Study on Green Hydrogen Production from Geothermal for Domestic and International Market

A part of the GIZ- Government of Indonesia ExploRE technical cooperation programme

Stakeholder Consultation Meeting with GIZ & Pertamina

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Agenda

1. Opening speech by GIZ and Pertamina
2. Study Background & Overview
3. Technical assessment of green hydrogen potential in Indonesia
   - Assessment of Indonesia's Geothermal Potential for Hydrogen Production
   - Potential Hydrogen Generation and LCOH Predictions
   - Pertamina's "optimization" projects
4. Market assessment of green hydrogen
   - Domestic market
   - Export market
5. Detailed analysis of green hydrogen in Indonesia

Study Background & Overview

Project Background

The Directorate General for New and Renewable Energy and Energy Conservation (DG-NREEC) Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) are jointly implementing the project called Strategic Exploration of Mitigation Potentials through Renewables (“ExploRE” and “Client”) which is funded by the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU).

This project is targeting those sectors where renewable energies can be applied economically, using innovative technologies and business models to generate clean energy and reduce fossil-fuel consumption.

Jacobs, a global technical and solutions advisory firm, was appointed by ExploRE to undertake a preliminary desktop study to assess the potential for Indonesia to develop green hydrogen geothermal sector of scale. Jacobs has brought together an international team with extensive experience in green hydrogen and geothermal technical and market feasibility analysis to conduct this study.

Jacobs

Canadian Nuclear Laboratories Jacobs is lead partner for $90M of hydrogen facilities supporting the development of hydrogen related expertise, products, and services, which support the deployment of a vast number of hydrogen end-uses

Metrolinx Hydrail H2 rail feasibility study

Caltrans conversion of fleet of intercity diesel locomotives to HFC

San Bernardino County Transit Authority Jacobs is the Owner's Engineer for the production of an HFC EMU by Stadler

H2 Sustainable Winery and Vineyard

Massachusetts Bay Transit Authority Preparation of design guidelines for the design of maintenance and refueling facilities for HFC buses

NASA Support to NASA across all but one of their operations centers covering storage, handling and refueling of rockets using liquified Hydrogen, plus advising on safety and materials.

Deeside Hydrogen Hub Development of the Strategic and Outline Business Case for N.Wales hydrogen hub, working for UK HM Treasury

Dundee Hydrogen Bus Deployment Project management and business case support

Strategy and delivery plan to develop of resilient, affordable and zero carbon energy supply to a large highway infrastructure programme and strategic infrastructure for hydrogen vehicles

Hydrogen Hub Planing for a green Hydrogen Industrial park in Netherlands

Masterplanning a green hydrogen hydrochemicals park and campus facility in Germany

Global Apparel Company Developed conceptual designs for a manufacturing facility to meet aggressive global sustainability targets around carbon and energy use. Multiple concepts were evaluated including 'green' hydrogen (solar PV to generate hydrogen via electrolysis), biomass, and natural gas boilers.

Global Data Centers Jacobs is supporting multiple global technology and software companies with the provision of sustainable energy advisory and engineering services globally. This includes innovative cooling and hydrogen storage solutions.

HyP Murray Valley Jacobs conducted energy market modelling for AGIG re integration of a 20 MW electrolyser to be blended with natural gas at volumes of up to 10% H2.

Yarra Valley Water preliminary engineering design, cost estimation and economic modelling for a 2.5 tonnes per day (6 MW) renewable hydrogen plant

Energy Port of Newcastle study to assess the pathways available to realise the vision for the Port of Newcastle as a future renewable energy hub, covering Hydrogen, solar, wind, tidal and biomass energy sources

AHC – Green Hydrogen Feasibility Studies In March, Jacobs was chosen by the newly formed Australian Hydrogen Centre (AHC) to assess the feasibility of renewable hydrogen production (via electrolysis) to achieve both up to 10% hydrogen blending and 100% hydrogen injection into the SA and Victorian gas distribution networks.

Welsh Government advised the Welsh Government and several local authorities to develop opportunities and outline delivery plans to accelerate the uptake of zero emission vehicles.

Welsh Government & North Wales Economic Ambition Board Hydrogen Market Assessment and Distributed Energy Generation Innovation - (heating, power and transport) and innovative distributed power and heating technologies

Energy Services 20 Year Business Strategy delivered an evaluation of market and policy drivers, capabilities and technology opportunities, including new flexibility and hydrogen markets for investment opportunities for distribution, transport and power generation

6MW renewable hydrogen plant provide preliminary engineering design, cost estimation and economic modelling for a 2.5 tonnes per day (6MW) renewable hydrogen plant

Green Ammonia Study Reviewed environmental baseline information and develop an approvals strategy for the proposed renewable H2 ammonia production facility at four potential locations in Western Australia

WA H2 Feasibility Study conducted a feasibility study to screen renewable and storage technologies and select feasible concepts to support production of green hydrogen across 5 deep water port locations in Western Australia

Hydrogen Hub Partnership Jacobs serves as equal partner, project manager and delivery lead along with two of our key energy and water clients. Ultimate capacity in the range of 50-100 MW

Jacobs: Hydrogen Expertise

Nuclear
Hydrogen High temperature electrolysis. Fusion design and safety

Liquified Hydrogen
NASA specialist teams operate across NASA launch & test facilities

Strategy
Developing decarbonization strategies and planning for hydrogen infrastructure

Energy Storage
Integration of HFCs into power infrastructure, manufacturing and commercial facilities. Based Crowdfunding

Export Import & Maritime
Design of facilities capable of handling liquified gases and LOHCs

Engineering design and Program Delivery
Undertaking the engineering and delivery of hydrogen developments

Safety & Risk
Detailed modeling and QRA capabilities relating to hazardous and explosive materials or substances

Specialty Chemicals & Hydrogenation
Specialist team of (de)hydrogenation SMEs with experience across industries re LOHCs and green ammonia

Materials Testing
2 * hydrogen materials testing laboratories located
- UK nuclear laboratories
- NASA test facilities

Energy Market Modelling
Specialist power modelling capabilities includes ability to accurately forecast prices, storage requirements and green hydrogen costs, supporting PPA agreements.

Mobility
HFC/EV integration and network planning for:
- Vehicles
- Rail
- Aviation
- Remote operations
- Green Fleet switch-outs

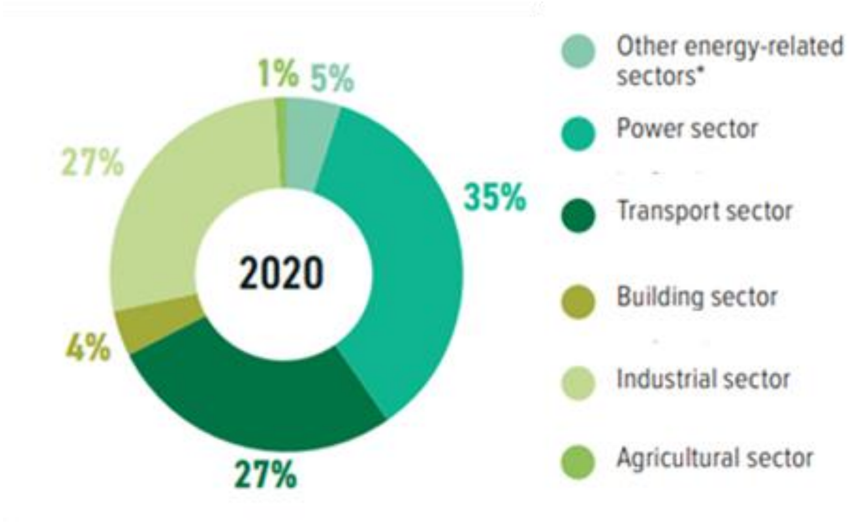
Power Gen and Networks
GT & Power team cover conversion of coal and gas plants to H2 and ammonia. Design of power networks integrating variable renewables/storage etc.

Gas Utilities
Integration of Hydrogen into gas utilities and power networks

Water
Developed unique economic models for integration of H2 into WWT facilities, for energy and efficiency

Emissions and Potential Hydrogen Demand

Indonesia CO2 emissions by Sector (2020)



Source: Climate Transparency, 2021

Indonesia has not drafted hydrogen strategy/roadmap. In general, the following potential green hydrogen demand or application are for sectors that cannot use direct electrification:

- Industrial sector: Ammonia, refinery, methanol production and direct reduction of iron ore in steel production
- Power sector: Long-term energy storage for off-grid systems, combustion in gas-fired power plant either in the form of ammonia or as an additive to natural gas
- Transport sector: FCEV for heavy transport operating over extended distance, synthetic fuel for air and maritime transport

Hydrogen Supply Chain – The Indonesian Opportunity

Manufacturing
- Advanced Facilities: FCs, Electrolysers

Production
- Green - Solar
- Green – Wind – on/offshore
- Green - Geothermal
- Green – wave/tidal
- Turquoise – waste/biomass gasification/pyrolysis
- Blue – CCS(U)
- Pink – Nuclear

Conversion & Storage
- Compression
- Tank Storage
- Geological storage
- Liquid Organic Hydrogen Carriers (LOHC)
- Ammonia
- Liquefaction
- Methanol
- Fuel Cells

Distribution
- Local H2/gas networks
- Road tankers
- Ports
- Shipping / Marine

Usage
- Aviation
- Marine
- HGVs/Buses/Mining
- Rail
- Light Vehicles
- Cement
- Iron and Steel/Metals
- Industrial heat
- Buildings
- Power
- Refining

Carbon Intensity Certification Requirements

H2 Required Now

H2 Required Future

Project Overview

The main objectives of this desktop study are:

- To assess potential production of green hydrogen from geothermal in Indonesia
    - Indonesia has committed, through its RUPTL, to use significantly more geothermal energy for electricity supply to support its energy transition to more renewal energy and decarbonize its economy.
    - Aside from these committed geothermal resources are there additional geothermal resources that could be used for green hydrogen production?
    - Are these geothermal resources of sufficient scale and suitable location to be viable as a source of energy for green hydrogen production?

- To identify and categorize the potential hydrogen applications – domestic and international.
    - Review latest hydrogen technologies
    - Note existing and future uses of green hydrogen
    - Map the domestic and international market potential for green hydrogen in Indonesia

- To provide detailed analysis on potential market priorities for green hydrogen geothermal in Indonesia
    - Combining key findings on the availability and suitability of excess geothermal resources in Indonesia and the market potential for green hydrogen the study will provide an assessment of overall potential for green hydrogen geothermal in Indonesia
    - Some specific commercial case studies are considered as part of this analysis
    - Some recommendations of next steps

Geothermal Resource Assessment

Geothermal Technical Assessment

Key Question

Are there suitable geothermal resources in Indonesia that would support the development of green hydrogen production?

Approach

- A high-level review of residual geothermal potential across Indonesia based on the Badan Geologi geothermal areas list, the ESDM "green book" (Buku Potensi Panas Bumi) and electricity plan (RUPTL) published by PLN
- Existing installed geothermal electricity power plants and planned additional geothermal generation stated in the PLN RUPTL 2021-30 are excluded
- An assessment of some existing brownfield optimisation geothermal power locations that might have potential to add further generation that could be used for green hydrogen production, without additional drilling
- Use a Jacobs modelling tool to estimate capex for greenfield projects with drilling and H2 Levelized Cost of Energy (LCOE) model to estimate the Levelized Cost of Hydrogen (LCOH2) per project

Indonesia's Geothermal Potential

National Geothermal Inventory

The national inventory of geothermal area is maintained by the Ministry of Energy (ESDM) and Badan Geologi – as summarised in the "Green Book" ("Buku Potensi Panas Bumi", Direktorat Panas Bumi, Ditjen EBTKE, 2017)

There are approximately **350 geothermal areas** - defined as physical locations that have some geothermal manifestations

Often several are included within one assignment or working area that has been defined

The study focuses on MW estimates for 'Possible', **'Probable' and 'Proven' categories** as defined within the Badan Standardisasi Nasional SNI 6009 system (BSN, 2017) and are best estimates with no ranges identified

We have excluded 'Speculative' and 'Hypothetical' category estimates as they are too poorly defined at this stage, but which may represent future additional potential

Some additional information added in the form of:

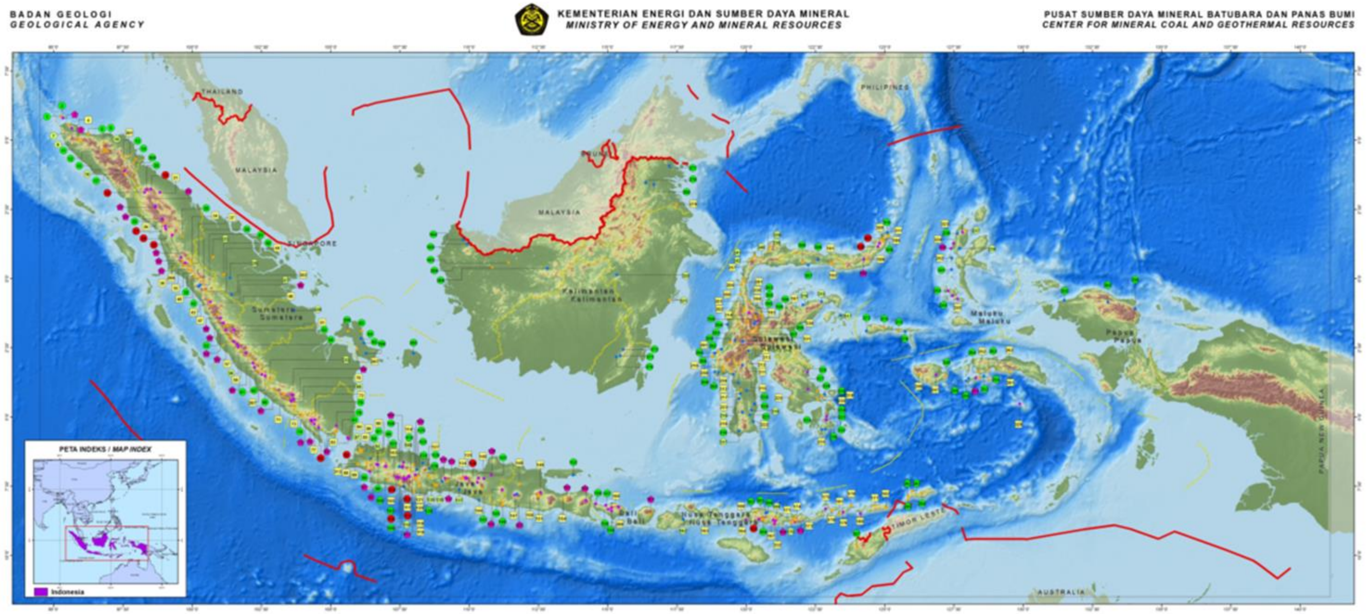
- Identified WKP, assignment areas and status (as far as practicable)
- Identified who is holding areas (where possible)
- Location data for producing maps (in the form of GIS data)

Existing identified resources in Indonesia

The national inventory of geothermal systems is maintained by the national geological agency (Badan Geologi) and identifies about 350 sites of geothermal activity.

