

## 2<sup>nd</sup> LATAM MEETING ON GREEN AMMONIA AND POWER-to-X

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# “Evaluation of the Green Hydrogen Generation Potential in the Antofagasta Region”

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Dr. Lindley Maxwell.

Lead of Energy

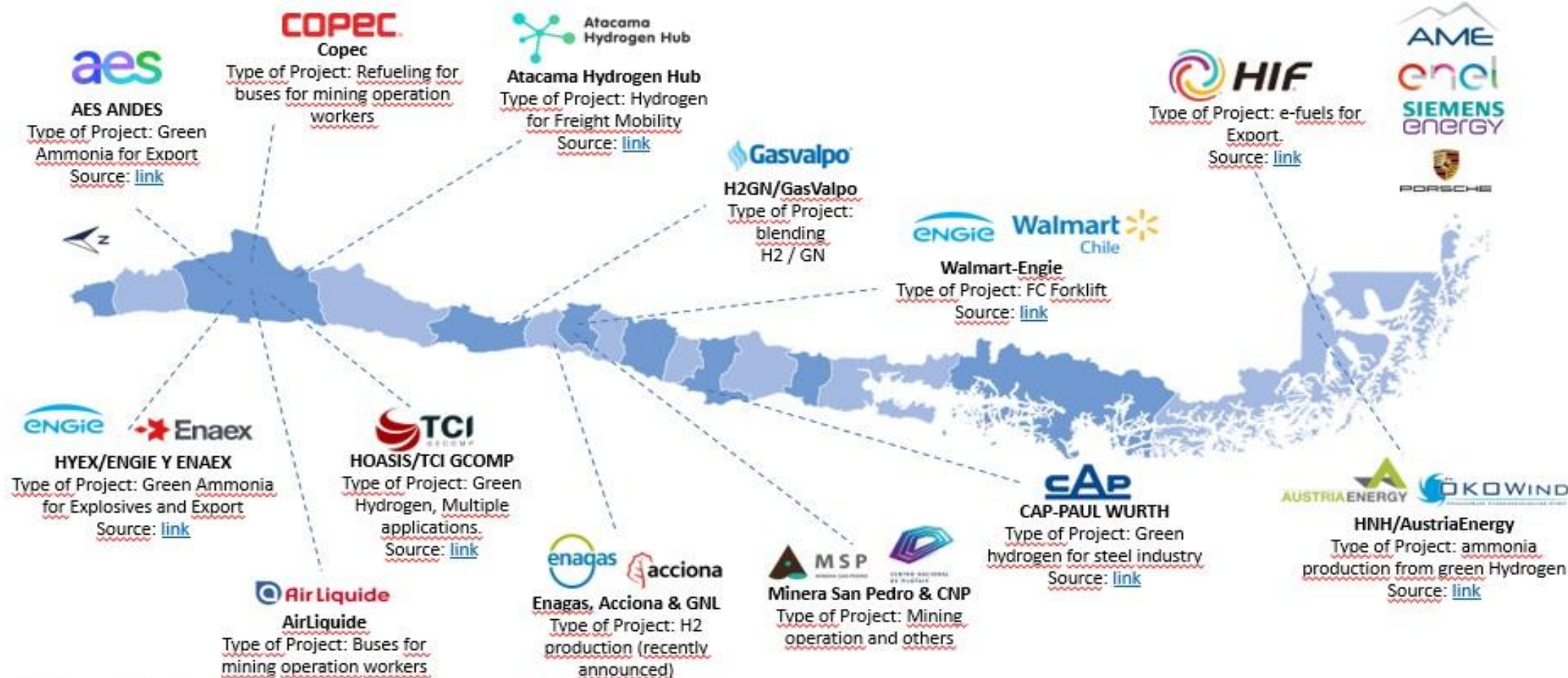
CICITEM, Chile.

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January 2025

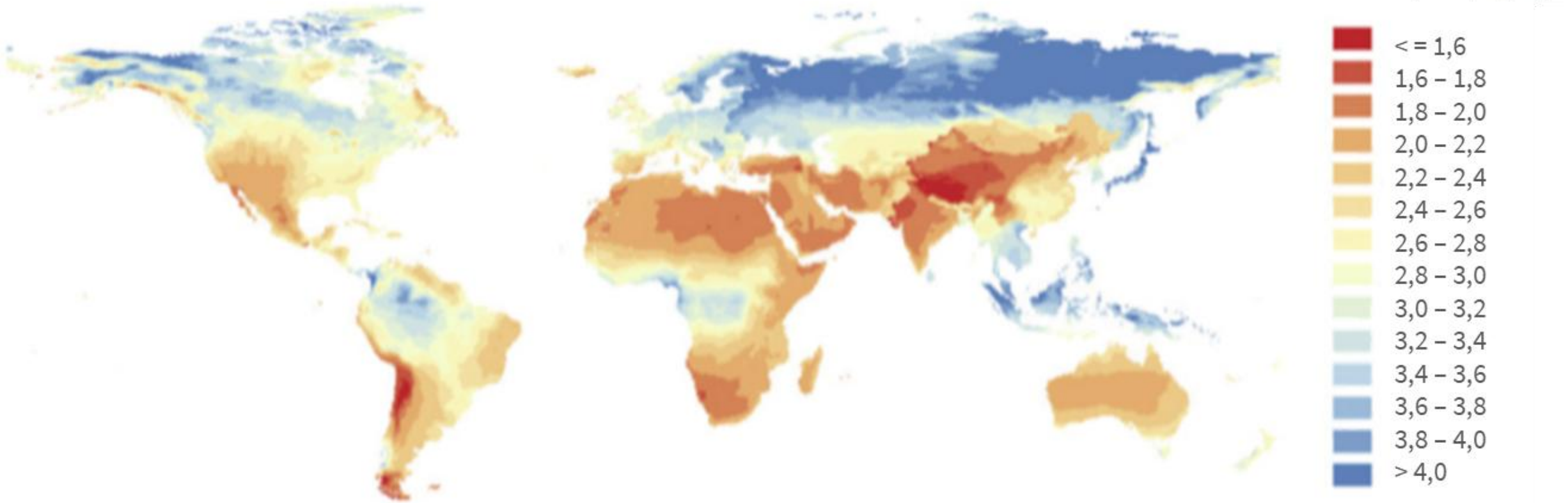


## Algunos proyectos en desarrollo en Chile



# MOTIVATION AND CONTEXT

## ERNC Potential vs LCOH



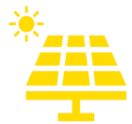
Notas: Este mapa es sin perjuicio al estado de soberanía de cualquier territorio, a la delimitación de fronteras y límites internacionales y al nombre de cualquier territorio, ciudad o área. CAPEX de los electrolizadores = 450 US\$/kWe, eficiencia (LHV) = 74%; CAPEX de energía FV solar y CAPEX de energía eólica costa adentro = entre 400–1.000 US\$/kW y 900–2.500 US\$/kW dependiendo de la región; tasa de descuento = 8%

