SUMMARY OF ENVIRONMENTAL IMPACTS FROM GREEN HYDROGEN PROJECTS

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Título:

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Santiago de Chile, 20 de octubre de 2020

Memorandum

September 16, 2020

TO: Donny Holaschutz, inodú

FROM: Jeffery Preece, EPRI

SUBJECT: **SUMMARY OF ENVIRONMENTAL IMPACTS FROM GREEN HYDROGEN PROJECTS**

The studies highlighted in this memorandum are for recently announced small pilot/demonstration projects often attached to existing renewable wind and/or solar installations and/or to the intended end use of the project. Larger projects have recently been presented in the media but are at initial stages and environmental impact studies are not available or have not been made public. We intend to incorporate additional information from larger projects in a future memorandum.

The following studies are evaluated from Australia, Canada, and Spain:

1. Yara Pilbara project in Australia: Generation of hydrogen to be used at an adjacent ammonia production fertilizer manufacturing plant.
2. Western Sydney Green Gas project in Australia: Hydrogen generation using green energy from the grid, storage, blending with natural gas and distribution through natural gas network to be used for power generation through combustion at a converted microturbine.
3. Wind energy project at Katinniq in Canada: Generation, storage, and use of hydrogen for fuel cell power generation using wind turbines at an existing mine site to meet power and heating needs.
4. Photovoltaic system for green hydrogen production at Plasencia del Monte in Spain: Generation with solar energy and green energy from the grid, and storage and transport to be used for mobility or to blend with natural gas and be injected into the natural gas network to be used as renewable gas.
5. Hydrogen liquefaction plant in the City of Carson, California, USA: Liquefaction of hydrogen gas generated in an adjacent steam methane reforming (SMR) plant that will be transported in trucks to industrial customers in Southern California.
6. Hydrogen fuel stations in California - Permitting and California Environmental Quality Act (CEQA) reviews: A review of relevant permitting and CEQA requirements for the installation and operation of hydrogen refueling stations in California. The environmental assessment report for the hydrogen refueling station in Burbank is briefly analyzed as a typical environmental impact assessment for a small (test) scale operation.
7. BlueMed Sealines Initiave, re-use of offshore infrastructures for energy transition: Repurposing of abandoned offshore platform in northern Adriatic Sea off the coast of Italy as a scientific research hub with a renewable generation demonstration project using

wind and solar energy to generate hydrogen and platform sea lines to transport or store and transport hydrogen for sale inland.

8. Expansion of Ganjam Chlor-Alkaly Plant in India to Produce Caustic Soda and Other Chemicals: Additional hydrogen boiler included in planned plant expansion to burn chilled hydrogen generated during salt processing with cell membrane technology to produce steam for caustic soda processing and other processes.
9. Hydrogen engines/turbines for power generation: Use of hydrogen engines and turbines for power generation is mostly at pilot or demonstration stage, especially for engines. Case studies and reports from around the world reporting on engine/turbine use and applicable standards and regulations are considered.

Environmental impact assessments typically focus on impacts to local human populations, national heritage, flora, fauna, land use, and air quality of projects that involve siting, construction, operation, and decommissioning and are found to be subject to existing regulations or policies. Countries around the world set a variety of standards on how these reports should be presented and areas of concern to be addressed. In most cases, these reports are prepared by specialized independent companies and are available for public scrutiny and comment for a period of time, typically one to three months but sometimes longer periods, depending the scope and social impact of the project. Our recommendation for a thorough environmental impact assessment, based on the studies reviewed and on information found in the literature, is to provide information on the following elements:

- Water use: source, consumption requirements, purification technology and components, fate and impacts of any wastewater generated by the purification process and fate and associated environmental impacts of wastewater produced by the electrolyzer.
- Land use, flora and fauna, and heritage site impacts: expanding existing facilities to accommodate great hydrogen projects or creating new facilities on undeveloped land both require specific investigations unique to each location.
- Hydrogen leaks: loading/unloading operations, storage, distribution through gas pipelines or dedicated hydrogen pipelines, road transport, refueling.
- Hydrogen hazards: strategies to minimize and mitigate impacts of fire or explosion from accidental leaks or releases, both on site and downstream.
- Community engagement: engagement of stakeholders, local communities, and potentially a wider audience is key for future project expansions. An assessment could list all project promotion efforts, community outreach programs, presentations, conferences, questions and answers.

