held to disseminate findings and lessons learned. These workshops may be held as stand-alone events or in conjunction with ExCo Meetings. If the ExCo Meeting cum Workshop event proves successful, the HIA might also hold topical workshops in conjunction with ExCo Meetings as a further contribution to technology evolution/progress.

7.0 Contribution to Technology Deployment/Market Facilitation

During the 2015-2020 term, **portfolio elements of all three HIA themes – R,D&D, Analysis and Awareness/Understanding/Acceptance** will shape activities and contributions aimed at technology deployment and market facilitation. They will be strongly influenced by the overarching and theme specific objectives for this term.

The objective to "focus on the development and implementation of the H_2 infrastructure, highlighting storage, safety and cost reduction" is particularly relevant as infrastructure development begins to take off in the 2015 timeframe. Therefore, **HIA infrastructure activities are expected to increase**. The Power to Gas/Hydrogen task will contribute to understanding of energy balance and related infrastructure design needs. A discreet new safety task is being defined to address the next generation of deployment and market concerns. Safety considerations will be explored separately in other tasks as well. Cost reduction will play a role in analytic activities through the Analysis task(s) and again through task-specific techno-economic analysis, thereby enlarging market opportunities.

The HIA expects that **strengthening analysis activities geared toward IEA analysis & publications will advance the case for hydrogen throughout the IEA**. Similarly, the HIA expects that **increased participation in the IEA Technology Network will facilitate diffusion of our messages to policymakers. Both outcomes should contribute to technology deployment and market facilitation.**

Furthermore, industry participation will play a large role in technology deployment and market facilitation. In the HIA's view, **the overarching objective "to cultivate and deepen industry participation at the task and ExCo levels" is intended to stimulate the study of business and innovation aspects of the competitive global energy technology environment**. For example, Task 33 – Local H2 Supply for Energy Applications is working to develop an industrial supply base for hydrogen components. This approach can only contribute to success in the market place. Consequently, industry will be recruited to participate at the task level whenever possible. At the same time, the HIA will also work to increase Sponsor membership, expanding the worldwide network of stakeholders with a direct interest in hydrogen's success in the marketplace.

As discussed in connection with the HIA contribution to technology evolution, an **End of Task Workshop will be held to disseminate findings and lessons learned on completion of tasks.** This may occur in conjunction with an ExCo Meeting. If the ExCo Meeting cum End of Task Workshop approach proves successful, the HIA might also hold topical workshops in conjunction with ExCo Meetings as a further contribution to technology deployment and market facilitation. The IEA Hydrogen Roadmap is an example of a possible topical workshop.

8.0 Policy Relevance

The HIA recognizes that the IEA is concerned more than ever with the formulation and communication of policy advice to decisionmakers at the Working Party and CERT levels, as well as in the Secretariat. The CERT's #1 objective for the period 2012-2016 is to "enhance and expand analysis to provide strategic energy technology policy guidance. REWP's #2 objective for the 2013-2015 period is to "give guidance to the IEA Secretariat." Moreover, The IEA is concerned not only with policymakers in IEA Member but also with policymakers in Partner countries. Outreach to non-Member countries is clearly a high priority.

Given the critical importance of policy to the advancement and adoption of hydrogen technology, the HIA is very encouraged with the IEA's enhanced focus on developing and delivering policy messages. By design, the IEA is a global policy channel, structured to transmit messages up to and beyond the Governing Board. Without doubt, the IEA's many publications impact policy and decisionmakers around the world.

Therefore, **the HIA is committed to contributing to IEA policy development, consistent with IEA strategies, during the 2015-2020 term**. This HIA Strategic Plan, a reflection of HIA member interests and priorities, is a step in that process. And in fact, **one of the overarching HIA objectives for the 2015-2020 period is to "formulate messages derived from technical and analytic activities that guide and inform IEA's policy making activities."** In the regular course of all tasks and activities, the HIA will distill its results and generate content and messages for IEA Secretariat analysis and diffusion to national and international policy-makers. In particular, the results of HIA analysis activities will likely have policy relevance. As in the immediate past term, HIA efforts will focus special attention on the ETP and WEO publications. Moreover, in the normal course of business, ExCo Representatives from HIA Member countries will feed the results and messages of HIA tasks and activities into their respective policy making processes. Wherever possible, they will apprise their REWP and CERT representatives of key findings. Finally, the preparation of the IEA Hydrogen Roadmap offers a special opportunity for IEA interaction in the development phase, and proactive policy related follow-up on completion. Through all of these activities, the HIA will strive during this term to communicate the value of hydrogen in the energy system.