# MOTIVATION AND CONTEXT

														DATABASE													
Ref	Project name	Country	Date online	Decommission date	Status	Technology			If dedicated renewables, type of renewable	Product	End use										Announced Size		Norm				
							Technology Comments	Type of electricity (for electrolysis projects)			Refining	Ammonia	Methanol	Iron&Steel	Other Ind	Mobility	Power	Grid inj.	CHP	Domestic heat	Biofuels	Synfuels	CH4, grid inj.	CH4, mobility	MWel	Nm <sup>3</sup> H <sub>2</sub> /h	
Ref	Project name	Country	Date online	Decommission date	Status	Technology	Technology_details	Technology_electricity	Technology_electricity_details	Product	Use_Refin	Use_Amm	Use_Meth	Use_Iron&Steel	Use_Other	Use_Mobility	Use_Power	Use_Grid inj.	Use_CHP	Use_Domestic heat	Use_Biofuels	Use_Synfuels	Use_CH4, grid inj.	Use_CH4, mobility	Announced Size	Capacity_MWel	Capacity_Nm <sup>3</sup> H <sub>2</sub> /h
2911	Punta Delgada	CHL	2032		Concept	Other Electrolysis	Unknown PtX	Dedicated renewable	Onshore wind	Ammonia	1														1.5GW	1500	333333
2912	Desierto verde	CHL			Concept	Other Electrolysis	Unknown PtX	Dedicated renewable	Others/Various	Ammonia	1														1.44GW	1440	320000
2930	Ammonia project - Antofagasta -phase 1	CHL	2027		Concept	Other Electrolysis	Unknown PtX	Other/Unknown		Ammonia	1														300 kt NH <sub>3</sub> /y, production	547,0	121562
2931	Ammonia project - Antofagasta -phase 2	CHL			Concept	Other Electrolysis	Unknown PtX	Other/Unknown		Ammonia	1														600 kt NH <sub>3</sub> /y, production	547,0	121562
2938	Ammonia project - Araucania	CHL			Concept	Other Electrolysis	Unknown PtX	Other/Unknown		Ammonia	1														0		
2942	H2V Frontera Project	CHL			Concept	Other Electrolysis	Unknown PtX	Dedicated renewable	Onshore wind	H <sub>2</sub>															227MW	227	50444
3042	H2 Magallanes - Phase 2	CHL	2033		Concept	Other Electrolysis	Unknown PtX	Dedicated renewable	Onshore wind	Ammonia															3.7Gwel	3700	822222

2433 projects worldwide - 69 Chile

# MOTIVATION AND CONTEXT



**Renewable Energy**



**Production of H<sub>2</sub>**



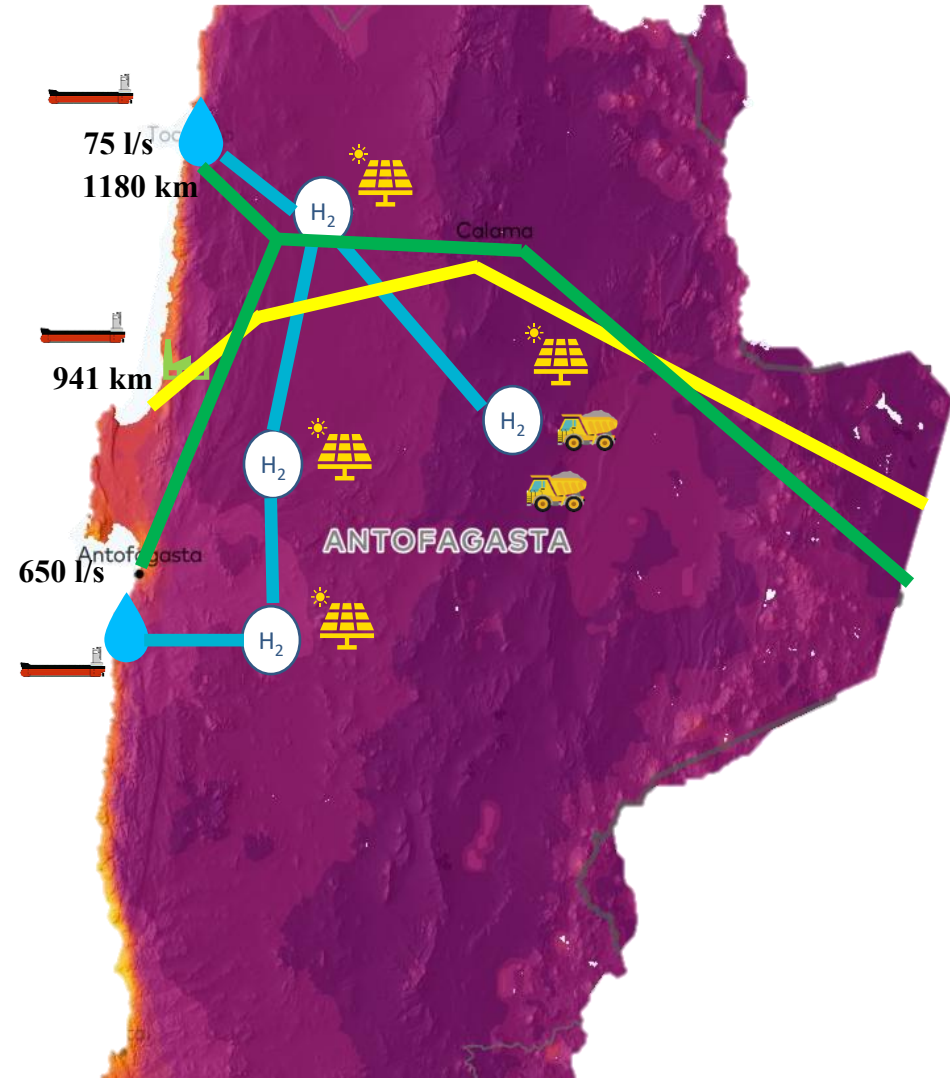
**Gas Pipeline Nor-Andino**



**Gas Pipeline Atacama**

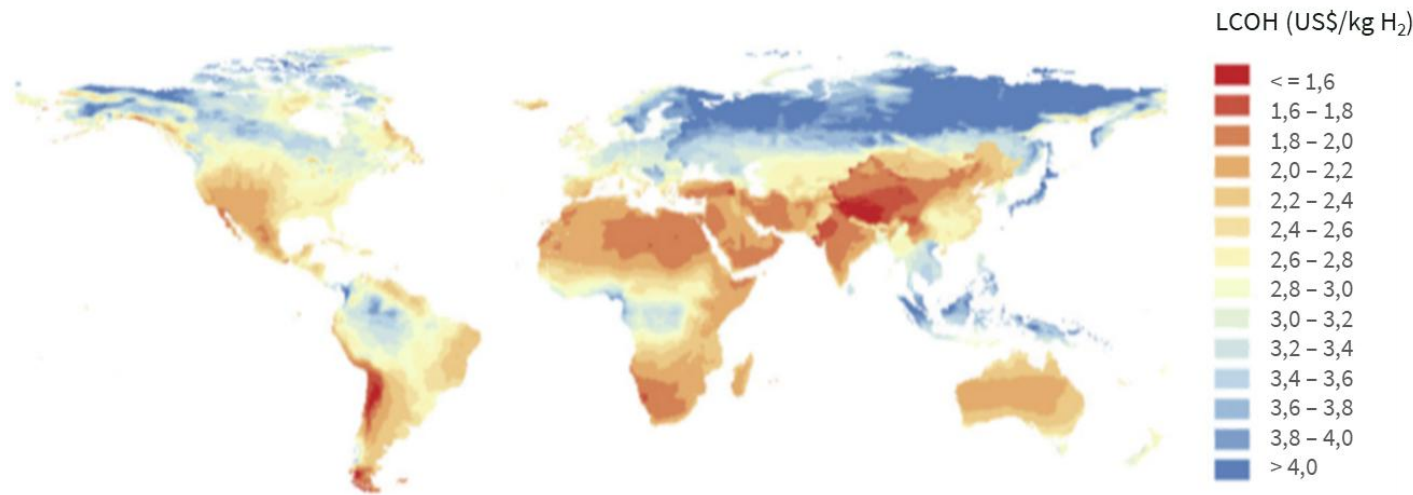


**Desalination Plant**



# MOTIVATION AND CONTEXT

Why is efficiency important?



Notas: Este mapa es sin perjuicio al estado de soberanía de cualquier territorio, a la delimitación de fronteras y límites internacionales y al nombre de cualquier territorio, ciudad o área. CAPEX de los electrolizadores = 450 US\$/kWe, eficiencia (LHV) = 74%; CAPEX de energía FV solar y CAPEX de energía eólica costa adentro = entre 400-1.000 US\$/kW y 900-2.500 US\$/kW dependiendo de la región; tasa de descuento = 8%

$$LCOH = \frac{\sum_{t=1}^n \left( \frac{CAPEX + OPEX + \$energía}{(1+r)^t} \right)}{\sum_{t=1}^n \frac{H_2 \text{ producción} * \eta}{(1+r)^t}}$$

CAPEX: **1,000,000 USD**  
Annual OPEX **50,000 USD**  
Annual energy costs: **200,000 USD**  
Hydrogen production: **50,000 kg/year**  
System efficiency: **70%**  
Lifespan: **20 years**  
Discount rate: **8%**

The Levelized Cost of Hydrogen (LCOH) in this example is approximately **9.84 USD/kg**.