We have summarized noteworthy information for the referenced case studies below.

1. Yara Pilbara (Australia) – inodú projects I & VIII

   The project involves the construction and operation of a renewable alkaline or proton exchange technology (PEM) hydrogen electrolysis plant and an 18 MW solar photovoltaic farm in the Burrup Strategic Industrial Area of the region of Pilbara in Western Australia. The plant will have an expected output of 640 tonnes of hydrogen per year that will be consumed for ammonia production (Haber-Bosh process with carbon capture and storage) in an adjacent fertilizer production plant (the electrolyzer will produce about 0.4% of the plant's hydrogen gas requirements). The electrolyzer will use desalinated water from an existing desalination plant that supplies water to the fertilizer plant. The electrolyzer plant will have electrolyzer modules, a purification system to remove oxygen and water from the hydrogen stream, a compressor to achieve the required spiking pressure needed for ammonia production, a cooling system and the necessary balance of plant elements[1]. The estimated 14,400 kg/day of oxygen produced by the plant will be vented to the atmosphere. No hydrogen storage is mentioned in the study.

The environmental impact study was a requirement of the Environmental Protection (EP) Act 1986, Part IV Environmental Impact Assessment, in accordance to section 3.1.3 of the Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2016. In addition, the study was referred to the DAWE[2] due to the presence of protected fauna species listed under the EPBC Act[3]. The conclusion of the impact assessment is that the impact of the proposed renewable hydrogen plant could be managed under Part V of the EP Act.

a. Water treatment – Desalinated water for the hydrogen electrolyzer, which is subject to strict purity requirements (very low concentrations of dissolved solids), is obtained from an existing Water Corporation desalination plant that takes in water from the Mermaid Marine Harbor and provides desalinated water for cooling and firefighting purposes to the fertilizer plant. The brine produced by the desalination process and treated wastewater from the fertilizer plant are discharged through a 4 km pipeline and 1.4 km Indian ocean outfall[4] into the Mermaid sound, King Bay. The desalination plant is approved under the EP Act (MS 594). The relevant policies applicable to the desalination plant are Australia's *Environmental Factor Guideline - Marine Environmental Quality* and Technical Guidance Protecting the Quality of Western Australia's Marine Environment (EPA 2016h). The desalination plant is authorized to operate at a capacity of approximately 1.6 ML of seawater per hour and a storage capacity of 2 ML. The additional water output required by the hydrogen plant will be within the existing desalination plant's current approvals. Consequently, the project is not considered to result in significant impact to marine water quality.
b. Construction and operation of the electrolyzer plant: It will require the update of the existing Dangerous Goods Site License and the Approval for the operation of a Major Hazard Facility of the fertilizer plant, according to the Dangerous Goods Safety Act of 2004[5] and obtained from the DMIRS[6]. The updates will refer to the

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[1] Separators, potash lye system, heat exchanger, circulation pumps, transformers, rectifier and metering.
[2] Department of Agriculture, Water and the Environment.
[3] Environment Protection and Biodiversity Conservation Act 1999.
[4] A 40 m mixing zone at the outfall allows wastewater and brine from the existing fertilizer plant to meet ANZECC & ARMCANZ (2000) 99% species protection criteria for toxicants on entry into the brine discharge system under the existing approvals to operate.
[5] Link for Dangerous Goods and Safety Act of 2004: https://www.legislation.wa.gov.au/legislation/prod/filestore.nsf/FileURL/mrdoc_43039.pdf/$FILE/Dangerous%20Goods%20Safety%20Act%202004%20-%20%5B01-f0-01%5D.pdf?OpenElement
[6] Department of Mines, Industry Regulation and Safety.

safe handling and disposal of the hazardous substances used during plant construction (fuel, oils, etc.) and any hazards associated with the operation of the hydrogen plant.

c. Land use – Even though this project is located at an existing facility, an impact study on land use, flora, fauna, and heritage sites was required. Australian policies included *Land use and development: Planning and Development Act 2005*; *Environmental Factor Guideline: Flora and Vegetation (EPA 2016a); Statement of Environmental Principles, Factors and Objectives (EPA 2018b);* technical guidance documents specifically for terrestrial fauna, vertebrate, bats, mammals, and reptiles; *Environmental Factor Guideline – Social surroundings (EPA 2016f).* There were no unique factors identified for this project.