These are categorized according to a 5 step system (Speculative, Hypothetical, Possible, Probable and Proven) of increasing confidence according to how much survey work has been done on each area. Each area can have some estimated potential in these categories.

The most confident assessment is for categories with some drilling (Proven and Probable) with 4,900 MW capacity, but almost half of this estimated capacity (2,180 MW) is already developed, leaving about 2,720 MW of high confidence resources.



Geothermal Potential Map (National data inventory, Direktorat Panas Bumi, Ditjen EBTKE, and Badan Geologi).

Classification	Based on	Total MW
Speculative + Hypothetical	Reconnaissance	9,800
Possible	More detailed surface surveys	11,700
Probable + Proven	Having at least one well	4,900
Total		26,400
Installed capacity	Plant operating	2,180
Remaining Probable + Proven	Probable + Proven, less MW Installed	2,720

Summary of Geothermal Potential (National data inventory, Direktorat Panas Bumi, Ditjen EBTKE, 2017)

Indonesia's Geothermal Potential

National Power Plan: RUPTL

The National Power Plan (RUPTL) is prepared by the Indonesian national power company (PLN) has been updated in 2021 and estimates the geothermal development potential on a project by project basis to 2030.

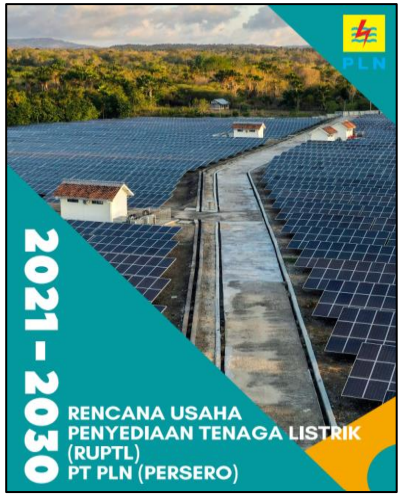
3,353 MW is planned to be developed by 2030, considering some reduced demand forecast, post COVID-19.

The RUPTL also indicates on a project by project basis that an additional 4,245 MW can be developed beyond 2030.

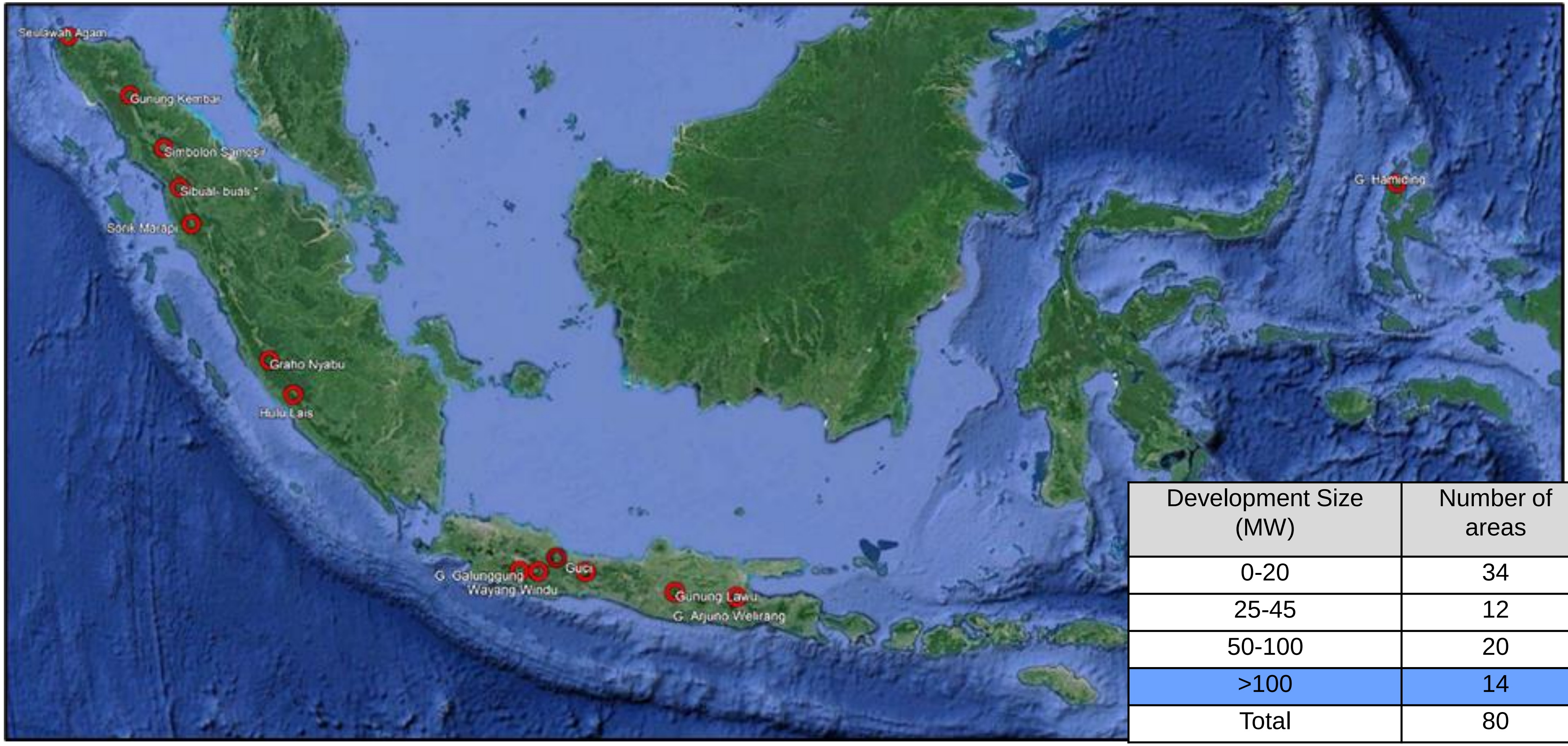
This assessment is probably the most reliable of what potential is reasonably available and not planned already for power production in Indonesia. This is because it is updated by PLN by discussion with developers who have conducted additional work in specific projects than is captured in the national inventory maintained by Badan Geologi.

Classification	Description	Total MW
On-going/planned capacity to 2030	Allocated project by project, with COD schedule to 2030	2,543
Quota Spread to 2030	More detailed surface surveys	810
	TOTAL Planned to 2030	**3,353**
Potential capacity (after 2030)	generating potential that can be developed according to system needs, probably after 2030	4,245

Summary of geothermal generation within the national power plan 2021-2030 (RUPTL)



Summary of Potential Development > 100 MW



More than 100 MW project mapping (National data inventory, Direktorat Panas Bumi, Ditjen EBTKE, and Badan Geologi)

The estimation of hydrogen production from geothermal is described in the following section, but listed here for clarity along with the basic source electrical MW potential within capacity bands.

Development Size (MW)	Number of areas	Total MW	H2 (kT/yr)
0-20	34	520	73
25-45	12	430	61
50-100	20	1235	174
>100	14	2060	290
Total	80	4245	599

Potential Capacity Summarised by Project Size (RUPTL, PLN)

Indonesia's Geothermal Potential

Key Findings

- While theoretical geothermal resources could potentially be 27GW, some **21GW** of these resources remain **highly speculative, undrilled and lack sufficient data** to be considered realistic geothermal resources for short to medium term development.

- Current **installed capacity** of geothermal electricity generation is **2.2GW** (2nd largest in the world)

- The resource areas that have been tested by drilling in some way amount to an estimated capacity of about 5 GW and are either developed already (the 2.2 GW already under production) or identified for development in the current RUPTL to 2030, totalling about 3.3 GW of identified geothermal developments. This leaves a relatively small and less certain capacity that may be available for hydrogen production.

- There is theoretical potential for existing or planned geothermal power plants to switch use from supplying the national electricity grid to dedicated green hydrogen production where excess electricity supply exists or market conditions dictate. Regulatory and policy settings would need to change to allow this to occur balancing Indonesia's energy transition goals across the primary energy sector. Consideration of this aspect is outside the scope of this study.

- The RUPTL (2021) has identified about **4.2 GW of "Potential**" geothermal developments that are in various stages of exploration which could be developed after 2030. This is assumed as the basis for assessing the foreseeable geothermal capacity that may be developed for hydrogen production in the near term.

- There are 14 potential geothermal locations of >100MW each which could contribute about half of the potential H2 production from geothermal should they be utilised for that purpose. Scale is important

- Existing geothermal operations have potential to add small scale hydrogen production utilising bonus energy available on these brownfield sites.

Green Hydrogen Geothermal Technical Assessment

Geothermally Produced Hydrogen

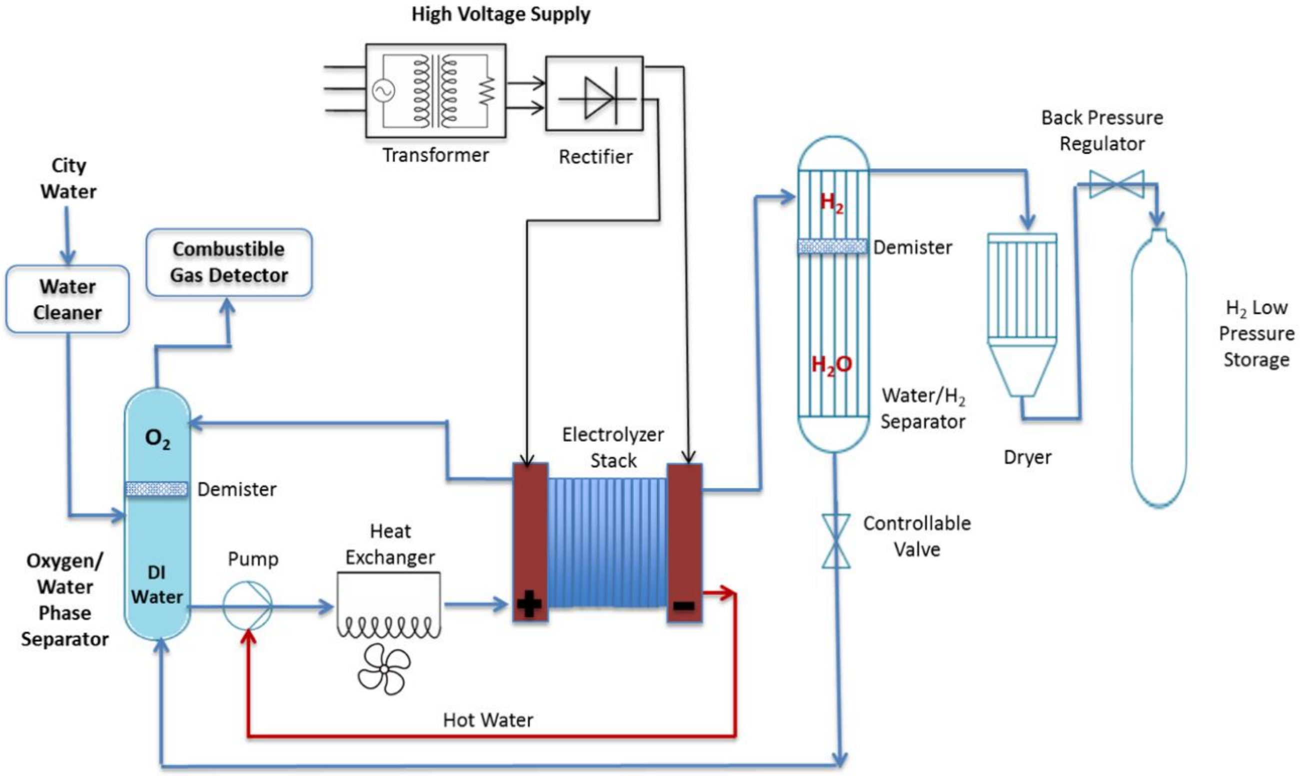
What are the common hydrogen technologies?