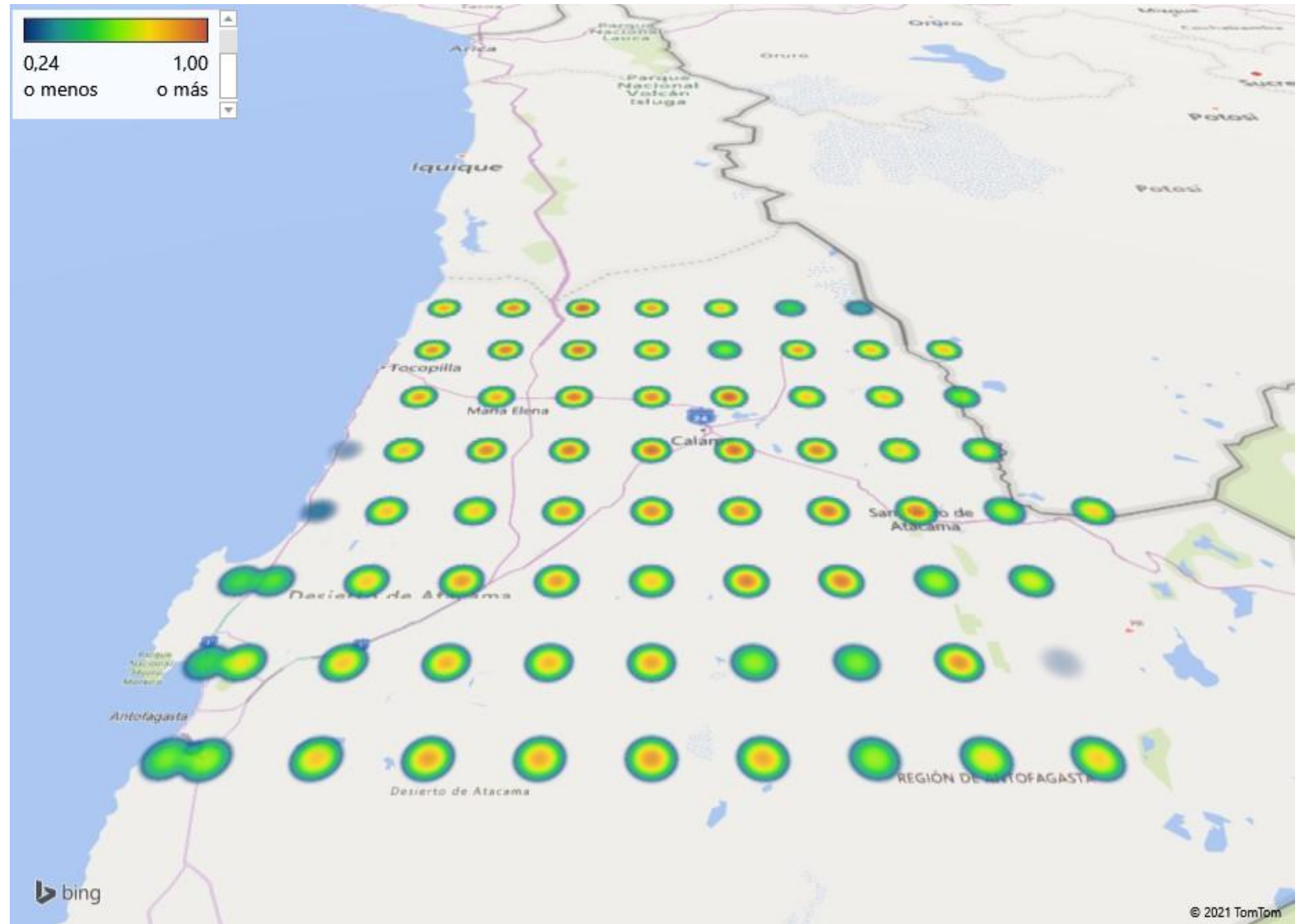
The variation in the Levelized Cost of Hydrogen (LCOH) with a 5% change in system efficiency is:

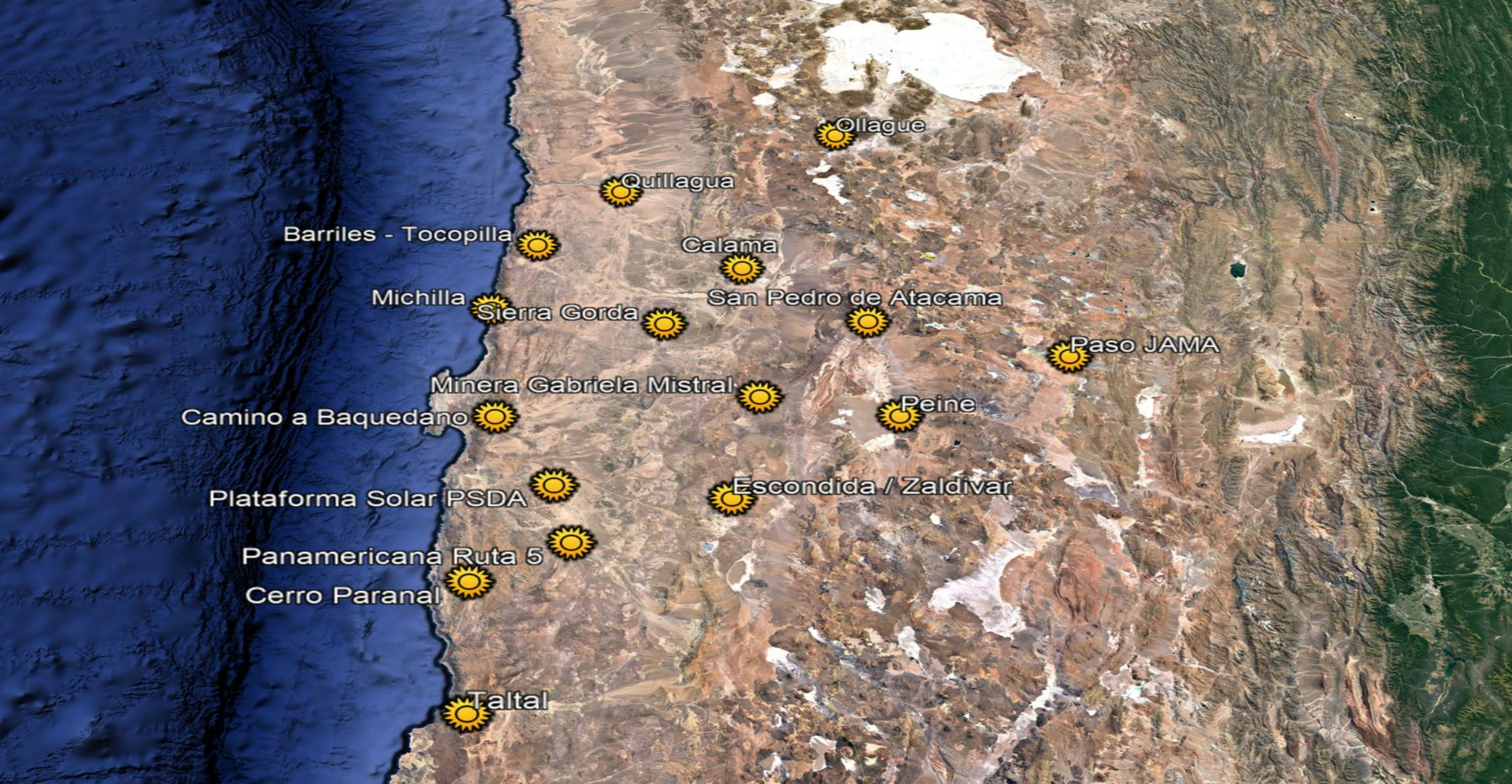
- Efficiency increased by 5% (75%) The LCOH decreases to **9.18 USD/kg**
- Efficiency decreased by 5% (65%): The LCOH increases to **10.59 USD/kg**