2. Western Sydney Green Gas (Australia) – inodú projects I, III, IX
Power-to-gas project in Horsley Park, New South Wales, Australia, promoted by Jemena Gas Networks (NSW) Limited to use green energy from the grid to generate up to 52,600 kg/yr of hydrogen using a 500 kW PEM electrolyzer and up to 2,135 L/day of deionized tap water. The project contemplates disposal of wastewater generated through an offsite authorized waste facility, reuse onsite for irrigation or onsite treatment and disposal and reuse. The power-to-gas plant will consist on a water tank, wastewater pump, control hut, electrolyzer package (including final water treatment, electrolyzer stack, purification & cooling systems), a 100 kg hydrogen buffer storage (a buried carbon steel pipeline), gas and injection panel package and hydrogen turbine. The hydrogen gas will be stored onsite and blended with natural gas with up to 2% by volume of hydrogen and injected into the Sydney secondary distribution network for domestic and industrial use. The hydrogen will be also supplied to a microturbine to generate electricity to export back to the grid, once the turbine is fully converted to burn hydrogen. Future project expansion contemplates building an adjacent bus hydrogen refueling station to use the hydrogen generated and perhaps installing 550 kW onsite solar generation to produce electricity.

   a. On-site hydrogen storage – Hydrogen is flammable and explosive over wide ranges of concentrations. Storing pure hydrogen on site requires engineering and safety protocols to ensure protection of workers, equipment, and nearby communities. An analysis was performed to identify scenarios of flash fires that would potentially extend outside of the site boundary. Conditions leading to various leaks and equipment failure are documented according to *GPA Engineering 2019c* along with events that could lead to failure, and frequencies and consequences of certain events. The consequence analysis was performed using the DNV GL hazard analysis program *Phast (version 8.1).* From this analysis, the final design will incorporate a firewall at the high-pressure storage area capable of mitigating the most severe event (in accordance to *AS 1596 'The Storage of Handling of LP Gas'* and the *U.S. NFPA 2 'Hydrogen Technology Code'*).

   b. Hydrogen blending in natural gas infrastructure – Distribution hydrogen to end users will be critical to economic viability of the entire value chain. This project starts with a 2% hydrogen blend and considers a limit up to 10% by volume which might only occur during temporarily release of hydrogen in the network (caused by a failure). An evaluation was conducted with the following policies and codes: *National Standard AS 4564-2011; Gas Supply Act 1996 (GS Act); Safety and Network Management Regulation 2013; and Pipelines Act 1967, Clause 11*. The analysis concludes that all considered blends are compliant to Australian standards and within allowable range for the expected range of natural gas compositions.

c. Water treatment – The 500 kW PEM electrolyzer used for this project is capable of producing 100 Nm^3/h of hydrogen and requires 1,600 L of desalinated water. The water desalination process would generate 535 L of wastewater (concentrated brine) with a concentration of 500 ppm total dissolved solids (TDS). The project intends to truck this wastewater to a water treatment plant (which has this exact salinity limit) or reuse it for irrigation (pending regulatory approval but noted compliance with *ANZECC and ARMCANZ, 2000;2018* guidelines). No decision or approval has been made yet for either option. The source water would be treated onsite and would be delivered by the local water authority. This agency has requested the site plan for recycled water to be included with potable water supply in order to minimize water security concerns.

d. Social considerations – Concerns over increased cost were expressed by various agencies. The cost of green hydrogen is higher than natural gas, but the Australian Gas Infrastructure Group (AGIG) believes hydrogen cost reach parity with natural gas by 2030. The cost of this specific project will not be paid for by consumers. Owners for nearby properties have expressed concerns that the property values of land will decrease in value over time. There is not a clear consensus whether this would occur.