Much of today's hydrogen is produced using steam methane reforming (SMR) equipment, which uses natural gas for a hydrogen source (Mayyas et al,. 2019). This is clearly a carbon emissions intensive approach.

Production of hydrogen via electrolysis (where water molecules are split) is a maturing technology with Alkaline and Proton Exchange Membrane (PEM) water electrolysers both emerging as alternative options to SMR.

The hydrogen production rate for PEM and Alkaline electrolyser systems is approximately the same at 59 kWh/kg of hydrogen, which at a 95% capacity factor gives approximately 141 tonnes of hydrogen per MW. This assumption is used in this geothermal inventory.

Steam Methane Reforming - Hydrogen Production (Air Liquide, 2022)



PEM Electrolyser system (NREL, 2019)

Assumptions of the LCOH2 Model

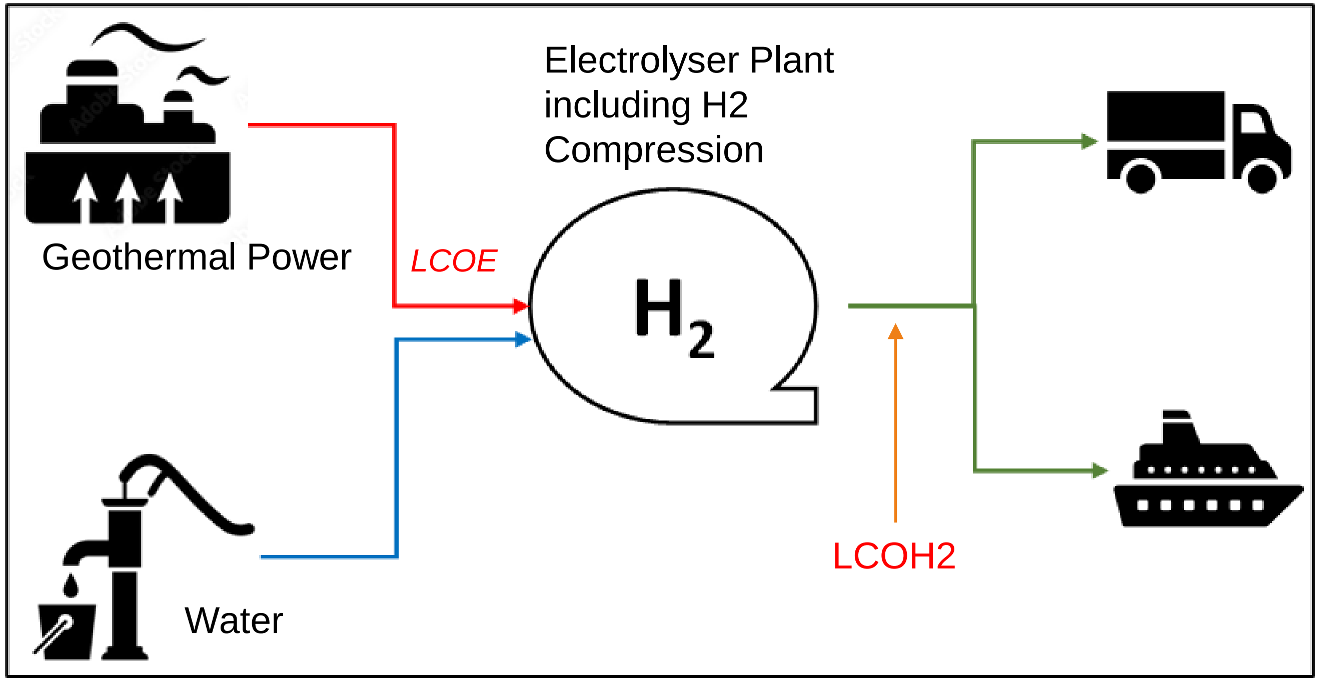
- The model uses electricity produced via geothermal, as well as a clean water source, to provide power to an electrolyser to produce green hydrogen.

- Once produced, hydrogen can be used locally or exported to other countries.

- Transmission costs are omitted for new generation projects as the hydrogen and geothermal plants are assumed to be co-located.

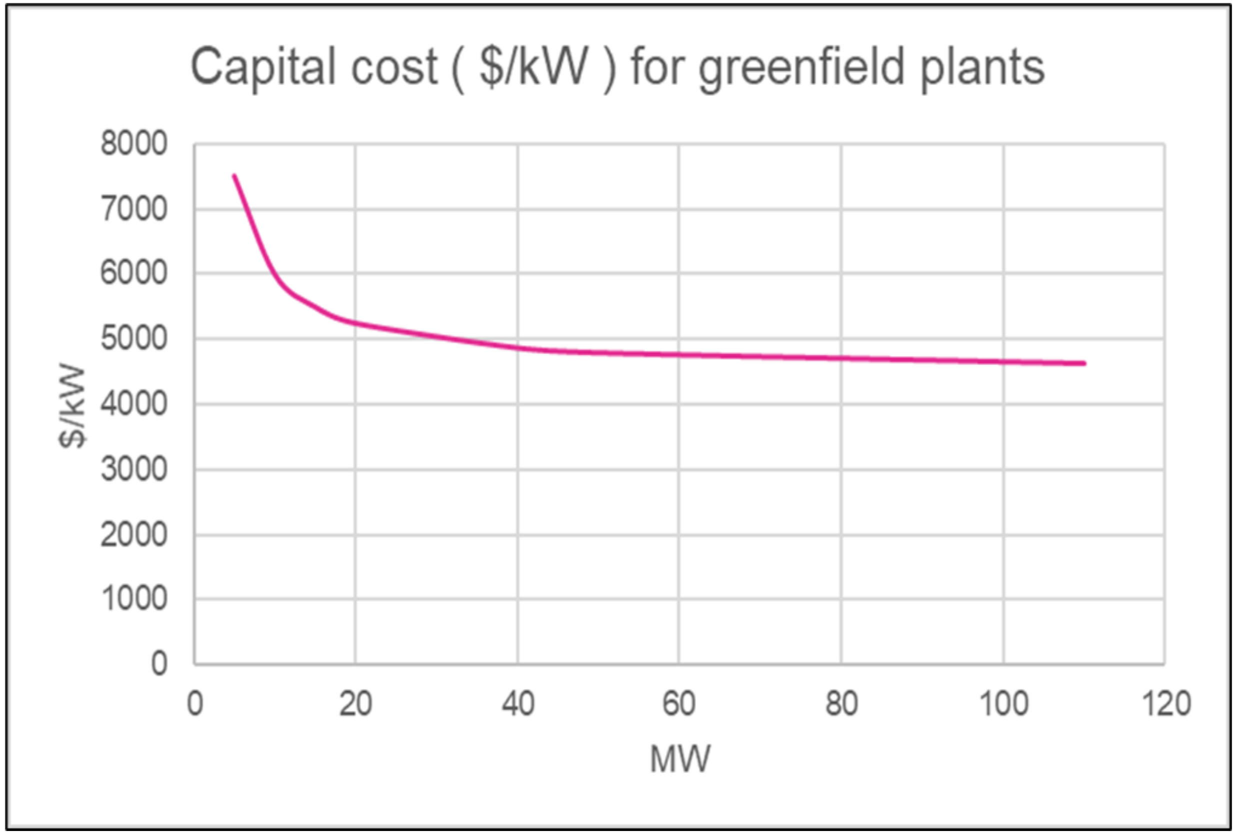
- The hydrogen production and cost model uses assumptions regarding the original capital cost, maintenance capital requirements, and operational cost of the power generation and electrolyser plant to derive a levelized cost of hydrogen (LCOH2).

- The cost of hydrogen as delivered at the project is estimated (without costs for distribution) because the destination is unknow without matching to market. It is also possible that industry may re-locate to near hydrogen sources.



A concept drawing of the inputs and outputs of the LCOH2 Model

Geothermal Costs



Estimated overall capital cost for "greenfield" geothermal projects

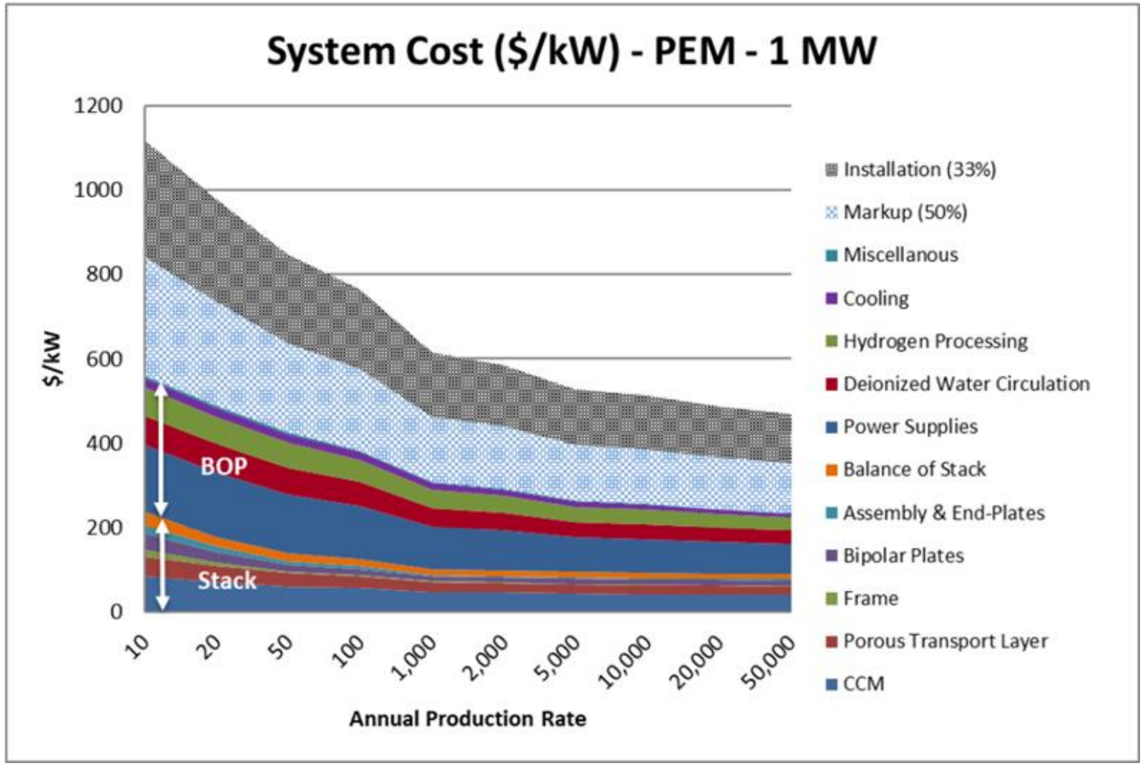
- Overall capital cost for greenfield projects includes all cost from exploration, drilling, and power plant development
- There are few reliable published and current references for geothermal capital cost. IRENA (2020) estimate an average $4,468/kW for total project including well drilling and power plant.
- From our experience, 50-90 MW projects in Indonesia have recently been in the $4500-5000 range for total capital cost including development costs, drilling, piping and power plant.
- To provide a realistic variation of capital cost according to project size, we have assumed that projects have an element of fixed establishment cost (we estimate $15M per project) in addition to the capital cost of $4500/kW
- This gives a higher $/kW for smaller plants but approaches $4500/kW for larger projects and reflects our experience with smaller projects.
- The graph to the left shows our working assumption for total capital costs for geothermal developments. This is a mid level estimate and could vary by +/- 50% according to resource quality, terrain and other local conditions.

Geothermal Power Generation Costs – Key Assumptions Used

List of key geothermal cost parameters and assumptions

Parameter	Assumption	Comment
Capacity factor	95%	Typical for geothermal
Base capital cost	$4500/kW	As described in previous slide. Mid level estimate
Establishment cost per project	$15 M	As described in previous slide. Results in overall higher $/kW for small projects. See previous plot.
Assumed well decline	5% per annum	This is a typical decline assumption and indicates the amount of additional drilling that is required to sustain production
Drilling as portion of base capital	40%	This is applied to the total capital cost ($/kW basis) to estimate the well costs and hence then multiplied by the assumed well decline rate to estimate annual drilling costs
Operation cost	$15/MWh	This is a typical operation and maintenance cost of geothermal and could vary by +/- 50%

Electrolyser Plant Costs



Costs of Hydrogen Proton Exchange Membrane (PEM) Electrolyser (NREL, Mayyas et al 2019)

- An IRENA report estimates capital expenditure brackets for Alkaline technology at $500 – 1,000 /kW and for PEM, $700 – 1,400 /KW$_e$ for a 'whole system' (plants under 10 MW).
- Others report prices up to $1,700 for a PEM plant (Noordende and Ripson, 2020)
- Considering these and other sources, we have assumed a base capital cost for electrolyser plant facility to be $850 /kW
- Electrolyser plant costs are predicted to reduce as mass production gets underway – see graph to left for a breakdown of plant cost and how volume production may decrease cost.
- We also assume some establishment costs of $2.5 M for each electrolyser plant
- We include a capital cost for the hydrogen storage tanks and compression
- Key elements of the Electrolyser plant cost included in our cost model are listed below:

Parameter	
Capacity factor	95%
Base capital cost	$850/kW
Establishment cost per project	$2.5 M
Storage cost (assume 1 day storage)	$19/kg
Electrolyser replacement cost	23% of base capital
Electrolyser life	8 years

Estimating cost of hydrogen production from geothermal

Approach

- Jacobs model for estimating levelized cost of power and hydrogen projects was adapted to calculate levelized cost of hydrogen (LCOH2).
- The model applies costs along an annual time series. Capital cost of initial construction is spread over the project development period (assumed to start 2023) and annual operation and periodic drilling and electrolyser costs are applied annually from the start of operations.
- LCOH2 is estimated from the NPV of all the cost streams divided by the 'NPV' of the total hydrogen mass produced, giving a $/kg
- An operation period of 25 years and discount rate of 7% are assumed.