# Looking for the best location

Rank	Sitio	Factor Eff	Rank	Sitio	Factor Eff
1	H5	1,00	37	B5	0,83
2	F7	0,99	38	G10	0,83
3	G5	0,97	39	G9	0,83
4	E6	0,97	40	D3	0,82
5	E7	0,96	41	H7	0,82
6	E5	0,95	42	F9	0,82
7	D8	0,95	43	B3	0,81
8	G4	0,94	44	E9	0,81
9	D9	0,94	45	C3	0,81
10	F5	0,94	46	F8	0,81
11	E8	0,93	47	A3	0,80
12	C8	0,93	48	D4	0,80
13	C7	0,93	49	C6	0,80
14	E4	0,92	50	A10	0,79
15	H4	0,92	51	D11	0,79
16	F6	0,92	52	A9	0,76
17	D6	0,91	53	B2	0,75
18	D7	0,91	54	E10	0,72
19	G3	0,91	55	C10	0,72
20	B9	0,90	56	D10	0,68
21	D5	0,90	57	C9	0,66
22	A6	0,89	58	A2	0,66
23	F3	0,89	59	A8	0,65
24	C4	0,88	60	B7	0,64
25	C5	0,88	61	F10	0,64
26	G8	0,88	62	B8	0,61
27	H6	0,88	63	G7	0,61
28	A4	0,87	64	A1	0,60
29	B6	0,87	65	C2	0,57
30	H3	0,87	66	C1	0,55
31	G6	0,86	67	H8	0,53
32	A5	0,86	68	B1	0,53
33	A7	0,86	69	H9	0,40
34	F4	0,85	70	D2	0,32
35	B4	0,84	71	E2	0,29
36	E3	0,84	72	B10	0,27
			73	F2	0,24

$$FE = \left( \frac{(P*0,4)+(FP*0,3)}{(Desv*0,3)} \right)$$





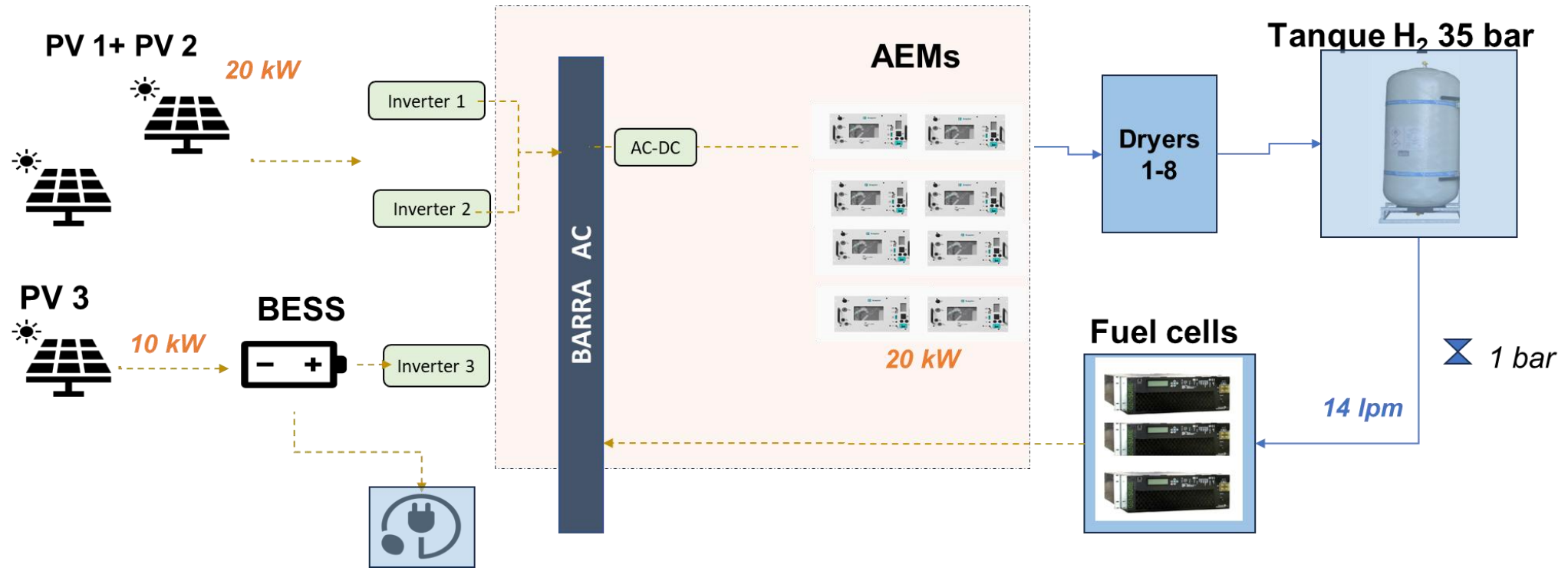
- Sites of Interest

# Looking for the best location

#	Localizaciones	Latitud (dec)	Longitud (dec)	Altitud [mslm]	Radiacion anual				Informacion metereologica		
					Global horizontal [kWh/m2/dia]	Global inclinado a 24° [kWh/m2/dia]	Directa normal [kWh/m2/dia]	Difusa horizontal [kWh/m2/dia]	Frecuencia de nubes [%]	Temperatura ambiental [°C]	Velocidad viento [m/s]
1	PSDA Antofagasta	-24.09	-69.93	964	7.14	7.66	10.43	0.65	3	18.3	3
2	Camino Baquedano	-23.56	-70.24	573	7.06	7.55	10.14	0.65	3	16.6	3.2
3	Sierra Gorda	-22.88	-69.31	1633	7.28	7.78	10.59	0.69	4	17.2	3.2
4	Calama	-22.43	-68.86	2381	7.42	7.92	10.88	0.67	4	13.7	5
5	Minera Zaldívar/ Escondida	-24.23	-69.00	3086	7.31	7.8	10.76	0.74	5	9	3.7
6	Cerro Paranal	-24.73	-70.36	2043	7.3	7.83	10.54	0.62	3	11	4
7	Barriles	-22.17	-70.02	1128	7.26	7.73	10.53	0.65	3	16.4	4.6
8	San Pedro de Atacama	-22.91	-68.18	2427	7.29	7.8	10.48	0.79	5	14.2	3.4
9	Paso Jama /Observatorio ALMA	-23.23	-67.10	4309	7.28	7.85	10.61	0.89	7	3.3	7
10	Ollagüe	-21.22	-68.24	3702	7.11	7.55	10.02	0.94	8	7.8	4.1
11	Quillagua	-21.70	-69.53	931	7.15	7.59	10.04	0.73	4	19.9	3.7
12	Michilla	-22.70	-70.27	44	5.88	6.07	7.09	1.19	16	17.6	2.5
13	Minera Gabriela Mistral	-23.49	-68.82	2564	7.27	7.75	10.54	0.89	5	12.9	4.4
14	Peine	-23.66	-68.07	2349	6.92	7.32	9.62	1.04	8	15.6	3.1
15	Taltal	-25.57	-70.36	800	6.91	7.46	9.97	0.67	5	15.9	2.7
16	Panamericana Norte, Ruta 5	-24.50	-69.84	1490	7.27	7.82	10.74	0.63	3	17.2	3.7

- Atypical measurement points in specific parameters (outliers)
- In particular, the outliers are concentrated in Calama, Paso Jama, and Michilla.

# Conceptual Design of Hydrogen Movil Plant



RESOLUCION EXENTA ELECTRONICA N° 20380  
Santiago, 24 de Noviembre de 2023



AUTORIZA A CENTRO DE INVESTIGACIÓN CIENTÍFICO TECNOLÓGICO PARA LA MINERÍA CICITEM PROYECTO ESPECIAL “PLANTA PILOTO MÓVIL PARA EL ESTUDIO DE EVALUACIÓN DEL POTENCIAL DE GENERACIÓN DE HIDRÓGENO SOLAR EN LA REGIÓN DE ANTOFAGASTA”, SEGÚN SE INDICA.