9.0 Contribution to Environmental Protection

In April 2014, the UN Intergovernmental Panel on Climate Change (IPCC) released its latest report, which indicates that nations still have a chance to reach the 2°C target but must work together to lower emissions "by 40 to 70%" of what they were in 2010. Action is needed now to avoid the most debilitating effects of global warming before the end of the 21st century. This report further substantiates the findings of recent WEO editions and the 2012 ETP. (See EOT Section 7.0 on Contribution to Environmental Protection) The WEO cautions that delayed action will result in massive cost increases.[18]

If hydrogen is produced from renewables, it can be a zero or near zero emission source. Even if it is produced from fossil fuel, it can be a near zero emission source at the tailpipe for transport. Consequently, many authorities have concluded that hydrogen can play a vital role in mitigating climate change and protecting the environment. Any and all progress toward in hydrogen technology and market development will therefore inure to the benefit of environmental protection. To ensure this outcome, the HIA's **2015-2020 overarching objectives and priorities are aligned to define tasks and activities that optimize technology and market evolution.**

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[18] Valladares, M. d., *HIA: Enhancing Prospects for Hydrogen in the Energy Mix* (for internal use only), 2010 September 16.

At the overarching objective level, the HIA is focusing on understanding the transformative role of hydrogen in an integrated future multi-sector energy system. It is also focusing on development and implementation of the H_2 Infrastructure, highlighting structure, safety and cost reduction. Specific R,D&D Priorities encourage: investigation of development, deployment and delivery challenges related to hydrogen infrastructure; pursuit of renewable energy for hydrogen production; and power to hydrogen for energy balancing. Reformer studies will involve natural gas and bio-fuels, which are less carbon intensive than other fossil fuels. Research in distributed generation will capitalize on hydrogen's flexibility and avoidance of carbon intense sources. Under the Analysis portfolio, the new analysis task is expected to perform life cycle sustainability analysis and explore the role of hydrogen in the future energy mix. Under the Awareness, Understanding and Acceptance portfolios, the HIA will formulate messages derived from HIA R&D and analytic activities and cooperation. Decreasing emissions and lowering associated costs will be a part of all this work.

10.0 Contribution to Information Dissemination

As explained in Section 4.1.3, Information Dissemination is a portfolio under the H_2 Awareness, Understanding and Acceptance theme in the HIA Strategic Framework. It is a cornerstone of the HIA strategy. In order to ensure continuing diffusion of information to participating countries, IEA member countries and the private sector, as well as the IEA itself, all current activities described in Section 4.1.3 will be continued. Similarly, all current channels of information distribution will remain in place.

To better promote the results and outcomes of our tasks, the HIA intends to strengthen and expand use of the End of Task Workshop. This workshop strategy might at some point in the 2015-2020 term be further elaborated to include workshops in conjunction with ExCo Meetings, particularly for analysis topics.

The HIA's renovated website will be far superior to its predecessor as a vehicle for public communication. It will also have an expanded private site for internal use. The expected improvement in internal communications is attributable to a more robust content management system (CMS) and an enhanced archival feature. These features allow the HIA website to host current and past task websites. The website's software will also permit migration to a SharePoint platform for easy electronic document flow when the time comes for multiple parties—whether the ExCo or the tasks—to work on-line. Externally, the website will provide more information about the hydrogen community and its activities for public consumption. Hence, the renovated website is expected to attract more interest in the HIA and by extension, its social media vehicles. Relative to social media, the planned approach to twitter is to first target other organizations and institutions with interest in sustainability rather than the general public.