Results

- The table to the right summarises the LCOH2 for different sizes of project (geothermal + electrolyser plant and hydrogen storage) for greenfield applications.
- The LCOE for the geothermal power is shown for interest, but is not in itself a direct part of the model that just considers all geothermal and hydrogen production costs.

Indicative cost of hydrogen estimated for new "greenfield' projects in Indonesia with development including well drilling, geothermal power plant and hydrogen production and storage.

MW	LCOE (US$/MWh)	LCOH2 (US$/kg)
10	95	6.7
20	86	6.2
30	84	6.0
40	82	5.9
50	81	5.8
60	81	5.8
80	80	5.7
100	80	5.7
110	80	5.7

CO_2 Emission Reduction Potential

The CO_2 emission reduction potential from geothermal green hydrogen is compared against grey hydrogen. The emissions factor of hydrogen production through natural gas reforming shows around 9 $kgCO_2/kgH2$ (IEA, 2019; IEA, 2020; Global CCS Institute, 2021; Fan et al., 2021). The CO_2 reduction is estimated using 2 approaches:

1. The lifecycle emissions of geothermal assets in New Zealand have a median of 62 gCO_2e/kWh. With the hydrogen production rate at 59 kWh/kg, the CO_2 emission intensity of geothermal green hydrogen is 3.66 $kgCO_2/kgH_2$.

2. The CO_2 emission of geothermal green hydrogen is to assume that the CO_2 produced is 1% of the total steam mass flow. The steam flow is generally 1.8 kg/s per MW power produced- thus, 0.018 kg/s of CO_2 produced per MW. Using 95% capacity factor and the hydrogen production rate of 141 tonnes of hydrogen per MW, then the CO_2 emission intensity for geothermal green hydrogen is around 3.82 $kgCO_2/kgH2$

With the emission factor range of 3.66 – 3.82 $kgCO_2/kgH_2$, the geothermal green hydrogen can produce about **60% less** of CO_2 emissions in comparison to grey hydrogen.

Indonesia Long-Term Strategy for Low Carbon and Climate Resilience 2050 (LTS-LCCR) has projected GHG emissions for Industrial Processes and Product Use (IPPU) sector to reach 50 million tonnes CO_2e in 2050. Total geothermal potential of 4.3 GW can produce up to 620 kT/year of green hydrogen. This presents an opportunity to reduce up to 3.3 million tonnes CO_2e per year as compared to being supplied by grey hydrogen. Therefore, **up to 7%** of the total CO_2 emissions from IPPU can be mitigated by geothermal green hydrogen production to support Indonesia's 2050 emission reduction targets.

Key Findings

Indonesian Geothermal Potential

- **4.2 GW** "potential" geothermal power development estimated from the National Power Plan This recognises that much of the most advanced projects are already allocated to power generation to 2030. This Potential capacity is less advanced, but has been identified by PLN and developers. This reflects the reasonably realisable geothermal potential in the foreseeable future (10-15 years)

- This potential development has generation capacity equivalent to a cumulative capacity of about **600,000 tonnes** of hydrogen per year.

- Typical geothermal development cycle in Indonesia is over a **5-to-15-year** period. So, unless some capacity already planned for power generation is redirected to hydrogen production, new capacity for hydrogen will take some years to be developed.

- High Temperature geothermal technology is mature so therefore there are limited "technological learning" gains to reduce capital costs significantly but larger scale does reduce costs per MW, however some greater potential cost reductions are likely in low and medium temperature geothermal technologies.

Hydrogen Technology

- Significant growth in use of Alkaline and Proton Exchange Membrane (PEM) water electrolysers is driving down capital costs of the technology and economies of scale support larger sized production facilities.
- The currently estimated cost of geothermal H_2 production is **comparable to other renewable sources** but due to greater technological learning (and cost reductions) for other renewables geothermal may struggle to compete with other renewables in the long term.
- This study uses conservative cost basis and costs are expected to **reduce over time**.
- The levelized cost of hydrogen is varied depend on the geothermal power plant capacity size.
- Up to 7% of the total CO_2 emissions from Industrial Processes and Product Use (IPPU) can be mitigated by geothermal green hydrogen production to support Indonesia's 2050 emission reduction targets

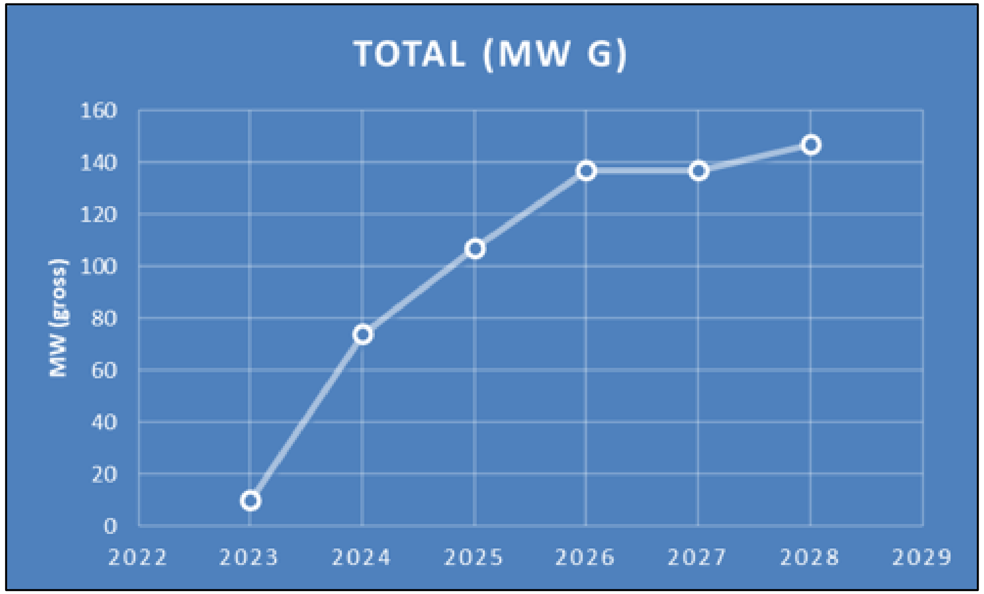
Pertamina-Specific Case Study: Geothermal Projects

Pertamina Project Summary

The Pertamina projects are using two types of geothermal energy source that are not developed within the scope of the main generation projects upon which they are hosted. These sources can be classified as either:

1. "Stranded" geothermal wells where wells that produce fluids at low pressure unsuitable for the main plant. These are typically spread around the geothermal field, and often on the margins of the main productive reservoir.
2. Waste heat sources from separated brine that could be developed as "bottoming" power plant using binary cycle technology. These opportunities are typically located near centralised steam-water separator stations where the fluids from several wells are collected for separation, or along the pipelines that carry separated brine to injection areas.

These projects are indicated to be available in a staged manner, but most are to be operational by 2026 as indicated in Figure 2 8.



Generation available at Pertamina geothermal projects from 2023 to 2028 (Modified from Green Hydrogen Study, Pertamina 2021, personal communications)

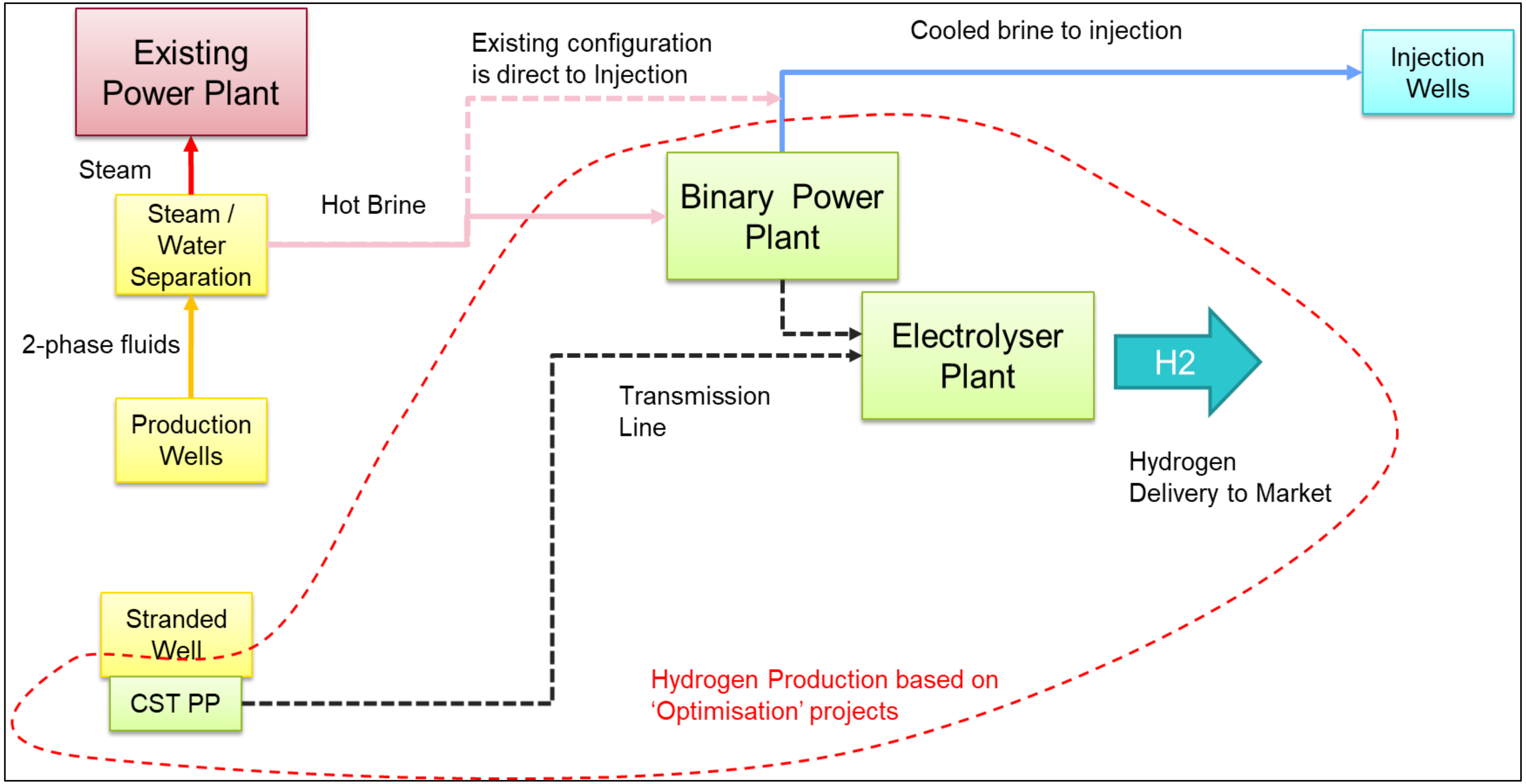
Plant	Potential			
	Planned capacity (MW)	Remark	H_2 kT/yr	Year
Kamojang	5 (7.5)	Low pressure	0.7 (1.1)	2024
Lahendong	16	Low pressure	2.3	2025
	5	Bottoming unit 1	0.7	2023
	5	Bottoming unit 2	0.7	2023
	5	Bottoming unit 3	0.7	2024
	10	Bottoming unit 4	1.4	2028
Ulubelu	11	Low pressure	1.6	2024
	10	Bottoming unit 1	1.4	2024
	10	Bottoming unit 2	1.4	2026
	10	Bottoming unit 3	1.4	2026
Lumut Balai	13	Low pressure 1	1.8	2024
	7	Low pressure 2	1.0	2025
	5	Bottoming unit 1	0.7	2024
	10	Bottoming unit 2	1.4	2026
Sibayak	5	Bottoming unit	0.7	2024
Hululais	10	Bottoming unit 1	1.4	2024
	10	Bottoming unit 2	1.4	2025
TOTAL	**142**		**20.0**	

Generation available at Pertamina geothermal projects in Indonesia (Green Hydrogen Study, Pertamina 2021, personal communications).

Planned Capacity is in MW of power generation. "Low pressure" is assumed to be wells with low operating pressure and generation using wellhead steam power plant, and "Bottoming unit" is binary cycle plants using heat from separated brine.