# Cost of I+D

Within the overall budget, the largest percentage of expenditure, **67%**, is allocated to investment. This is justified by the acquisition and construction of the Mobile Pilot Plant.

Following this, **operational expenses account for 19%**, which include transportation, accommodation, and spare parts related to a study of this scale across different points in the region.

Item	Global Budget	%
1.- Human Resources	68,732,155	12.4
2.- Subcontracts/Co-executor	0	0.0
3.- Training	0	0.0
4.- Technological Tours	0	0.0
5.- Dissemination and Technology Transfer	5,300,000	1.0
6.- Operational Expenses	107,772,685	19.4
7.- Investment Expenses	372,078,312	67.2
8.- Administrative Expenses	0	0.0
9.- Publication Expenses	0	0.0
<b>TOTAL BUDGET</b>	<b>553,383,152</b>	<b>100</b>



# Movíl Pilot Plant of H2V





$H_2$

PLANTA MÓVIL DE  
HIDRÓGENO  
VERDE

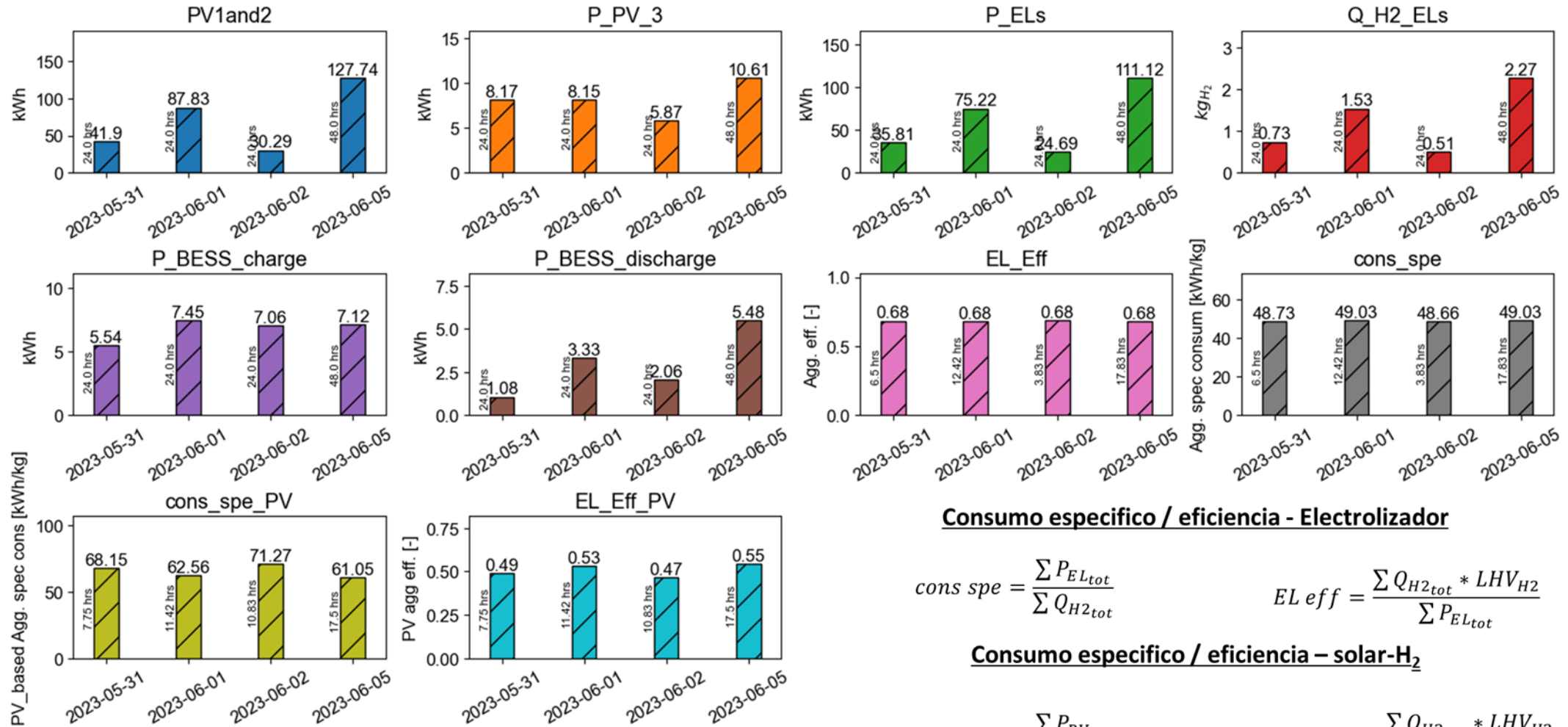
GR HG-26





# Results

## Aggregate analysis for location: San\_Pedro



### Consumo específico / eficiencia - Electrolizador

$$cons\ spe = \frac{\sum P_{EL_{tot}}}{\sum Q_{H2_{tot}}}$$

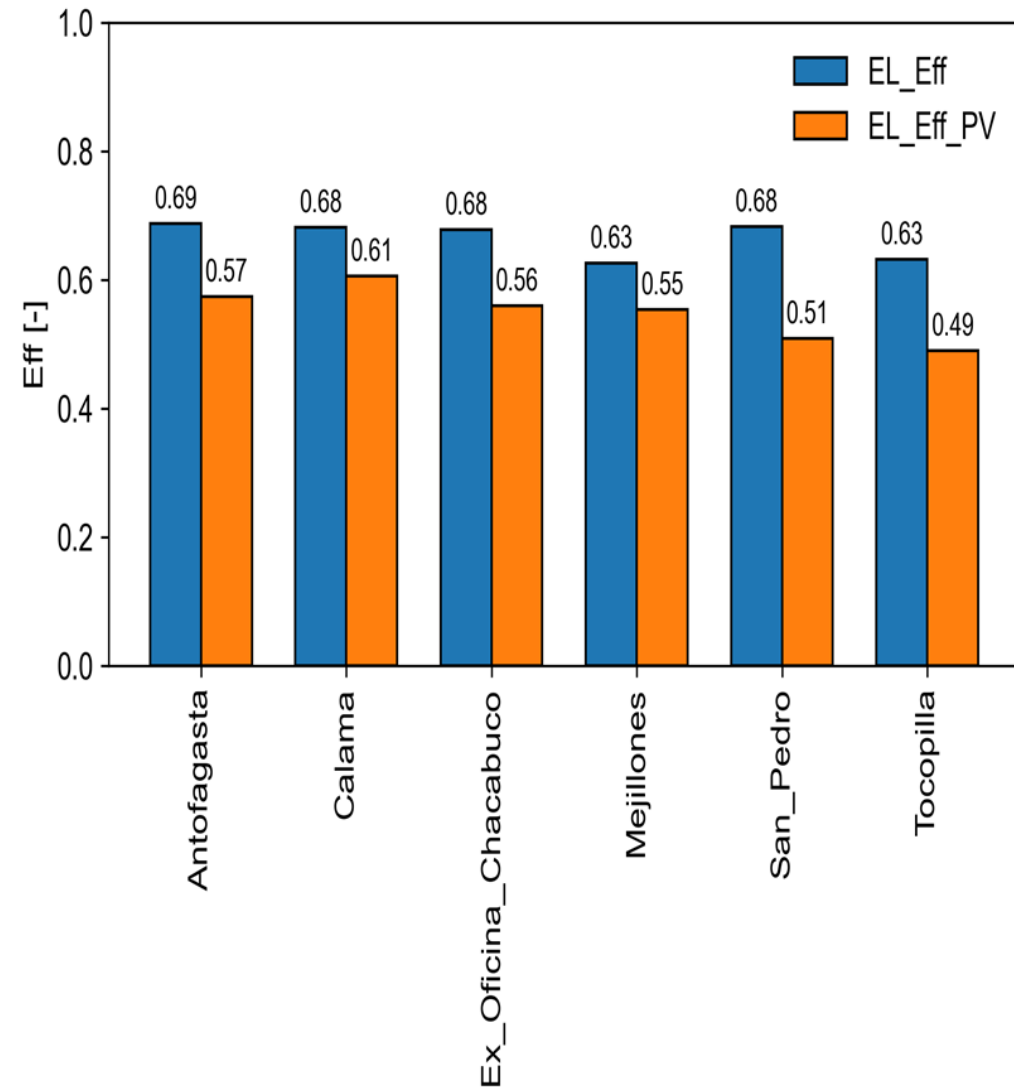
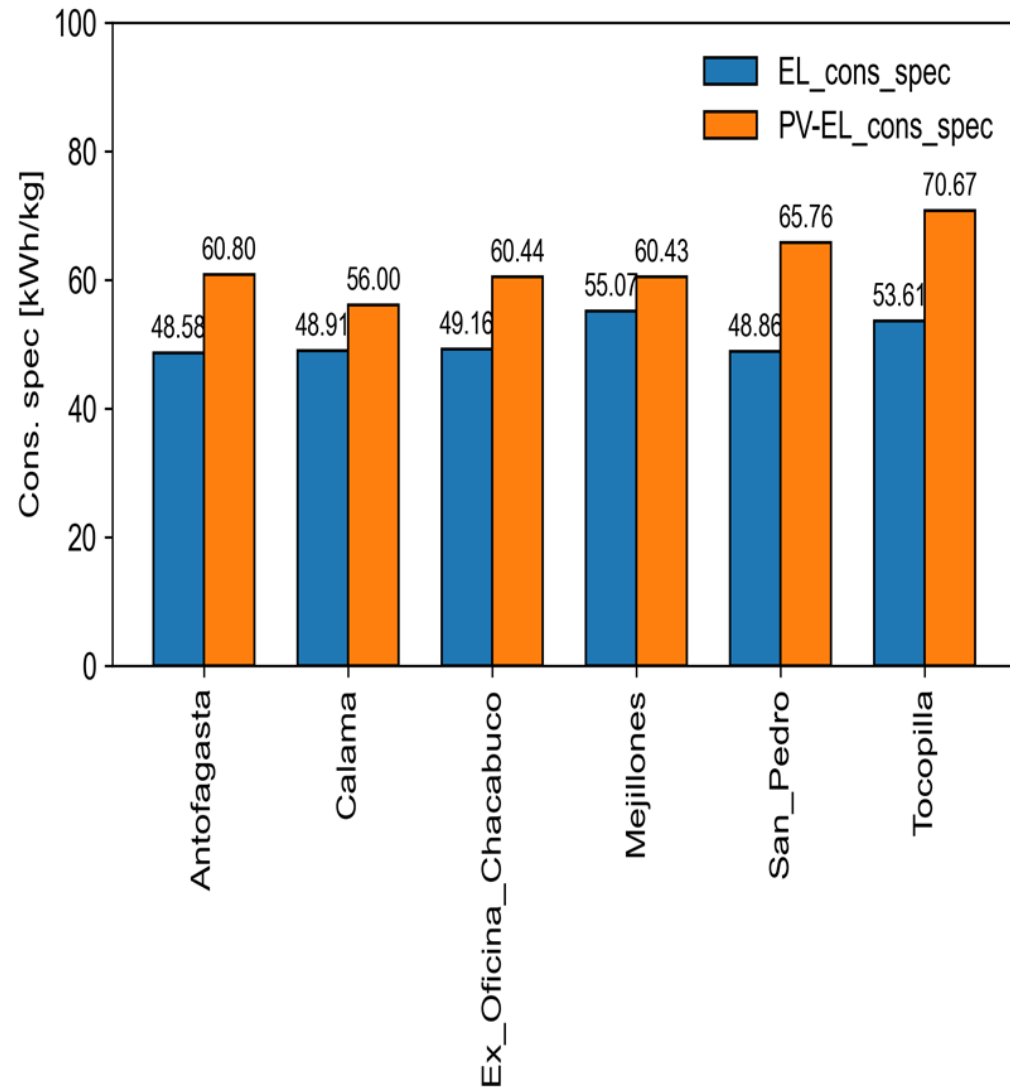
$$EL\ eff = \frac{\sum Q_{H2_{tot}} * LHV_{H2}}{\sum P_{EL_{tot}}}$$

### Consumo específico / eficiencia - solar-H<sub>2</sub>

$$cons\ spe\ PV = \frac{\sum P_{PV_{tot}}}{\sum Q_{H2_{tot}}}$$

$$EL\ eff\ PV = \frac{\sum Q_{H2_{tot}} * LHV_{H2}}{\sum P_{PV_{tot}}}$$

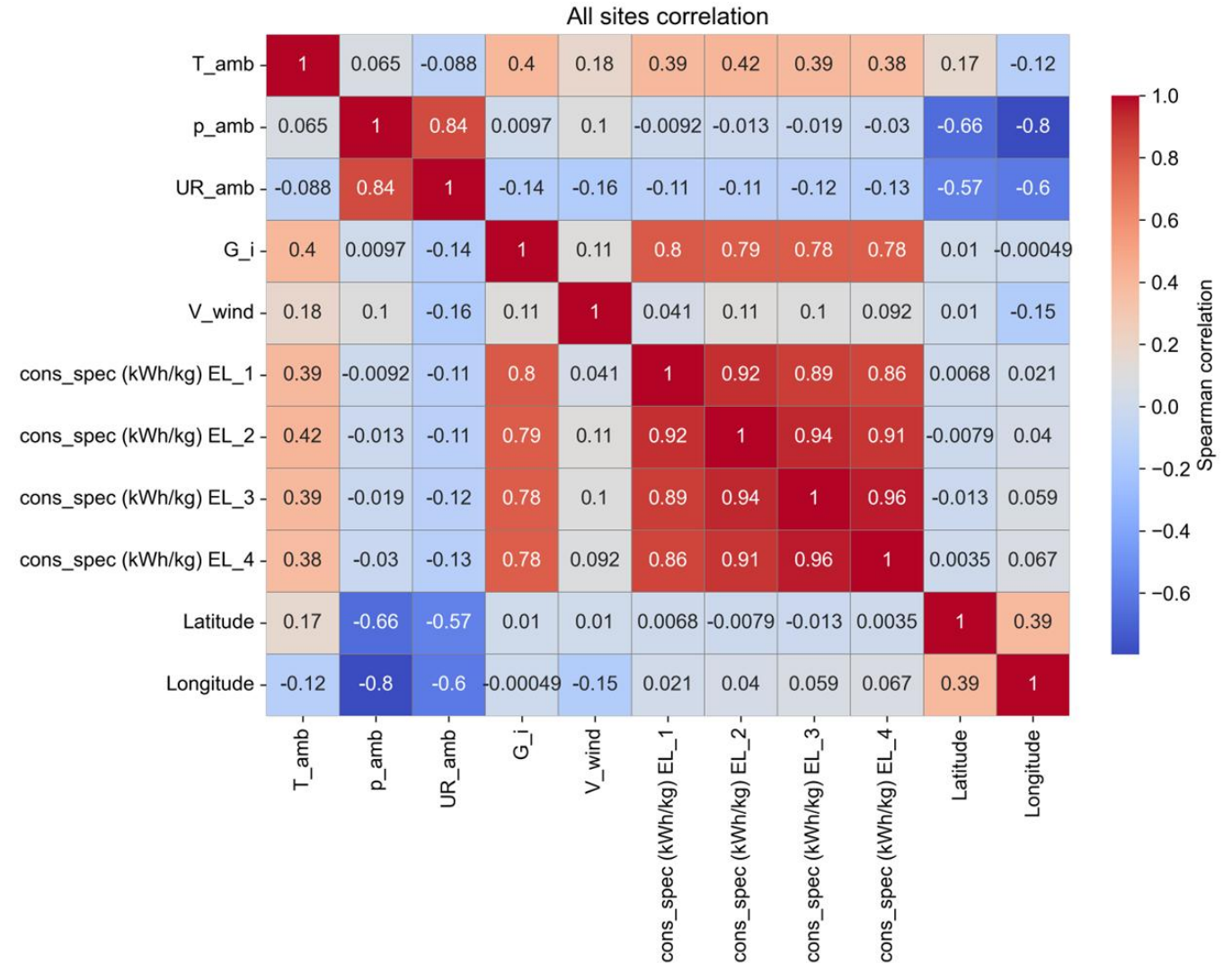
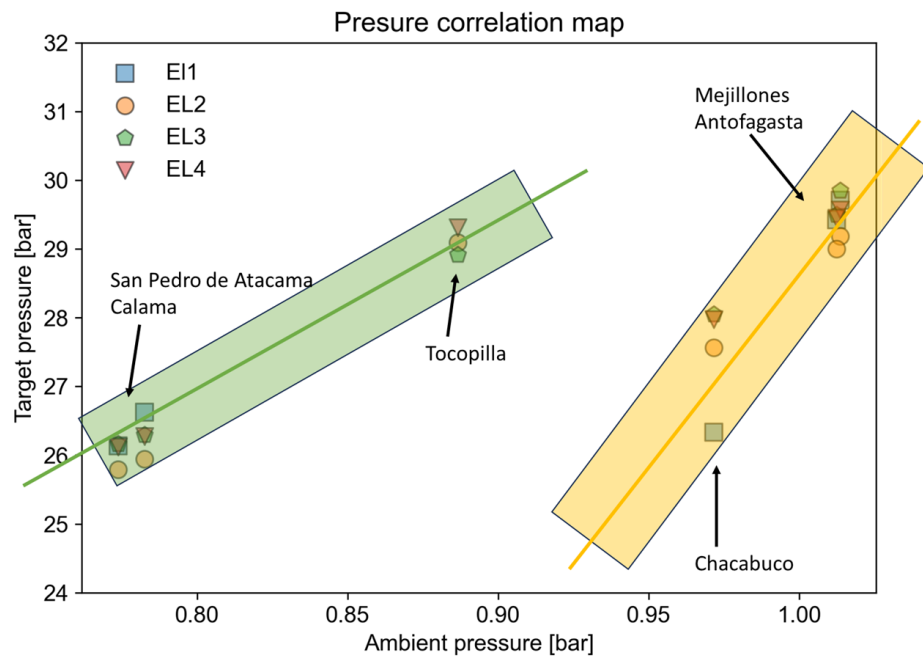
# Results