The HIA anticipates that its information dissemination efforts will feed into and complement IEA promotional efforts at the Working Party, CERT and Secretariat levels such as the Open Bulletin. The HIA is also prepared to support IEA efforts such as the very successful Ministerial Fair that was held some years ago.

11.0 Outreach to IEA non-Member countries

Outreach to IEA non-Member countries is expected to intensify in the coming 2015-2020 period. As already discussed, the many facets of information dissemination to IEA non-Member countries are the first steps in the outreach process.

The BRICS nations (Brazil, Russia, India, China and South Africa), IEA partner countries, are key recruiting targets as discussed in section 4.4.1. The Chinese accession process is underway as of this writing. Brazil and South Africa are qualified prospects that have demonstrated interest in international hydrogen activities.

Given the Asian interest level in hydrogen and biohydrogen in particular, Asia appears to be fertile ground for HIA recruiting. To this end, the HIA will follow-up on contacts from the World Hydrogen Energy Conference (WHEC 2014) to engage Asian non-IEA Member countries.

In general, the HIA **experience in IEA non-Member country accession teaches that membership recruiting can be a slow process, as communication channels are often neither clear nor accessible**. Consequently, **IEA Secretariat cooperation is considered essential to the success of IEA non-Member recruiting efforts.** The HIA will work with our Desk Officer and other IEA non-Member Country Desk Officers to disseminate HIA results and pursue HIA participation and recruiting opportunities.

It is also possible that interested parties in non-Member countries may choose the path of Sponsor Members rather than Contracting Parties. The HIA is prepared to respond to this opportunity.

12.0 Added Value

The HIA has an established reputation as a premier global resource for technical expertise in H_2 RD&D. In the 2015-2020 term, the HIA expects to further enhance its value proposition through the twin approaches of our own work and collaboration with the IEA and other organizations/efforts that results in reduction of research costs, whether direct or indirect. Refer to the End of Term Report 2009-2015 for outcomes for the past term, including the results and achievements of each task coupled with the success stories of the tasks and the HIA. For the 2015-2020 term, overarching objectives as well as priorities for each theme appear in 3.0 Strategic Direction. Section 4.0 Scope of Work elaborates the rationales for work program content. The mixture of these strategic and operational elements is summarized in Table 6 – Proposed Work Program Timeline and Appendix 1 – Proposed Work Program.

The foundation of the HIA strategy is collaboration, described in our strategic framework as "international cooperation and information exchange." The HIA is a lean but high-functioning organization for which leverage is a critical success factor. The leverage is built on collaboration that yields returns on member investments of capital and labor in the form of: scientific and technical advances in hydrogen; reduced R,D&D costs for individual members; reduced technology costs; expansion of member knowledge, technical learning networks, national R&D capabilities and member partnership opportunities. Moreover, the HIA is an active member of the IEA Technology Network and intends to remain that way through cooperation with REWP, two of EUWP's working groups, and several sister IAs as well as the IEA Secretariat, notably its Analysis sections.

In conclusion, **hydrogen has a leading role in the saga of the transforming energy system**. This epic is close to an inflection point as the zeitgeist of climate change and the allied forces of industry and government converge on deployment planning for clean technology and related infrastructure. The HIA expects to add value from 2015-2020 by broadening the perspective on hydrogen, supporting relevant analysis at both HIA and IEA, fostering infrastructure development and formulating messages to guide and inform IEA's policy making activities. Delivering on the HIA's overarching objectives and thematic priorities will improve the competitive position of hydrogen.

Without doubt this outcome will require increased collaboration with all constituents of the IEA technology network from the CERT and the REWP to our sister IAs. It will also require increased cooperation with HIA Members and allies, along with the growing involvement of industry as participants and Sponsor Members, and the continued efforts of HIA experts. All of our assets will be deployed to achieve the RD&D, analysis and outreach progress and growth contemplated in the 2015-2020 Strategic Plan.