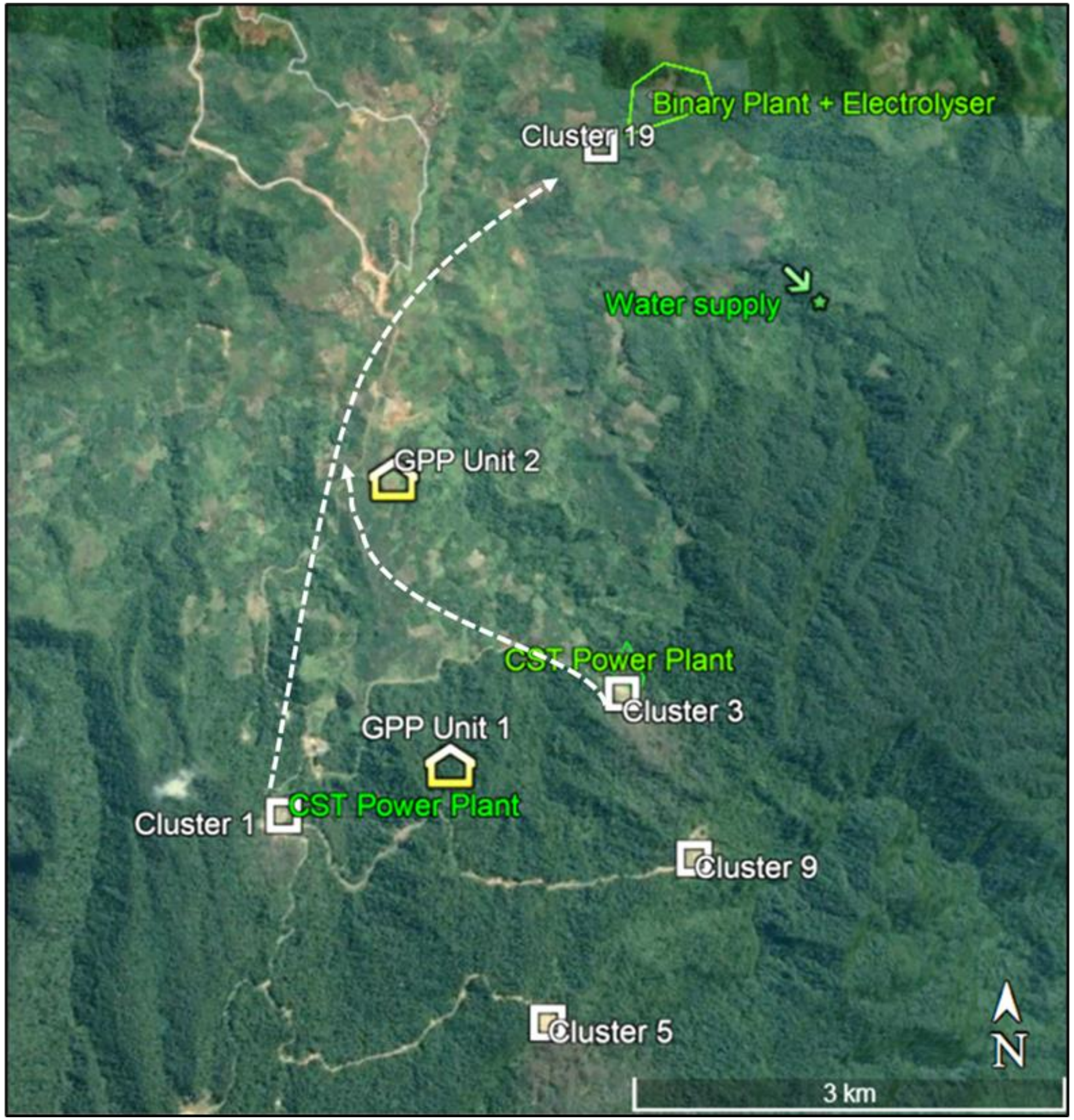
Project Configuration : Conceptual

- Binary on brine injection system
- Steam turbine on stranded well sites
- Connect via wires (not piping)
- Centralised Electrolyser



Example concept – Lumut Balai

- Binary on brine injection system
- Steam turbine on stranded well sites
  - Connect via wires
- Centralised Electrolyser at binary plant site



Cost assumptions

- Areas based on reference sites
- Unit costs based on reference projects (Jacobs experience)
  - +50% / - 30%
- Plan specific Capex ($/kW) based on reference sites (Jacobs experience for small plant)
  - +50% / - 30%
- Development costs – a simple assumption – could vary greatly (many fold)

Item	Inputs	Units
Area for BHR	0.1	ha / MW
Area for CST	0.05	ha / MW
Area for electrolyser	0.05	ha / MW
Civil works	$ 70	per m2
Capex for BHR	$ 2,000	$/kW
Capex for CST	$ 3,500	$/kW
Separation and piping	$ 1M	per CST site
Capex for Transmission line	$60,000	$/km
Transformer and switchyard at wellpad	$50,000	per pp
Transformer and swithchyard at BHR plant	$50,000	per pp
Transformer and switchyard at Electrolysis plant	$ 250,000	per plant
Engineering cost	10%	of total capex
Development costs	$ 500,000	per power plant

Capital and LCOH2 costs

- Discount rate of 7% assumed
- Hululais is lowest cost – only has binary plant
- Costs lower than for greenfield : no well costs

Project	MW	H_2 Production (kT/yr)	Capital Cost (US$)	$/kW	LCOE ($/MWh)	$LCOH_2$ ($/kg)
Kamojang	7.5	1.1	$ 32,800,000	$ 4,370	$ 64	5.0
Lumut Balai	35	4.9	$118,000,000	$ 3,370	$ 53	4.2
Ulubelu	41	5.8	$119,400,000	$ 2,920	$ 48	3.9
Lahendong	41	5.8	$129,500,000	$ 3,160	$ 51	4.0
Sibayak	5	0.7	$ 12,500,000	$ 2,490	$ 43	3.9
Hululais	20	2.8	$ 49,300,000	$ 2,470	$ 43	3.6

Kamojang

- Available:
  - About 7.5 MW, spread over 3 locations
  - Low pressure steam (1-3 bar inlet pressure)

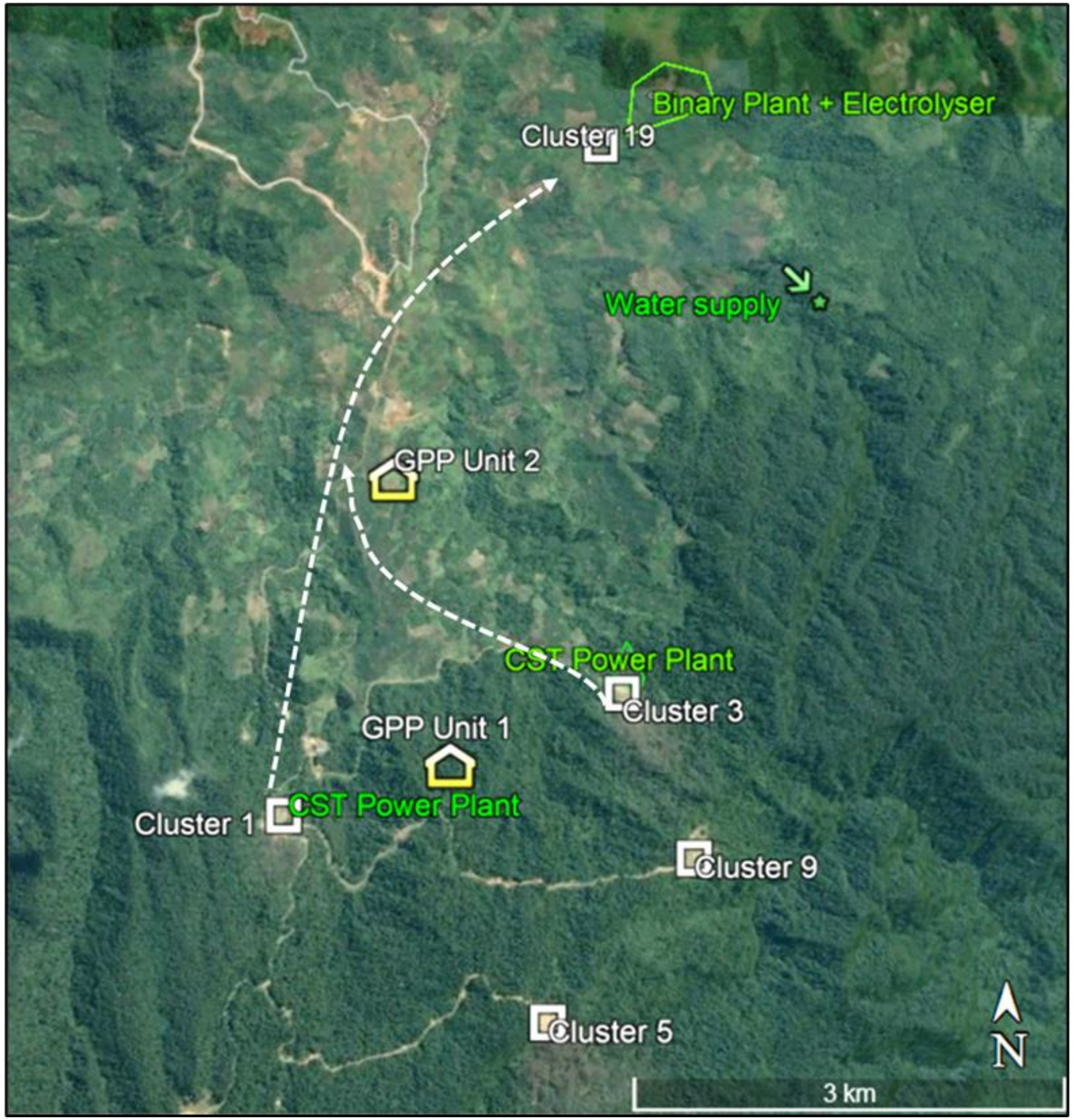
- Proposed Configuration
  - Steam turbine technology
  - Assume small wellhead Condensing Steam Turbine (CST) plants
  - No separated brine as this system produces only dry steam. Condensate disposal via existing well pad pond drainage.
  - Connect via transmission line to Electrolyser rather than piping to central plant
  - Assume other wells on pad act as long term make up wells

Field	Cluster	Sumur	SSC Low	SSC High
Kamojang	KMJ-12	KMJ-87, 92	3.9	3.12
	KMJ-8	KMJ-40	2.8	2.2
	KMJ-28	KMJ-66	1.7	1.4
Total MW			8.4	6.7

Lumut Balai

- Available
  - 15 MW from Brine heat recovery (binary plant).
  - 20 MW from low pressure steam.

- Proposed Configuration
  - Binary plant located near Cluster 19 injection wells in north.
  - Electrolyser located adjacent the binary plant and Cluster 19.
  - Steam turbine for low Pressure steam from wells, 10 MW on each of Cluster 1 and Cluster 3 (wells LMB-1/1, 2/1 and LMB 3/1, 3/2) . (PGE indicated using Cluster 3 area only, but Cluster 1 is too far for low pressure piping to Cluster 3). Steam separation on each pad, and brine disposal assumed to pad ponds and then through the water disposal system for each pond. Enthalpy unknown, and hence separated brine flow unknown.
  - Connect with transmission to central electrolyser at Brine heat recovery location (north).



Ulubelu

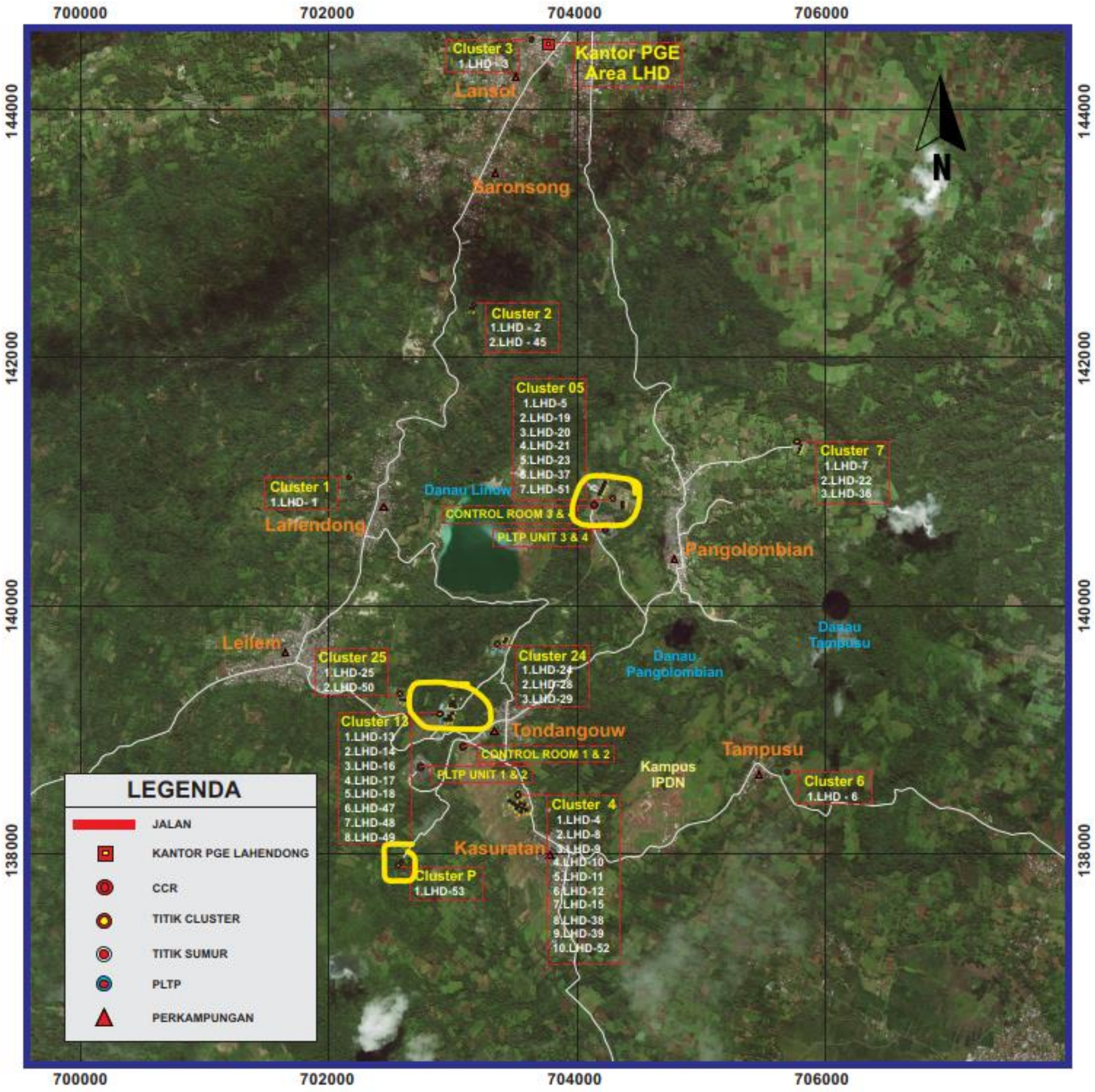
- Available
  - 30 MW of brine heat recovery from main injection system to south
  - 11 MW of low pressure steam at 3 wells. Wells = UBL12, 29, 30

- Proposed Configuration
  - Brine heat recovery (binary plant) located near Reinjection Cluster R1.
  - CST units located at each of UBL12, 29 and 30
  - 30MW Binary cycle plant. Assume that little additional piping as brine piping already in place.
  - 11MW wellhead CST power plant. CST units on each of pads UBL-12, 29, 30. Steam separation on each pad, and brine disposal assumed to pad ponds and then through the water disposal system for each pond. Enthalpy unknown, and hence separated brine flow unknown.
  - Electrolyser located near the binary plant at R1 Cluster. Power transmitted from CST plants to the electrolyser site.