3. Wind energy project at Katinniq (Canada) – inodú projects I, III, & V
   Installation of six wind turbines (3 MW each) to produce a nominal power of 18 MW for the grid. Excess energy will be used for hydrogen production, storage and electricity generation with a fuel cell unit to also feed the grid and meet local thermal and power needs. The hydrogen production system will consist on a water purification system capable of processing about 1000 L/day of tap water, electrolysis system, compressor, hydrogen storage in a 200 bar and 276 kg horizontal tube trailer, a fuel cell system and a demineralized water management system. Information regarding electrolyzer technology, fuel cell type or demineralized water management system is not provided.

   a. Public perception – Many consultation events were carried out over multiple years to gain input from various organizations. The proposed project to generate hydrogen and use fuel cells at an existing mine site faced many concerns raised by the public. A list of concerns related to land use, environmental impacts, water quality, and socio-economic impacts is documented by the project team. The list relates to the use of wind turbine to generate electricity (both to the grid and for site use), production of hydrogen, and use of hydrogen to generate electric power. The original project considered multiple locations and only the Katinniq project is being pursued, partially in response to feedback various organizations.

   b. Hydrogen safety – A safety zone will be created based on the results of a technical study conducted to assess risks of fire and explosion. Concern is expressed by the community on potential hazards of hydrogen storage and operation of the fuel cell. In the section dedicated to questions from the community these concerns are addressed indicating that the technology is mature, regulations exist to ensure proper handling and storage of hydrogen, and an inspection of the facility will be carried out every five years.

c. Water use - Concern is expressed on disposal and source of water needed to produce hydrogen. The water will be supplied by Katinniq, and no disposal will be needed as the water will be reused in the system (closed-circuit).

4. Photovoltaic system at Plasencia del Monte (Spain) – inodú projects I, III, IV, & V
Production of about 6000 ton/yr of hydrogen in Plasencia del Monte, Huesca, Spain, with a 40 MW alkaline electrolyzer using an onsite 39,36 MW photovoltaic plant and green energy from the grid. The hydrogen will be loaded in trucks and used for mobility or transported through a 2.5 km pipeline to a station built in a nearby gas line to be blended with natural gas and injected into the gas network to be sold as renewable gas. The water (1,5 L used per m^3 of hydrogen produced) required for the electrolysis unit will be demineralized and the 4,000 L/h of wastewater generated will be recycled through a separate demineralizer to be reused for electrolysis or for agricultural irrigation and PV panel washing. The system will have a water pre-treatment system, the electrolyzer package, a water purification system, a storage system (to store about 3,2 tons of hydrogen at 500 bar through a series of connected storage tanks), a compressor, an additional purification system by deoxidation, a gas drying system and a hydrogen dispenser to fill the trucks. No specific information on the truck characteristics, dispensing and ratio of hydrogen blending with natural gas is provided.
   a. Water use – Water for the electrolysis unit will be demineralized and wastewater will be recycled through a separate demineralizer to be reused for electrolysis and ultimately reused for agricultural irrigation and PV panel washing. The source of water is not identified in the environmental study.
   b. Hydrogen storage and distribution – Part of the hydrogen will be loaded in trucks to be transported offsite and used as fuel for hydrogen vehicles and part injected into the natural gas network. For the latter, a pipeline for the transport of hydrogen to the nearest gas pipeline will be built. This project requires building the necessary infrastructure to blend the hydrogen with the natural gas and injection of the blend into the gas pipeline. While regulations are not specifically referenced in this particular document, we would like to point out relevant work in the HyLAW project conducted through European Union's Horizon 2020 research and innovation program. The European Union and United Kingdom are each working towards defining relevant regulatory frameworks for future projects.

5. Hydrogen liquefaction plant in the City of Carson, California (USA) by Air Products and Chemicals, Inc. – inodú projects II and IV

   Initial study for the installation of a 10-metric ton/day cryogenic hydrogen liquefaction plant to process about 4% (4 million standard cubic feet of hydrogen gas per day) of the hydrogen gas produced by the existing adjacent Air Products and Chemicals, Inc. Carson SMR hydrogen gas production plant. The project will increase onsite storage of hydrogen by 70,000 pounds (120,000 gallons) and the liquified hydrogen will be stored in two 60,000-gallon horizontal stainless steel (inner shell) and carbon steel (outer shell) vessels. The transport of the liquid hydrogen to industrial customers in Southern California will require an average of 4 tanker diesel heavy duty truck trips per day. The liquefier will have feed pre-treatment, heat exchangers, catalyst vessels, and compression equipment for providing refrigeration duty along with other process vessels (aftercoolers, oil removal and separators).