Appendix A

Table I Proposed Work Program

	THEME & PORTFOLIO	KEY ISSUES	APPROACH In place 2014	APPROACH Proposed/Potential
FUNDAMENTAL	R,D&D Production PORTFOLIO H_2 PRODUCTION	Photosynthesis and anaerobic digestion: anaerobic use of bacterial dark fermentations and photosynthetic microbes; biological electrochemical, light driven and bio-inspired processes.	Two Tasks 21 - BioHydrogen & successor Task 34, Biological Hydrogen for Energy and Environment	Successor Task 34 divided into basic research and applied research on biohydrogen with greater emphasis on economic and social conditions
		Renewables – growth in use of renewables and progress in renewable technologies	Task 35 - Renewable H2 Production(renewable electrolysis; Photo-electrochemical water splitting; and Solar-thermochemical water)	Successor Task 35 a secondary research task Possible dedicated task on materials and PEC for waterphotolysis
		Electrolyzers and high temperature electrolysis	Task 33- Local H2 Supply for Energy Applications	Task 33 – likely extension on completion; Task 35 – Renewable H2 Production possible cooperation with IEA AFC
		Basic Materials		TBD
APPLIED TECHNOLOGY	R,D&D Production PORTFOLIO H_2 PRODUCTION	Anaerobic use of bacterial dark fermentations and photosynthetic microbes	Successor to Tasks 21, Task 34 - Biological Hydrogen for Energy and Environment	applied subtask of new task
		Renewables (renewable H_2 pathways: renewable electrolysis, photoelectrochemical watersplitting and solar thermochemical water splitting); research areas to include: thermodynamics, catalysis, membranes/ separations, metrics, standards, techno-economic analysis Design/development of photo-electrochemical (PEC) devices	Task 35- R renewable H_2 production	may extend beyond initial three years Possible successor to Task 26 on development of PEC devices and scale-up
		High temperature electrolysis		**integration of different methods of high temp H2 production** **likely to extend beyond initial three year term**
		Fluctuating/seasonal renewable energy; energy balancing (electric and gas power sectors) and electrolysers		new Power to Gas/H_2/fuel task
		Biomass Gasification and reforming: Biofuels for reformers; CCS & emission handling; pre-combustion decarbonization; reforming and gasification of fossil fuels; (fuel requirements and feedstock options);		TBD
		Conversion technologies: electrolyser and reformers; on-site emerging technologies	Task 33- Local H2 Supply for Energy Applications	likely to extend beyond initial three year term

		Fully integrated wind and H_2 application	Task 29- DISCO H2 Task 33- Local H2 Supply for Energy Applications	possible successor training task possible collaboration with IEA AFC on electroyzers new Power to Gas/H_2 /fuel
	THEME & PORTFOLIO	**KEY ISSUES**	**APPROACH In place 2014**	**APPROACH Proposed/Potential**
FUNDAMENTAL	R,D&D Storage	Gravimetric density and H2uptake Reversible/regenerative H_2 storage media fulfilling int. targets; metal hydrides; chemical hydrides; nanoporous materials; rechargeable liquids and solids Fundamental & engineering understanding Materials for stationary applications	Task 32-H2 Based Energy Storage R&D in all issue areas; mobile, stationary, and portable applications; electrochemical storage. Hydride use for heat storage in solar thermal plants	Task 32 - likely extension on completion
FUNDAMENTAL	R,D&D Storage	Applied Aspects of H_2 storage systems in vehicles: compressed gas, liquid and materials-based; solid storage Increased installed capacity of renewable energy and associated curtailment create demand for large-scale hydrogen storage Hazard assessment/QRA for H2 and HCNG/CNG apps	Task 32- H2 Based Energy Storage Task 31- Hydrogen Safety	Task 32 - likely extension on completion; increasing emphasis on solid storage New power to Gas/H_2 task; large scale storage - in gas grid and underground (aquifers, depleted gas fields and caverns, both salt mine and hard rock.) Safety and International goals for applications in vehicles, namely gravimetric and volumetric capacities, temperature and pressure for hydrogen update and release of the process Optimization study for solid storage for stationary and mobile applications would be useful
APPLIED TECHNOLOGY	R,D&D Integrated Systems	Harmonization of components for electrolysers and reformer systems; development of norms; technology performance and cost; CCS & emission handling; optimized reformer and electrolyzer systems Information exchanges on H2 infrastructure and costs	Task 33- Local H2 Supply for Energy Applications	Task 33 – likely extension on completion
APPLIED TECHNOLOGY	R,D&D Integrated Systems	Distributed and community level generation	Task 29 - Distributed and Community Hydrogen; models for each community type	Task 29 - on completion, possible extension or new task to develop handbooks on community models that will contain guidelines for system integration; then design and undertake training
APPLIED TECHNOLOGY	R,D&D H_2 Integration in Existing Infrastructure	Infrastructure development challenges: infrastructure for transportation: development and deployment of refueling infrastructure; RCS and standardization of technical components and systems; large-scale storage	Task 28- Large Scale H2 Delivery Infrastructure	Task 28 – creation of Infrastructure Roundtable and/or successor task to preserve the industrial network and continue HRS and related work Information on H2 refueling stations in Annual Report
APPLIED TECHNOLOGY	R,D&D H_2 Integration in Existing Infrastructure	Distributed systems	Task 29 – DISCO H2	Task 29 – possible extension on completion