Lahendong

- Available
  - Assume 2 Brine heat recovery plants (3x5 + 10 MW)
  - Assume low pressure wells using wellhead units (total of 16 MW)

- Proposed Configuration
  - Pertamina indicate that generation from low pressure steam is expected in Clusters 05, 13, and P as highlighted in the map above. With LHD-19, 20, 21, 51 on Cluster 05, LHD-13,14,16 on Cluster 13, and LHD-53 on Cluster P. We assume CST units of 6, 6, 4 MW respectively at each Cluster, a total of 16 MW. Steam separation on each Cluster, and brine disposal assumed to pad ponds or pumped into existing nearby brine disposal system. Enthalpy unknown, and hence separated brine flow unknown.
  - We assume that the binary plant are allocated to centralized separation stations also in the locality of clusters 05 and 13
  - Connect the CST and feed from binary plant at Closter 13 via transmission to Electrolyser plant at near Cluster 05



Hululais

- Available
  - 2 x 10 MW binary plants near stage 1 main Power Plant (power generation by 2 x 55 MW units in one power plant).

- Proposed Configuration
  - The main 2 x 55 MW power generation project is still in Feasibility Study stage.
  - Brine heat recovery (binary plant) of 2 x 10 MW for main power plants.
  - Located close to planned centralized separator stations or brine injection line for the main power plant.
  - Centralized electrolyser near binary plant and main power plant

Sibayak

- Available
  - 1 x 5 MW binary plant

- Proposed Configuration
  - No site-specific suggestions from Pertamina.
  - Assume steam – brine separation is close to the small main power plant
  - Centralized electrolyser near binary plant and main power plant

Hydrogen Market Assessment

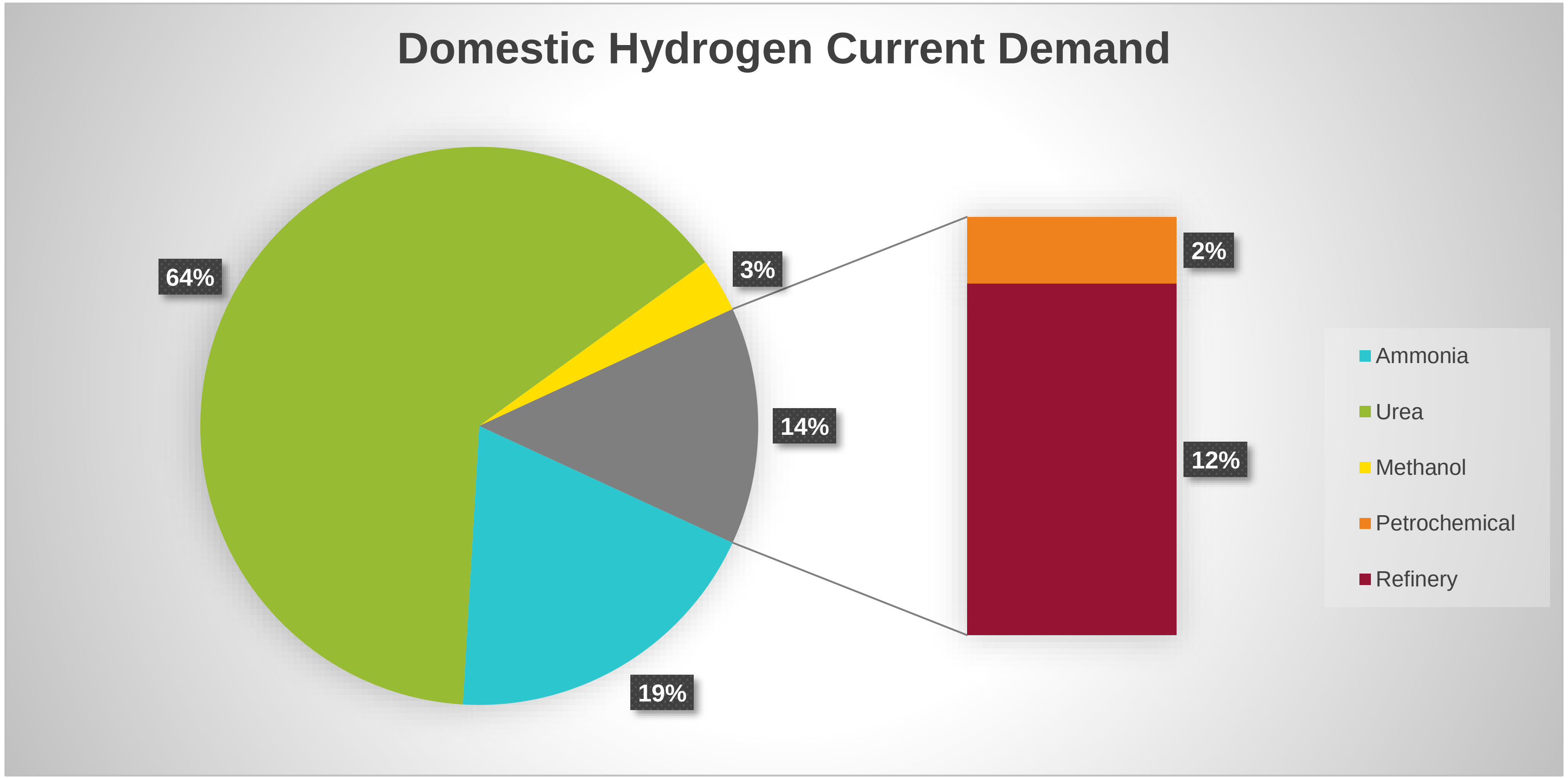
Introduction to Hydrogen Market Assessment

The main objectives of the Hydrogen Market Assessment include:

1. Mainly Domestic (Indonesia) and international market analysis: examining the near-term potential for hydrogen uptake by reviewing government legislation, objectives, and targets to reduce carbon emissions.

2. This includes analyzing the domestic market size and potential for the below categories:
   - Ammonia and fertilizer production.
   - Hydrocracking (refining, petrochemicals).
   - “Green” steel potential (where hydrogen is used in the reduction process).
   - Long distance transport opportunities (rail and road) and logistics operations.
   - Island grids.
   - Domestic gas replacement.

Indonesia Green Hydrogen Potential Demand



- Currently in Indonesia, the largest potential green hydrogen demand is for the urea industry (64%), followed by the ammonia industry (18%) and refinery industry (11%) and methanol (3%)
- However, urea and methanol plants will require coupling with CO_2 supply. Therefore, it is difficult to compare these industries.
- If urea and methanol industries are taken away, then the main potential green hydrogen markets are the ammonia and refinery industries.

Other Potential Green Hydrogen Demand

Biodiesel making

Green Steel

Island grid

Heavy Vehicle Fuel Cell

Ammonia and Urea Production

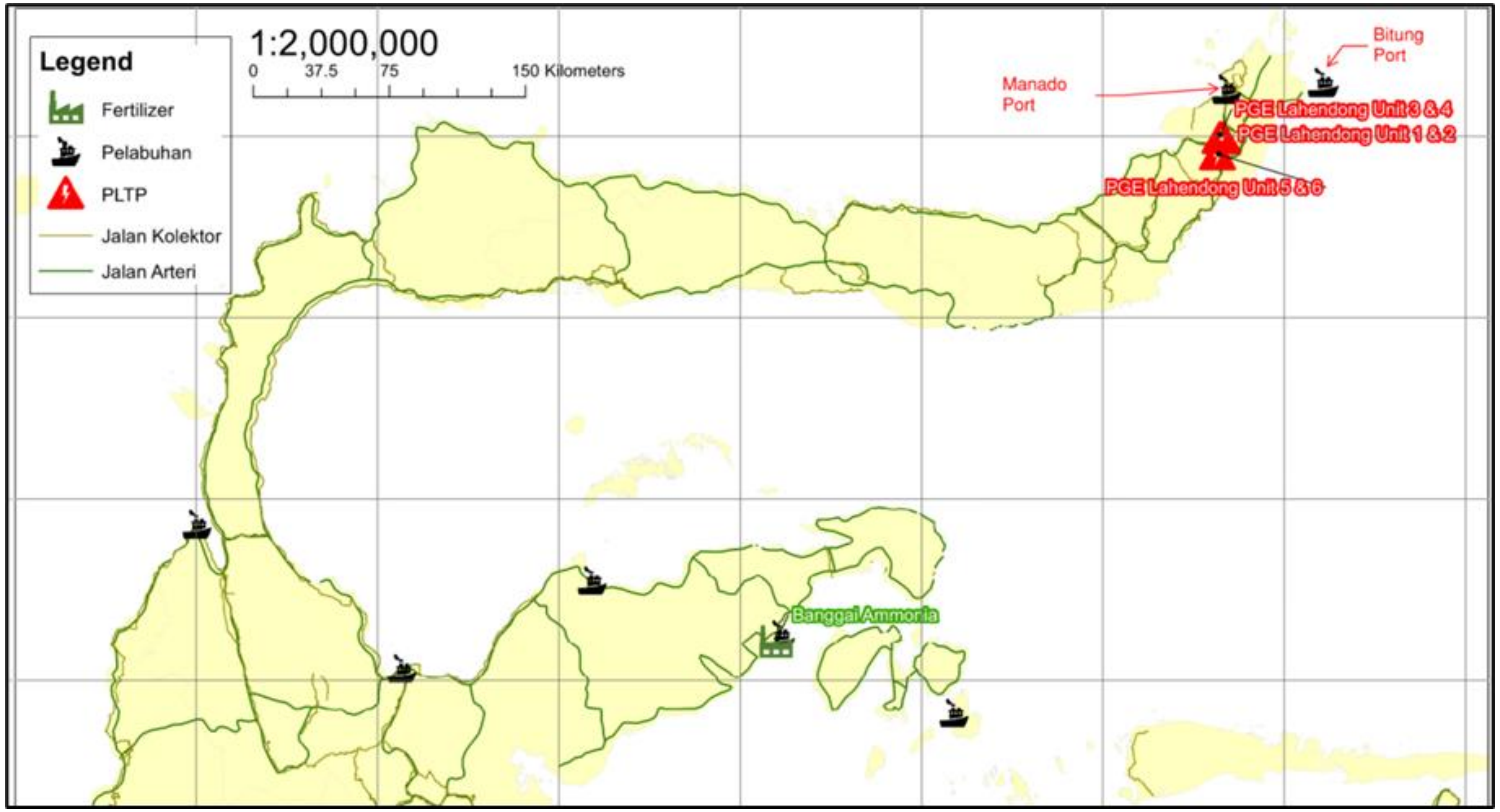
- The ammonia industry is one of the main hydrogen users in Indonesia.
- In year 2020, in total there are 8.1 million tones per year of ammonia production.
- However, only two company that produce ammonia as their final product (PAU and Kaltim Parna Industri) while the others are producing ammonia for urea production.