a. Plant construction and operation −The project will require application to SCQAMD[7] for an Authority to Construct (ATC) permit as a facility that will emit regulated airborne emissions and comply with several rules[8]. The existing Air Products hydrogen gas production facility's permit to operate (PTO) will have to be modified to reflect anticipated emissions from the liquefaction plant, in accordance with emissions thresholds set in the ATC for the new equipment. The study concludes that the additional air emissions created by the operation of the project will be within the envelope of the contemplated operational capacity functionally assessed within the existing Air Product's hydrogen gas facility 1998 CUP (Conditional Use Permit). Additional direct and indirect operation emissions are below the SCQAMD's daily significance threshold levels. Mitigation measures contemplated in in the Air Product's 1998 CUP permit and environmental impact report (EIR) were reviewed for applicability to this project and modified where appropriate to reflect existing regulatory requirements. Greenhouse gas emission are also evaluated for construction and operation and found to be not significant (less than 10% of the SCAQMD CEQA significance threshold for GHG C02 equivalent of 10,000 metric tons per year).
b. Project hazards: Air Products conducted an off-site consequence analysis document addressing a worst-case, accidental on-site release scenario as well as an informational document on design considerations, procedures/processes and training to ensure safe LHY transport/delivery that were provided with the application package. The analysis concluded that impacts of the proposed hydrogen liquefaction system would produce smaller impact zones than those examined in the exiting facility's 1998 EIR and will not extend into residential areas. In addition, the study indicates that Air Products may have to update the existing California Unified Program (CUPA) of the existing hydrogen gas production facility with the Los Angeles County Fire Department, Hazardous Materials Division, the existing Notice of Intent (NOA) and SWPPP[9] with the Los Angeles Regional Water Quality Control Board, the monitoring plan for the mandatory reporting regulation under AB 32 for greenhouse gases with the

[7] Southern California Air Quality Management District.
[8] Rule 201 (permit to construct), Rule 203 (permit to operate), Rule 212 (standards for approving permits), Rule 301 (permitting and associated fees), Rule 401 (visible emissions), Rule 402 (nuisance), Rule 404 (particulate emissions), Rule 407 (liquid and gaseous contaminants), Rule 1166 (volatile organic compound emissions from decontamination of soils), Rule 1303 (new source review requirements), Rule 1401 (new source review of toxic air contaminants), Rule 1403 (asbestos emissions from demolition/renovation activities), Rule 1402 (control of toxic air contaminants from existing sources), Rule XX (Regional Clean Air Incentive Market (RECLAIM) including key rules (Rule 2005: NSR for RECLAIM), Rule XXX (Title V permits).
[9] Storm Water Pollution Prevention Plan.

CARB[10], and probably add an amendment to the California Accidental Release Program (CalARP) and Federal Risk Management Program (RMP).

c. Truck trailer transport: The trucks will be using designated routes for commercial vehicles over 6,000 pounds to minimize emissions and hazards to residents and cover an average of 500 miles. The trucks have a double walled steel trailer with a maximum capacity of 14,000 gallons equipped with pneumatic fire control valves and relief valves located at the rear. Offloading of hydrogen will be done through connection to a system with double walled metal hose that is purged with helium. Any excess vapor will be vented at the offloading site. The study finds that the risks of truck transport of hazardous materials would be below the levels identified in the 1998 EIR for the existing Air Products hydrogen gas facility (average of 14 trucks per day), so no additional mitigation measures are required.