# Results

Correlation with altitude is indirectly incorporated through the correlation with ambient pressure.

The specific consumptions used to verify the correlation are those of the electrolyzers themselves, not the aggregated values related to the overall solar-H<sub>2</sub> balance.



Location: **San Pedro de Atacama** (-22°91"N, -68°18"E) ALT

**2432 msnm**

Average Global Horizontal Irradiance: **7.29 [kWh/m<sup>2</sup>/day]**

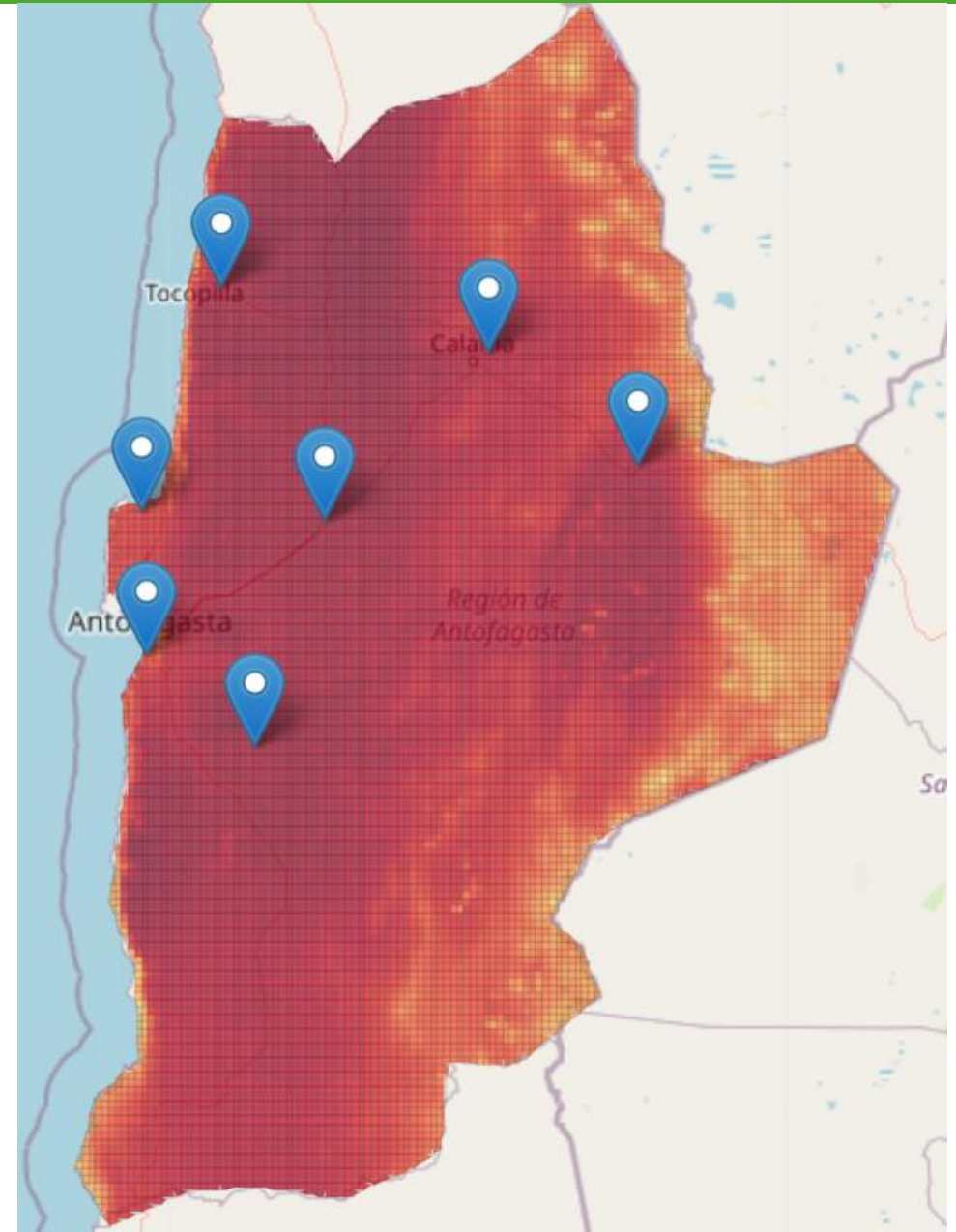
Ambient Temperature: **14.2 [°C]**

Ambient Pressure: **0.77 [bar]**

Specific Consumption EL: **48.86 [kWh/kg]**

Electrolyzer Efficiency: **68%**

Specific Plant Consumption: **65 [kWh/kg]**





# CASO 07 | GENERACIÓN DE ENERGÍA EN SITIOS AISLADOS, BASADO EN FC

## DESCRIPCIÓN DE LA OPORTUNIDAD

La cooperativa eléctrica CESPBA busca migrar a la energía fotovoltaica con el objeto de ser sustentables y sostenibles, a través de un plan que contempla 2 MW en una primera etapa, y dos etapas posteriores que busca terminar con un sistema integrado de 9 MW con almacenamiento.

El principal sistema de generación de energía de ALMA, en el Llano de Chajnantor, es en base a GLP (3 MW); teniendo además de un equipo electrógeno a diésel <sup>3</sup> (1 MW) para compensar los peaks, aunque se cuenta con una demanda

## SISTEMAS AISLADOS

Los sistemas aislados representan un gran desafío para cumplir con las metas de descarbonización, debido a que no se encuentran conectados a la red y no pueden depender totalmente de las ERNC sin almacenamiento. Este tipo de sistemas está siendo abordado por distintas iniciativas que involucran el respaldo en base a hidrógeno verde, como alternativa sostenible a los respaldos en base a combustibles fósiles.