		Bringing H_2 to the customer	Task 28, 29, 33	On completion of Tasks 28, 29 and 33 – extension or new tasks
		Distributed and community infrastructure; the optimization and replication of hydrogen especially "green" hydrogen	Task 29- Distributed and Community Hydrogen (DISCO H2) Task 33-Local H2 Supply for Energy Applications	Task 29-on completion, possible extension or new task to develop handbooks on community models; then design and undertake training Task 33 – likely extension on completion Power to Gas (P2G)/Power to H_2 /fuel task
		Infrastructure development challenges for multiple applications and the whole H2 value chain; storage - power to gas (H_2) – gas grid, geologic storage RCS and Safety	Task 31, Hydrogen Safety	New safety task
		Marine sector applications – foster smarter, greener, safer shipping in marine systems	-	Possible task to address reduced fuel consumption, emissions, noise, vibration and maintenance requirement
	THEME & PORTFOLIO	**KEY ISSUES**	**APPROACH In place 2014**	**APPROACH Proposed/Potential**
CROSSCUTTING	THEME: ANALYSIS THAT POSITIONS HYDROGEN Analyses that position H_2 *Technical* PORTFOLIO TECHNICAL	Role of H_2 in the energy mix; H_2 and competition, including cost data; System analysis on regionally differentiated resources, energy requirements and costs	Task 30 – Global H2 Systems Analysis: Subtask A – Global H2 Resources; Subtask B – H2 Data Base; Subtask C – Interaction with IEA analytics Techno-economic analysis in tasks	Successor task in definition; Life-Cycle Sustainability Assessment (LCSA); continued proactive cooperation with IEA analytics; updating of Task 30 Subtask B Hydrogen Technology database and companion handbook; Techno-economic analysis in tasks will continue
		Global roadmap for hydrogen	Development of IEA H_2 Roadmap underway; Task 28-Infrastructure played key role	Strategic and tactical response at all levels to Roadmap opportunity
		Status report on leading stakeholders and relevant global expertise		TBD – possible subject of ExCo Workshop; Annual Report
		Studies on H_2 from CO_2-free sources		TBD
		Status reports on maturity of technologies and state of the art	Included in Annual Report	LCSA; an analysis recapping all H_2 technologies; state of the art including costs, efficiencies, gaps to be used as reference manual
		Development/deployment of refueling infrastructure and expertise in associated risk analysis	Task 28, Infrastructure	Task 28 successor or infrastructure roundtable; TBD