6. Hydrogen refueling stations in California – Permitting and California Environmental Quality Act (CEQA) reviews − inodú project VI.
The State of California in the USA has the most stringent air quality regulations in the country and is aggressively investing in carbon free technologies for power and mobility, among other objectives. As a result of more than a decade-long experience fostering hydrogen technologies for mobility, several guides have been published to inform potential investors of the permitting and regulatory requirements they may have to face when installing refueling stations with or without onsite generation. According to the guides the four key environmental permits and regulations to watch for are the following:
    a. Land Use permits: These permits are required for new developments and issued by the local city or county. Typically, they require compliance with detailed fire code and technical safety standards, and requirements for site drainage, water discharge, grading, electrical and similar issues. Because of the hazards of handling hydrogen technical requirements concerning piping, tankage, fire safety, ignition control, emergency shut-off, electricity, corrosion protection, and related matters drawn from the California Fire Code, the California Building Code, and various professional standards.
    b. Air quality permits: Hydrogen is not a regulated pollutant and storage and dispensing of hydrogen will not usually require a permit. However, if onsite generation is also installed and produces emissions (such as SMRs) a permit may be required by the local air quality district. Typically, the air quality district will require permits from the natural gas burners that are part of SMRs if the emissions are above a certain level. For small scale operations the emissions are usually well below those limits.
    c. The CalARP: Existing hydrogen refueling stations in California have not been typically subject to the CalARP because they handle less than the threshold amount of 10,000 pounds of hydrogen. Buildings handling more than 10,000 pounds of hydrogen are required to prepare a Risk Management Plan (RMP). The RMP includes information about the safety information, a hazard review, safe operating procedures, training and maintenance requirements, compliance audits, and incident investigation procedures. CalARP also implements the federal Risk

[10] California Air Resource Board.

Management Plan regulations adopted by the U.S. Environmental Protection Agency (US EPA) under the Clean Air Act, together with more stringent California requirements. CalARP is administered by local certified unified program agencies (CUPAs).

d. California Business Plan: Stations that handle more than 55 gallons of liquid hydrogen or 200 standard cubic feet of gaseous hydrogen must prepare business plans and inventories. The plan includes a chemical inventory and site map, safety and emergency response procedures, and training programs and are administered by the CUPAs.
e. Compliance with the CEQA: Usually the lead agency responsible for the area for the proposed project will decide whether a project is subject to the CEQA through an initial study. Based on this study the agency will declare that the project has no negative impacts, negative impacts that can be compensated with mitigation or significant impacts. If significant impacts are found, the agency will require the preparation and certification of an environmental impact report to further assess the project. Several exceptions may apply for hydrogen refueling stations that may release the projects from compliance with CEQA[11]. For example, if the refueling station is built in an existing gas station it may be exempt from compliance with CEQA.
f. Case study: Burbank hydrogen refueling station.
The Burbank hydrogen refueling station was proposed by Chrysler LLC., BP America Inc., and the City of Burbank and consisted in the upgrade (removal and replacement) of an existing electrolysis hydrogen gas station for a SMR generator, storage system, dispensing system for both 350 and 700 bar and necessary associated equipment. The station will be able to store and dispense approximately 108 kg/day of hydrogen and will consist on five primary modules, a 108 kg/day SMR hydrogen generator and low pressure surge vessel, a 350 bar compression system, a gaseous buffer storage (~240 kg), a 700 bar buster compressor and an automatic dispenser/cooler system. Because of the design features of the system and the safety procedures stablished to be followed by operators, a HAZID evaluation conducted for the study concluded that any accidental hydrogen release will be minimized and the impact to public safety would be less than significant. The study finally concluded that, after analyzing potential impacts to air quality, land use/planning, hydrology/water quality, safety hazards and hazardous materials, a negative impact declaration was appropriate.

7. BlueMed Sealines Initiave, re-use of offshore infrastructures for energy transition − inodú projects I and III.
Repurposing of abandoned offshore platform in the northern Adriatic Sea off the coast of Italy to build a research station and test system, technologies and methods to support energy transition from fossil fuel to green energy. The proposal is to install 60 330-W peak solar panels and one 100-kW wind turbine to feed a 100-kW peak PEM electrolyzer for the production of hydrogen. Wave energy generation is also considered but not

[11] Most of CEQA's statutory exemptions are listed in Article 18 of the CEQA Guidelines, sections 15260-15285

included in the final project proposal. The project contemplates using the existing sea lines as power lines to send electricity generated by wind/solar/wave energy combination (option 1), the storage and transport of the hydrogen generated inland using nearby platforms gas lines to inject the hydrogen and sell it at the same price as natural gas (option 2), transportation of the hydrogen gas inland using the existing platform sea lines and store onshore before selling it as technical gas (option 3) or storing up to 1,852 kg of hydrogen at a maximum pressure of 330 bar in the sea lines before selling inland as technical hydrogen gas (option 4). Information on components of PEM electrolyzer, source of water, water purification system and fate of wastewater generated by the electrolyzer is not provided. Water consumption by the electrolyzer is indicated to be about 1 L of demineralized water per 0.09 kg of hydrogen produced.