User	Location	Ammonia Production (ton/year)	Final Product	H_2 Demand (ton/year)
Petrokimia Gresik	Gresik – near port	1,105,000	Urea	195,585
Pupuk Kujang	Cikampek – industrial estate	660,000	Urea	116,820
Pupuk Kaltim	Bontang – near port	2,740,000	Urea	484,980
Pupuk Iskandar Muda	Lhokseumawe – near port	726,000	Urea	128,502
Pupuk Sriwijaya	Palembang – river port	1,832,000	Urea	324,264
Panca Amara Utama (PAU)	Banggai, Sulawesi Tengah – near port	570,000	Ammonia	284,161
Kaltim Parna Industri	Bontang – near port	495,000	Ammonia	87,615
	Total	8,128,000		1,621,927

Source: Petromindo, Indonesian Hydrogen Report, June 2021

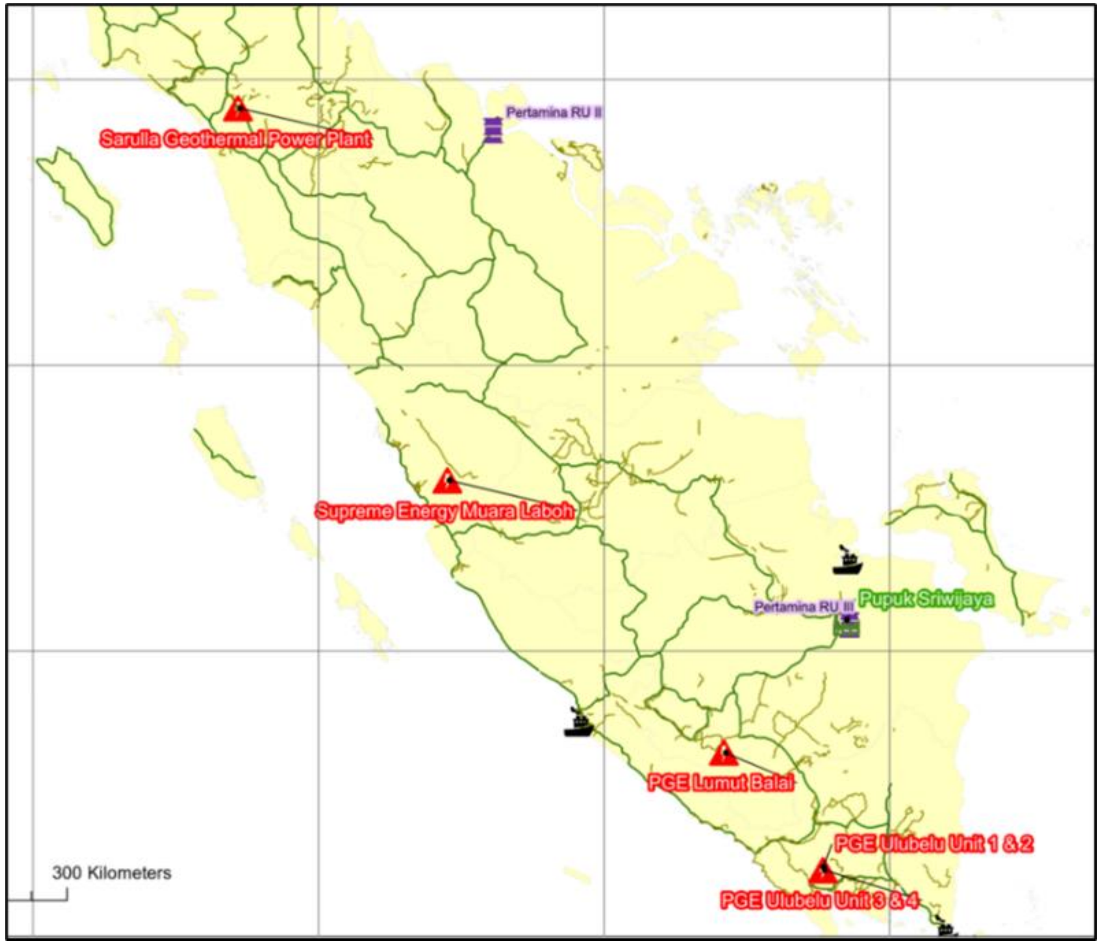
Ammonia - Route distance and travel times (Sulawesi)

- Panca Amara Utama (PAU) is located in Banggai which is the same island as Lahendong Geothermal Power plants(s)
- However, the green hydrogen producer would still need to travel more than 500km by road (likely via truck)
- If green hydrogen is to be produced in the Lahendong area, it may be beneficial to establish the green hydrogen port and shipping. It will be beneficial to supply users in Kalimantan as well, including the future New Capital. Bitung and Manado port are candidates for green hydrogen transportation via seaport.



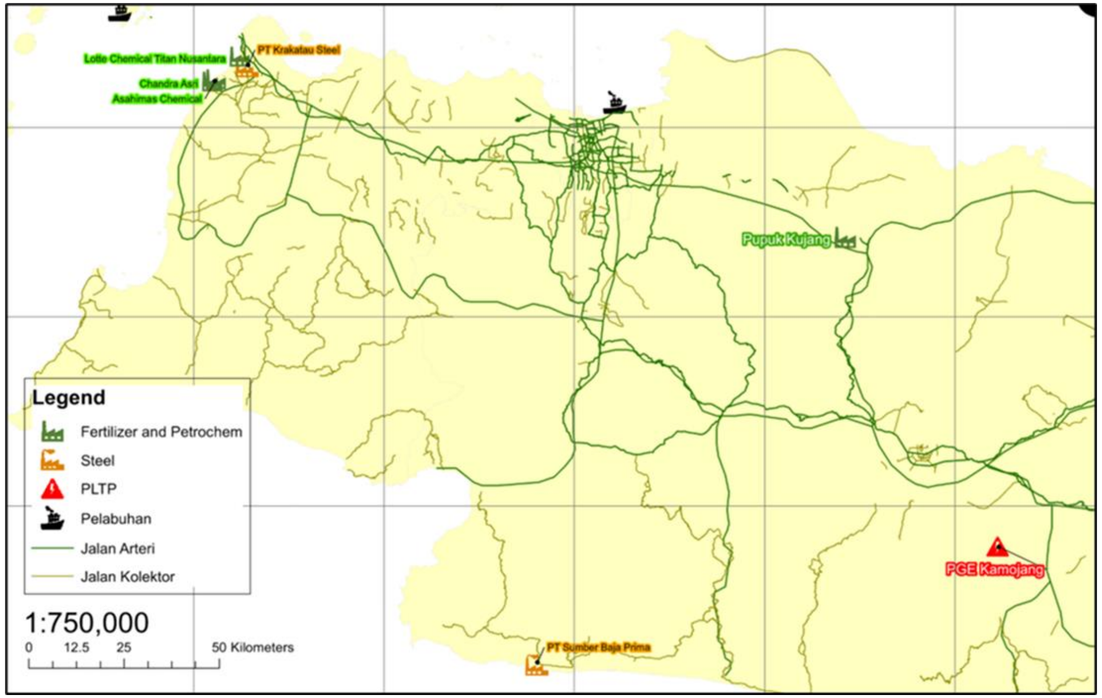
Ammonia - Route distance and travel times (Sumatera)

- Pupuk Sriwijaya (the second largest ammonia producer with 1.8 million ton/year ammonia production) in South Sumatra is the closest plant to a geothermal power plant and can be accessed by land transport. Some distance related to Pupuk Sriwijaya are as follows:
- Around 150 km from PGE Lumut Balai 1 Geothermal Power Plant (55MW). Lumut Balai expansion program to Unit 2,3,4 is currently on going.
- Around 400 km from PGE Ulubelu Geothermal Power Plant (220MW)
- Around 180 km from Supreme Energy Rantau Dedap Geothermal Power Plant (55 MW)
- Around 430 km from PGE Hululais (Bengkulu) – project on going
- Around 500 km from PGE Sungai Penuh (Bengkulu) – project on going



Ammonia - Route distance and travel times (Java)

- Pupuk Kujang is located in the Cikampek industrial estate, in West Java, around 150km from Kamojang Geothermal Power Plant and can be accessed via land transport



Refinery

- Pertamina refinery uses hydrogen in the hydrocracking, hydrotreating of naphtha, gasoline, diesel, process, etc.
- In most Pertamina Refinery Units, hydrogen is produced via the Steam Methane Reforming (SMR) process with total hydrogen generation is approximately 225,000 ton/annual, with assumptions of 360 days per year.
- In addition to the data below, we also understand that Pertamina aim to build Biodiesel plant in the near future which also need hydrogen in its process (which we don't have the number of demand so far); but it will be relatively easy entrance for green hydrogen entry as it will be a green field

Unit	H_2 Generation, in Nm3/hr*	H_2 Generation, in ton/day	H_2 Generation, in ton/annual
RU II – Dumai	43,914	94.8	34,118
RU III – Plaju	30	0.1	23
RU IV – Cilacap	79,750	172.1	61,960
RU V – Balikpapan	80,000	172.7	62,154
RU VI – Balongan	85,000	183.4	66,038
RU VII – Kasim (Papua)	1,300	2.8	1,010
		Total	225,303

**Resource : Pertamina*

Sumatera H_2 Market Gap

- Rule of thumb : 141 tpy/MW.
- The potential Sumatra geothermal production is ~ 1.8 GW. This equivalent to 259 kT/year green H_2 potential production (53% demand), although there is still gap -228 kT/year.
- With only small project, the gap will be significantly larger. As illustration, 10MW project will generate green hydrogen of only 1.4 kT/year
- However, Unit III Refinery (Plaju), can be the starting point for market entry.

Market Plant	H_2 Required for Plant (kT/year)	Max Possible H_2 Produced from Geothermal Potential in Sumatera (kT/year)	H_2Market Gap in Sumatera (kT/year)
Pupuk Sriwijaya (Palembang) (Ammonia)	324	259	-228
Pupuk Iskandar Muda (Lhokseumawe) (Ammonia)	129		
Pertamina Unit II (Refinery)	34		
Pertamina Unit III (Refinery)	0.23		
Total	487	259	-228

Jawa H_2 Market Gap

- Rule of thumb : 141 tpy/MW.
- The potential Jawa geothermal production is ~ 1.5 GW. This equivalent to 216 kT/year green H_2 potential production (44% Jawa demand)
- With only small project, the gap will be significantly larger.
- As illustration, 10MW project will generate green hydrogen of only 1.4 kT/year.
- To replace 100% Pertamina Unit IV demand, it will require 450 MW green hydrogen from geothermal plant

Market Plant	H_2 Required for Plant (kT/year)	Max Possible H_2 Produced from Geothermal Potential in Jawa (kT/year)	H_2Market Gap in Jawa (kT/year)
Pupuk Kujang (Cikampek) (Ammonia)	117	216	-272
Petrokimia Gresik (Ammonia)	196		
Krakatau Steel (Steel)	48		
Pertamina Unit IV (Refinery)	62		
Pertamina Unit VI (Refinery)	66		
Total	488	216	-272

Sulawesi H_2 Market Gap

- Rule of thumb : 141 tpy/MW.
- The potential Sulawesi geothermal production is ~ 395 MW. This equivalent to 56 kT/year green H_2 potential production (20% Jawa demand)
- With only small project, the gap will be significantly larger.
- As illustration, 10MW project will generate green hydrogen of only 1.4 kT/year.
- Need at least ~2GW geothermal generation to meet 100% PAU demand

Market Plant	H_2 Required for Plant (kT/year)	Max Possible H_2 Produced from Geothermal Potential in Sulawesi (kT/year)	H_2Market Gap in Sulawesi (kT/year)
PAU (Banggai) (Ammonia)	284	56	-228

Key Findings

- Ammonia and urea require high volumes of hydrogen. However, there is significant gap between potential green hydrogen from geothermal generation with the demand. Green hydrogen production need to be large enough to meet the market demand. The development can be in stages. It will also require aggressive geothermal development to meet the required fuel supply
- Refinery with low hydrogen generation capacity such as Pertamina Refinery Unit 3 can be potential 1st market entry, as it also geothermal producer in the same island.
- For the 1st step, green hydrogen to ammonia and refinery industry could be the market priority as it can be stand alone supply. Urea (fertilizer) will need couple with CO_2 supply

International Hydrogen Market

SOUTH KOREA ($7.84/Kg, Argus (2022))

- South Korea intends to be a global leader in hydrogen and is actively supporting the creation of hydrogen economy through R&D, subsidies, policies, etc
- South Korea has a medium-term (2030) hydrogen targets with 1.94 million tones/year
- South Korea has a target of 5.26 million tons per annum of hydrogen by 2040; 30% of which will come (grey hydrogen) and by-product hydrogen, electrolysis and imports.
- In 2050, South Korea's target increases to 27.9 million tons per year hydrogen with 40% coming from imported clean hydrogen.
- Ansan, Pyeongtaek, Daejeon, Daegu, Gwangju Hydrogen Facilities
- SK liquified hydrogen & CCS

Europe ($10.09/Kg, Argus (2022))

- In 2021, the use of hydrogen in the EU was approximately 9.7 million tonnes, with 50% used in ammonia production and 30% for refineries, which use fossil fuel.
- According to the 2019 Hydrogen Roadmap Europe, the hydrogen demand will increase to 16.9 million tonnes in 2030.