	Analyses that position H_2 Market	Role of H_2 in the energy mix; H_2 and competition; Analysis of relevant expertise and lessons learned in other countries; periodic evaluation of gaps and barriers	Task 30 - Global H2 Analysis	Successor task in definition; Life-Cycle Sustainability Assessment (LCSA); build on Task 30 Subtask A Global H2 Resources Study, with likely use of GPAT; continued proactive cooperation with IEA analytics
		Status report on leading stakeholders and relevant global expertise		TBD
		How to bring H_2 to the customer	Task 33 - Local H2 Supply for Energy Applications Task 29 - Distributed and Community H2	Task 33 – likely extension on completion; update Task 23 database of commercial electrolysers Task 29-on completion, possible extension or new task to develop handbooks on community models; then design and undertake training
		Examine relevant market impacts as well as technical concerns; full hydrogen value chain; regional, country and international impacts of integrated gas and electricity projects on infrastructure and market design Information exchanges on H_2 infrastructure and costs;	Technology maturity Included in Annual Report	An analysis recapping all H2 technologies state of the art including costs, efficiencies, gaps to be used as reference manual; Competitive market analysis including a matrix of cost & performance for economic analysis
		Development and risk analysis for H_2 infrastructure deployment	Task 28 — Infrastructure	The Power to H2/Gas/fuel task in definition TBD
		Increase uptake of renewable energy		Study on financial mechanisms to integrate H_2 into renewable energy funding flows
		RCS and Safety	Task 31 — Safety	Successor safety task
	Analyses that position H_2 Support for Political Decision-making	Role of H_2 in the Energy Mix: lack of information and clarity about the benefits of hydrogen among stakeholders and decision makers whose influence is needed and useful for R&D, planning, demonstration and deployment		Successor task in definition
		Analysis of relevant expertise and lessons learned in other countries		Messages developed from all tasks and portfolios; plus briefs and Position Papers from
		Policy and advising;		Messages developed from all tasks and portfolios; plus briefs and position papers on selected topics
		RCS and safety		New safety task plus include in individual tasks

	THEME & PORTFOLIO	KEY ISSUES	APPROACH In place 2009	APPROACH Proposed/Potential
CROSSCUTTING	H_2 Awareness, Understanding and Acceptance *Information Dissemination*	Broader and deeper information dissemination needed along with targeted dissemination. how to bring H_2 to the customer) -status reports on maturity of technologies -renewable H_2 only (EC long term goal) -being active in the media (visibility) -active lobbying to lower "activation energy" in H_2 technology deployment	An element of Outreach Program managed by Secretariat, it features: Website Annual Report Conference strategy Communication/Promotion materials, including newsletter Public relations and media -Contributions to IEA events and publications -End of Task Workshops Target audiences include: IEA member countries and partners as well as non-member countries and IEA family BRICS and potential H_2 members Hydrogen community	Increase information Dissemination by Continuing current activities and augmenting with: ▪ Enhanced Conference Strategy that features HIA End of Task Workshops /broader workshops ▪ Full use of new website ▪ Social media strategy ▪ Webinars as tool for disseminating all task products ▪ Increased visibility via media and conferences ▪ Expand target audiences Non-IEA member countries/ Developing world ▪ Greater energy community
	H_2 Awareness, Understanding and Acceptance *Safety*	All aspects of hydrogen safety and consumer comfort with hydrogen Hazard assessment / QRA tools for H_2 and HCNG/CNG applications	Tasks 1 and 31	Successor task expected to be approved early in term.
	H_2 Awareness, Understanding and Acceptance *Outreach*	Inform and engage with HIA and hydrogen RCS and safety how to bring H_2 to the customer status reports on maturity of technologies renewable H_2 only (EC long term goal) being active in the media (visibility) active lobbying to lower "activation energy" in H_2 technology deployment deepen cooperation with Paris regarding the WEO and ETP reports	An Element of Outreach Program directed by ExCo and managed by Secretariat. Some key aspects: Opened ExCo Membership to Sponsors Ongoing outreach to IEA, notably to Analysis groups and REWP Include country Member profiles in Annual Report Established Intern Program	Enhance strategy and activities to inform and engage through information dissemination and targeted networking. Increase membership. Build participation. Influence stakeholders and decision makers. Enhance visibility. Some specifics: Actively seek Sponsor Members Follow up with targeted/prospective Contracting Parties Initiate Post-Doctoral Fellowship program Formulate and disseminate policy related messages