a. Decommissioning of abandoned platform: <u>Regulations, responsible parties and costs for platform decommissioning and repurposing must be considered for the project</u>. If no other local or regional regulations exist the international requirements for offshore decommissioning that usually apply are the United Nations Convention on the Law of the Sea (UNCLOS III) 1982 jointly with the International Maritime Organization's (IMO) Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone (EEZ), adopted in 1989. In the Mediterranean Sea the 1976 Barcelona Convention and Articles 5 and 20 of the Offshore Protocol (effective from 2011) covering Oil & Gas activities apply. The articles require decommissioning plans for any exploitation application and require that the operator dispose of any unused or abandoned structure to ensure other safety of other users of the sea, navigation and to safeguard the environment. Operators are also required to remove any existing sea line or to provide cleaning and burying of the lines. The Italian framework also applies in this case and applications for reuse or repurpose of decommissioned platforms must be filed with the Ministry of Economic Development. <u>Project participants recognize that there are gaps in local and international legislation that must be corrected</u>. The report also provides case studies of decommissioning regulations and protocols followed in UK, Norway, Greece and Croatia as a guide for the project.
b. Use of sea lines for hydrogen storage and transportation: The report considers issues such as hydrogen energy content and volume considerations compared to those of natural gas (to transport and sell hydrogen inland), addressing of potential material embrittlement by hydrogen and leaks in the sea lines with careful pipeline and welding testing, testing for volumetric losses during normal operations at different flow rates, choice and number of compressors to transport the hydrogen and maximum pressure and amount of hydrogen that can be stored in the sea lines.

8. Expansion of Ganjam Chlor-Alkali Plant in India to Produce Caustic Soda and Other Chemicals − inodú project XI.
The project involves the expansion of an existing membrane cell caustic soda production plant in Ganjam, India, to increase caustic soda production and add the other chlorine-based chemicals. The project will add a 12 ton/day capacity hydrogen boiler to the existing 9 ton/day capacity hydrogen boiler. Both boilers will be started-up with furnace

oil (about 2.5 ton/day of oil will be needed for both boilers burning 2600 Nm^3/day of hydrogen). The manufacturing process involves the electrolysis of sodium chlorine and demineralized water to produce caustic soda with hydrogen and chlorine as coproducts. The 0.09 tons/day of hydrogen generated by the process will be chilled and used partly to produce HCl and partly to burn in a hydrogen boiler to produce steam for caustic soda processing and other processes and reduce emissions. No storage of hydrogen is required. The boiler will produce PM_{10}, NO_x and SO_x emissions when burning furnace oil. The hazards transporting hydrogen through pipelines to the boiler are evaluated.

a. Water use, recovery and disposal: A second reverse osmosis plant will be added with the expansion project to increase water recovery from the wastewater effluent. About 15 kL/day of wastewater will be produced from boiler blowdown and will be processed by the effluent treatment plant and disposed in the guard pond. Water use estimated for the two hydrogen boilers will be about 120 kL/day and will be sourced from groundwater.
b. Hydrogen boiler emissions: PM_{10}, NO_x and SO_x emissions will be produced by burning furnace oil during boiler start-up. The emissions from the additional boiler will reduce amount of furnace oil needed to produce additional steam for the plant. The emissions were evaluated with the dispersion model AERMOD and are within permissible levels and will not exceed the NAAQS (National Ambient Air Quality Standards).

    Hydrogen hazards analysis: pipeline failure frequency, possible causes of pipeline leak of rupture and, ultimately, ignition are evaluated and compared to the 9th European Gas Pipeline Incident Data Group (EGIG) database. Failure frequency for the pipeline is below EGIG database values and risk of leak or rupture is considered remote. Ignition probability from pipeline leaks or rupture estimated using IGEM/TD/2 standard is found to be unlikely. A consequence analysis is also undertaken to evaluate risks to onsite personnel, infrastructure and the environment from pipeline failure, ignition and jet fires (explosions are considered unlikely for a hydrogen gas plant). The risk scenarios evaluated using the ALOHA model are found to be below levels of concern and limited to a radius of 12 m. from the source. No sensitive areas are expected to be impacted. A disaster management plan is prepared assigning actions to contain the hazardous situation, minimize risks and provide rehabilitation to affected persons and prevent damages to property and the environment.