Para aumentar la costo-eficiencia de este tipo de proyectos, se suele destinar la energía renovable producida directamente como suministro para el sistema en sí, donde el superávit generado se destina a la electrólisis, con el objetivo de almacenar hidrógeno y que sea utilizado para producir energía cuando no haya sol ni viento.

## CASOS DE USO

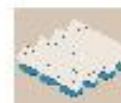


## CONTEXTO SOBRE LA OPORTUNIDAD

Para este caso ejemplo en el complejo observatorio ALMA, las características del sistema dependerán de los siguientes aspectos:



Producción propia de H2 u oferta de hidrógeno para almacenamiento y dispensado.



Generación propia de electricidad ERNC o contrato de suministro eléctrico de ERNC.



Existe capacidad de almacenamiento de hidrógeno.



Generación de energía mediante FC solo en cierta cantidad de horas, el resto proveniente de ERNC directa.

## REDUCCIÓN DE 27.376 TONELADAS AÑO DE CO<sub>2</sub>

Para una potencia media consumida de 2 MW, se estimó un consumo de GLP de aproximadamente 2.568 toneladas al año.

El reemplazo de dicho GLP por equipos a celdas de combustible a hidrógeno, implicarían la reducción de 27.376 toneladas año de CO<sub>2</sub> aproximadamente.

Potencia media consumida, MW

	2 MW	0,5 MW	1 MW	3 MW
Consumo anual de GLP, ton/año	2.568	642	1.284	3.852
H2 requerido por ton/año	1.056	264	528	1.583
Potencia instalada requerida, MW	6,43	1,61	3,21	9,64
Reducción emisiones de CO2 al año, ton	7.376	1.844	3.688	11.064



Escanea este código QR para obtener información adicional

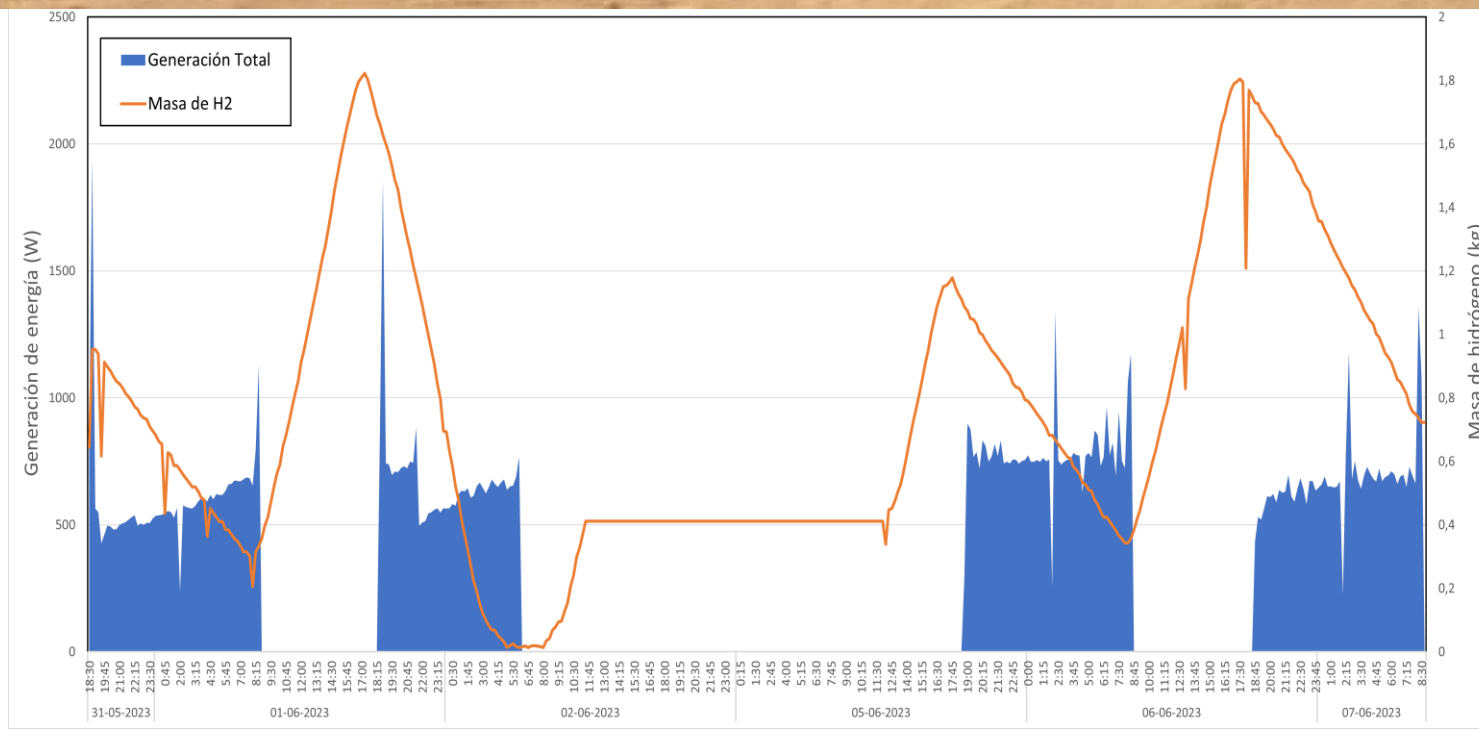


## TECNOLOGÍA

Para aumentar la costo-eficiencia de este tipo de proyectos, se suele destinar la energía renovable producida directamente como suministro para el sistema en sí, donde el superávit generado se destina a la electrólisis, con el objetivo de almacenar hidrógeno y que sea utilizado para producir energía cuando no haya sol ni viento.



# Experimental execution



# Possible scenarios

	Scenarios	Considerations and Limitations Regarding the Expansion of Renewable Energy and Storage Systems
1	CESPA does not receive the BESS system as a donation	- 100% photovoltaic renewable energy participation in the system by 2040. - 10% of energy comes from the green hydrogen storage system.
2		- 100% photovoltaic renewable energy participation in the system by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
3		- 100% renewable energy participation in the system from photovoltaic plants and the use of biodiesel in the existing diesel generation park by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
4	CESPA receives a BESS system as a donation. Installation and operation are outsourced to a third party, and the use of the system is charged to CESPA through a PPA.	- 100% photovoltaic renewable energy participation in the system by 2040. - 10% of energy comes from the green hydrogen storage system.
5		- 100% photovoltaic renewable energy participation in the system by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
6		- 100% renewable energy participation in the system from photovoltaic plants and the use of biodiesel in the existing diesel generation park by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
7	CESPA receives a BESS system as a donation. Installation and operation are managed by CESPA.	- 100% photovoltaic renewable energy participation in the system by 2040. - 10% of energy comes from the green hydrogen storage system.
8		- 100% photovoltaic renewable energy participation in the system by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
9		- 100% renewable energy participation in the system from photovoltaic plants and the use of biodiesel in the existing diesel generation park by 2040. - Combination of storage that generates the lowest levelized cost of energy, whether BESS, green hydrogen, or a combination of both.
10	CESPA does not receive the BESS system as a donation	- No integration of other renewable energy sources (RES), BESS, or hydrogen systems. - System operation is assumed without automatic control.
11		- No integration of other renewable energy sources (RES), BESS, or hydrogen systems. - It is assumed that the operation includes an automatic control system for the hybrid system.

# San Pedro de Atacama 100% Renewable

- Total consumption: 36 MWh/day
- 8 MW PV (2 MW already built)
- 10 h PV generation - 14 h H<sub>2</sub> generation
- 5.5 MW electrolyzer and 2.5 MW PV
- 84 kg/h of hydrogen (810 kg of hydrogen total)
- 5 MW Electrolyzer
- 2 MW Fuel Cell



# Conclusions

The Antofagasta region possesses undeniable **comparative advantages for green hydrogen production** due to its **unique natural and geographic conditions**. However, to fully capitalize on this potential, it is imperative to **establish the capacities needed to foster a new chemical industry**.

This requires a concerted effort in **human capital training, infrastructure development, and R&D investment**. By addressing these gaps, Antofagasta **can become a global leader in the green hydrogen economy**, contributing significantly to carbon neutrality goals and establishing a robust industrial base for future generations.