MALAYSIA ($5.72/Kg, ASEAN Centre for Energy (2021))

- Malaysia is expected to unveil a hydrogen economy roadmap by early 2022 to utilize more renewable energy in the country. A green hydrogen industry may develop alongside renewables.
- Petronas planning 1 ammonia and 1 MCH development
- Sarawak: multiple consortiums and groups aiming to utilize excess hydropower
- Malaysian green hydrogen project opts for Perth-based flow batteries

JAPAN ($7.84/Kg, Argus (2022))

- The target hydrogen production for the short-term target is 300,000 tons per year.
- Technologically demonstrating the feasibility of storing and transporting hydrogen from abroad by 2022
- Introducing full-scale hydrogen generation by around 2030
- Realizing full-fledged domestic use of carbon dioxide-free hydrogen by around 2050

SINGAPORE ($6.48/Kg, ASEAN Centre for Energy (2021))

- Decarbonization options for Singapore rely heavily on more efficient use of resources and imports of clean energy sources
- CCS & Hydrogen Feasibility study published in July 21
- Multiple consortiums assessing use of blue/green ammonia
- for bunker fuel and power
- Japan led consortium leading LOHC (MCH) initiative

INDONESIA ($4.61/Kg, ASEAN Centre for Energy (2021))

- Indonesia's Pertamina eyes hydrogen to meet 2026 goal
- Pupuk Indonesia signs deal to explore hydrogen, clean energy supply
- Promotion of Autonomous Hydrogen Energy Supply System "H2One™" in Indonesia
- Green hydrogen utilization for Indonesia New Capital City, especially related to energy infrastructure
- KAI plan to explore hydrogen train
- Fortesque Future Industry in Kalimantan

Note: The cost provided is for grey hydrogen

Detailed Analysis

Detailed Analysis

Key Question

Is there a viable market for the production and sale green hydrogen geothermal in the locations identified in Indonesia?

Approach

Detailed analysis on potential market priorities for green hydrogen geothermal in Indonesia

- Combining key findings on the availability and suitability of excess geothermal resources in Indonesia and the market potential for green hydrogen the study will provide an assessment of overall potential for green hydrogen geothermal in Indonesia
- Some specific commercial case studies are considered as part of this analysis
- Some recommendations of next steps

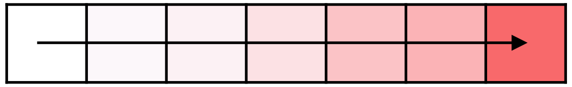
Cost competitive analysis with other sources of green hydrogen

- Relative LCOH for green hydrogen delivered to end user
- Assumes hydrogen is produced at the geothermal site and then piped to end user
- Cost of hydrogen at electrolyser gate is based on technical analysis reported above
- Pipeline cost in $/kg is based on distance to end-user and volume (proxy for diameter). Distance data based on straight line distance data collected by Jacobs.
- Pipeline costs vary between $0.7 to 0.9/kg in 2025 and $0.4 to 0.6/kg in 2030 for domestic market applications
    - For smaller volumes road transport may be more suitable
    - Note risk of damage by earthquake may mean piping of hydrogen may not be suitable due to safety concerns
- For export markets (and for imports into Indonesia), shipping and liquefaction costs are added
    - Range from $2 to $3.50/kg in 2025 and $1.7 to 2.5/kg in 2030
- Data for international and Indonesian renewable based green hydrogen options based on a range of sources

Cost competitive analysis – Domestic Indonesian market – USD/kg - 2025

End use	Trains	Long Haul Trucks	Ammonia	Oil Refinery	Steel	Power generation	High grade heat	Building heating
Price range	High	High	Moderate	Moderate	High	Low	Low	Low
Market volume	Low	Low	High	High	Moderate	Low	Moderate	Low
Australia Wind+Solar	7.5	7.5	7.9	7.6	7.6	7.9	7.9	7.9
NZ Wind+Solar	7.5	7.5	7.9	7.6	7.6	7.9	7.9	7.9
Middle East solar	7.2	7.2	7.6	7.3	7.3	7.6	7.6	7.6
Malaysia solar	8.3	8.3	8.7	8.4	8.4	8.7	8.7	8.7
Indonesia solar	10.3	10.3	10.7	10.4	10.4	10.7	10.7	10.7
Indonesian geothermal (greenfield projects)	6.4-7.4	6.4-7.4	6.8-7.8	6.5-7.5	6.5-7.5	6.6-7.6	6.6-7.6	6.6-7.6
Indonesian geothermal (optimised projects)	4.5-5.9	4.5-5.9	4.9-6.3	4.6-6.0	4.6-6.0	4.9-6.3	4.9-6.3	4.9-6.3

Relative Cost ↑

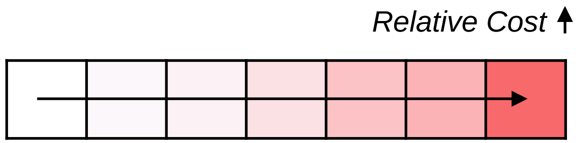


Colour shading in body of table indicates the relative costs with the lighter the colour showing the lower the cost

Note: For Price range: High means cost of hydrogen needs to be in the $4/kg to $6/kg range; medium = $2/kg and $4/kg and Low = below $2/kg
For market volume: High = high demand for hydrogen to Low = low demand for hydrogen

Cost competitive analysis – Domestic Indonesian market – USD/kg - 2030

End use	Trains	Long Haul Trucks	Ammonia	Oil Refinery	Steel	Power generation	High grade heat	Building heating
Price range	High	High	Moderate	Moderate	High	Low	Low	Low
Market volume	Low	Low	High	High	Moderate	Low	Moderate	Low
Australia Wind+Solar	5.8	5.8	6.2	5.9	5.9	6.2	6.2	6.2
NZ Wind+Solar	5.9	5.9	6.3	6.0	6.0	6.3	6.3	6.3
Middle East solar	5.4	5.4	5.8	5.5	5.5	5.8	5.8	5.8
Malaysia solar	6.8	6.8	7.2	6.9	6.9	7.2	7.2	7.2
Indonesia solar	9.4	9.4	9.8	9.5	9.5	9.8	9.8	9.8
Indonesian geothermal (greenfield projects)	6.1-7.1	6.1-7.1	6.5-7.5	6.2-7.2	6.2-7.2	6.3-7.3	6.3-7.3	6.3-7.3
Indonesian geothermal (optimised projects)	4.3-5.7	4.3-5.7	4.7-6.1	4.5-5.9	4.5-5.9	4.8-6.2	4.8-6.2	4.8-6.2



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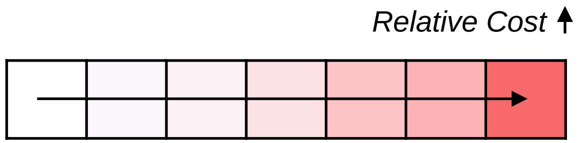
Note: For Price range: High means cost of hydrogen needs to be in the \$4/kg to \$6/kg range; medium = \$2/kg and \$4/kg and Low = below \$2/kg
For market volume: High = high demand for hydrogen to Low = low demand for hydrogen

Cost competitive analysis – Singapore market – USD/kg - 2030

End use	Trains	Long Haul Trucks	Ammonia	Oil Refinery	Steel	Power generation	High grade heat	Building heating
Price range	High	High	Moderate	Moderate	High	Low	Low	Low
Market volume	Low	Low	High	High	Moderate	Low	Moderate	Low
Australia Wind+Solar	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
NZ Wind+Solar	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Middle East solar	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Malaysia solar	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Indonesia solar	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Indonesian geothermal (greenfield projects)	8.1-9.1	8.1-9.1	8.1-9.1	8.1-9.1	8.1-9.1	8.1-9.1	8.1-9.1	8.1-9.1
Indonesian geothermal (optimised projects)	6.2-7.6	6.2-7.6	6.2-7.6	6.2-7.6	6.2-7.6	6.2-7.6	6.2-7.6	6.2-7.6



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Note: For Price range: High means cost of hydrogen needs to be in the $4/kg to $6/kg range; medium = $2/kg and $4/kg and Low = below $2/kg
For market volume: High = high demand for hydrogen to Low = low demand for hydrogen

Medium term market assessment

Market segment	Market size, t/year by plant site	Breakeven price	Breakeven price with carbon price	Suitablity for geothermal based hydrogen	Notes
Ammonia/urea	87,000 - 485,000	Moderate	Moderate to high	Suited to size of geothermal greenfield sites	Goethermal based hydrogen can provide constant supply
Methanol	60,000	Low	Moderate	May be suitable for geothermal greenfieldsites	Need CO2e source which can be provided by some geothermal sites
Petrochemical	700 - 5,900	Low	Low	Suited to production levels of optimised sites	Needs continuous supply of H2 so suits geothemal based hydrogen
Oil refining	34,000 - 66,000	Low	Moderate	Suited to production levels of greenfield sites	Needs continuous supply of H2 so suits geothemal based hydrogen
Green steel	47,000	High	High	Suited to production levels of greenfield sites	Potential for growth
Island grids	3,000 to 24,000	Low	Low	Suited to production levels of optimised and brownfield sites	Needs to be shipped which adds to cost of hydrogen

Cost Comparison of Green hydrogen and Grey Hydrogen in Indonesia

Year	Cost of hydrogen (USD/kg)	
	Grey (SMR)*	Green (Geothermal)
2020	4.5 – 7.2	-
2025	-	6.4 – 7.6
2030	2.5 - 3.4	6.1 - 7.3

*The cost might be lower at some industrial sites where they use off gases as feedstock

The cost of grey hydrogen in Indonesia is derived from ASEAN Centre for Energy (2020) and BNEF for different end use.

Key Insights (Risks and Opportunities)

1. **Hydrogen from all sources are still not quite there in terms of meeting customers willingness to pay for hydrogen for domestic and export market**
   I. Costs of green hydrogen expected to decline so will be close to breakeven levels from mid 2030s
   II. Carbon impost on fossil fuel alternatives may make hydrogen more attractive to fossil fuel by 2030. Would require a carbon price of over $50/t to $100/t CO_2 to make hydrogen an attractive alternative
      a) This is in the range of most plausible estimates for the long-term value of the social cost of carbon
   III. Recent energy security concerns in Europe and elsewhere (with natural gas prices elevated due to short term issues such as the war in Europe) may incentivize end-users to pay a premium for hydrogen
2. **Geothermal hydrogen must compete with other renewable based hydrogen**
   I. Geothermal's advantage relative to other renewable options is its ability to provide continuous supply
   II. However, the cost of other renewable technologies (with the cost of generation making up something of between 65% to 75% of the total cost of hydrogen) are projected to continue to fall whereas the cost of geothermal is relatively static
3. **For domestic (Indonesian) markets, geothermal hydrogen is relatively competitive with other sources of green hydrogen (imported and other renewables within Indonesia) in the short to medium term**
   I. But the cost reduction for other sources means that geothermal will become relatively less competitive from 2030
   II. From a strategic point of view this would tend to mean there should be a focus on the low-cost geothermal options
   III. One option is diverting spare capacity at existing geothermal facilities to hydrogen production (as the LCOH should be very competitive due to reduced capital cost)

Key Insights (Risks and Opportunities)

4. **For the domestic (Indonesian) market, the largest and most prospective near-term markets are in the ammonia (and urea which utilises ammonia), methanol and green steel segment**
   I. These segment may be willing to pay more for hydrogen
   II. The volumes required suit some of the larger geothermal prospects
   III. They have a preference for continuous supply sources.
   IV. Would help to decarbonise these segments

5. **For Pertamina's development options at existing sites, these would be a highly competitive option for hydrogen but are smaller in volume**
   I. May not be suited to some market segments with large volume requirements (except as a blended product with other geothermal hydrogen)
   II. However, would suit low volume markets including the high value transport markets (long distance rail and road haulage)

6. **The Government of Indonesia might need to conduct further assessment for geothermal potential use after 2030 based on electricity demand in each area in Indonesia and assess which geothermal sites that have potential for green hydrogen production.**
7. **Geothermal hydrogen's competitive advantage may erode over time so it might be useful to lock in markets in this decade**
8. **Potential piping damage caused by earthquake may mean that distribution of hydrogen using piping may not be suitable due to safety concerns. The use of road transport may be suited to smaller volumes.**
9. **Consider ammonia and methanol as hydrogen carrier fuel for domestic transport and for international supply chain. Ammonia is being heavily considered for many end-use applications (especially for international sales due to lower shipping and liquefaction costs) but methanol will be preferred in some applications due to lower costs and established supply chains. .**

Key Insights (Risks and Opportunities)

10. Only 32% of the Indonesia's hydrogen demand can be fulfilled by the total potential of geothermal generation

Indonesia Region	Hydrogen Demand (kT/year)			
	Ammonia Industry	Refinery	Steel	Total
Jawa	312	128	48	488
Sumatra	453	34		487
Sulawesi	284			284
Kalimantan	573	62		635
Papua		1		1
Total	1,622	225	48	**1,895**

Indonesia Region	Hydrogen Supply from potential geothermal (kT/year)
Jawa	216
Sumatra	259
Sulawesi	56
NTB	6
NTT	20
Maluku	42
Total	**599**

Key Insights

Next Steps

- Consideration of a small scale pilot plant using excess generation on brownfield sites is appropriate.
- Identify the large scale geothermal developments that could bring sufficient scale and production capacity and work with stakeholders to fast track development.
- Consider all future geothermal developments (including those in the RUPTL) open for electricity generation for national grid OR dedicated use for green hydrogen and allow market mechanisms (such as cost of carbon, decarbonisation objectives) to drive utilisation objectives.
- Review/engage with existing ammonia and refining clients to determine interest and capability to utilise green hydrogen.
- Engage with international partners from Korea, Japan etc to review potential for long term collaboration
- The government of Indonesia to prepare regulatory framework to enable green hydrogen from geothermal to be developed with the aim to reach the target of utilizing green hydrogen by 2030.

Q&A

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