9. Hydrogen engines/turbines for power generation − inodú project X.

Hydrogen engines and turbines for power generation are mostly at the pilot or demonstration stage Hydrogen engines are mostly considered for use in ships and airplanes to provide propulsion and power. Small natural gas turbines retrofitted to burn hydrogen are already a reality, as indicated in the Western Sydney Green Gas project. The Australian national hydrogen roadmap published by the Australian National Science Agency considers the combustion of hydrogen rich gases (co-firing) for large scale (>100 MW) energy requirements. The most recent European Turbine Network (ETN) Global report on zero-carbon gas turbines focuses on the hydrogen gas turbines value chain, retrofitting and available technologies. The Japan Technology Ship Association published a 2020 report titled "Roadmap on Zero Emissions for International Shipping" is one example. Use of hydrogen engines for airplane propulsion is not considered here, but pilot projects exist mostly in Europe.

a. Australian Hydrogen Roadmap: The report discusses the combustion of hydrogen-rich gases (cofiring of blends of 5-60% hydrogen) for large-scale centralized electricity generation systems (> 100 MW). Turbines burning 100% hydrogen are not considered because of issues with material stress from high temperature H_2/O_2 reaction, high NO_x emission when air is used and management of corrosion on low temperature materials from water produced by the reaction. Applicable regulations and standards and gaps with respect to hydrogen are analyzed in Appendix B. If the hydrogen and natural gas blend are transported through pipelines or trucks, in Australia, the Gas Supply Act and National Gas Law are applied for gas processing, transport, commercialization and customer protection. The safety regulation that applies is the Workplace Health and Safety Regulation, mandated through the Commonwealth Work Health and Safety Act (2011). Major hazard facilities, like those operating with hydrogen, are classified according to the various state regulations and may require further licensing, regulation and safety studies. Existing Australian standards relevant to hydrogen turbines are AS/NZS 5601.1 - Gas installations, and AS 3814 for industrial and commercial gas-fired appliances. General international standards that may apply are the ISO/TR 15916 – Basic considerations for the safety of hydrogen systems and ISO 26142 – Hydrogen detection apparatus for stationary applications.
b. European Turbine Network (ETN) Global report on zero-carbon gas turbines: Hydrogen combustion technologies for power generation are discussed, including issues with high temperature reaction and NO_x emissions. Most turbines work with a diluted hydrogen mixture with other fuels (typically ~20% in volume of hydrogen but with some turbines able to handle 30-60%). Use of hydrogen strongly alters the combustion properties of "hydrogen blends" with respect to natural gas. Adding hydrogen to natural gas tends to increase its flame speed, reduce its ignition delay time, and enlarge its flammability. Retrofitting of natural gas turbines is possible but must account for hydrogen flammability, embrittlement of materials and different hydrogen purging needs. There are no specific international standards applicable to hydrogen operation for gas turbines, but general rules for hydrogen operation that may apply are ISOTR 15916:2000 Basic Considerations for the Safety of Hydrogen Systems, the U.S. Department of Energy Office of Scientific and Technical Information technical report INEEL/EXT-99-00522 Safety Issues with Hydrogen as a Vehicle Fuel and in the National Fire Protection Association standard NFPA 50A Gaseous Hydrogen Systems at Consumer Site. Local and regional existing standards and zone classifications for use of hydrogen will usually apply for gas turbine enclosures operating with hydrogen.
c. The Japan Technology Ship Association "Roadmap on Zero Emissions for International Shipping": Designs of hydrogen engines for two different sizes of ships using liquified hydrogen as fuel are considered. Regarding use of hydrogen, thermal protection systems and measures to prevent hydrogen leaks are considered in the design. International Maritime Organization (IMO) existing standards on liquefied natural gas-fueled ships in the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) may apply. However, the report recommends revisions to make the standards more specific to

the use of liquefied hydrogen as fuel in ships. Revision of existing marine fuel standards, such as ISO 8217, or the formulation of new standards may also be necessary.

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