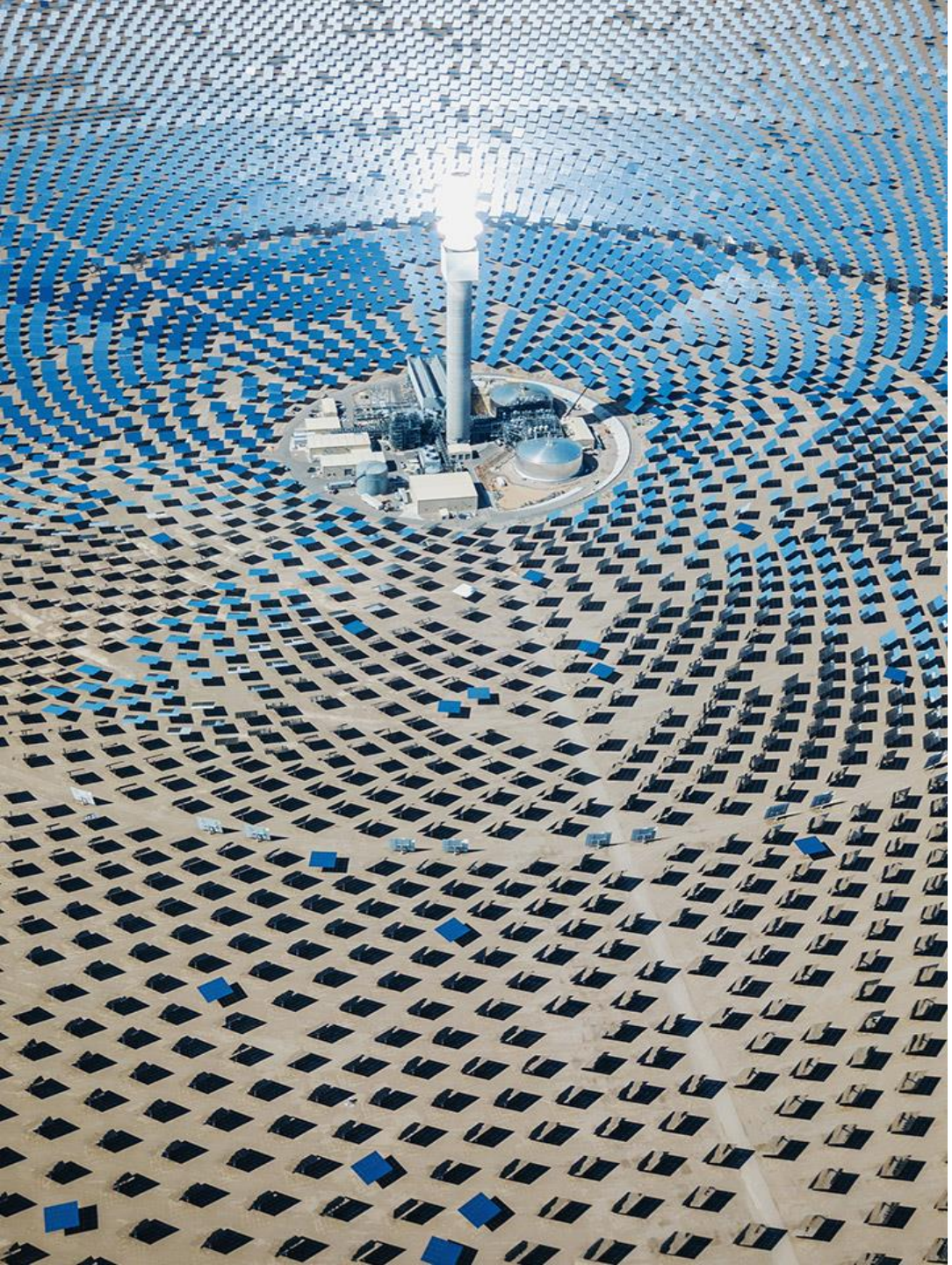

How to reduce the LCoA of green NH3 with hybrid CSP-PV plants

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PacificGreen Solar Technologies

AMMONIA ENERGY ASSOCIATION

PacificGreen Technologies Group

PGTK Technologies & Company Development

Leading environmental technologies group

Vision

PGTK's vision is a world in which the issues of climate heating and resource scarcity are addressed by technological innovation and sensible stewardship

Mission

PGTK's mission is to develop and deliver renewable technologies globally

Development

Evolved from a niche technologies development start-up into a globally recognized environmental and renewables group across multiple sectors

PacificGreen Technologies Group

Rapid five-year development across seven different technologies

2016 — PacificGreen Marine Technologies

Marine FGD Systems

2017 — PacificGreen Air Technologies

Land-Based FGD Systems

2018 — PacificGreen Solar Technologies

Photovoltaic Solar

2019 — PacificGreen Solar Technologies

Concentrated Solar Power

2019 — PacificGreen Water Technologies

Freshwater Desalination

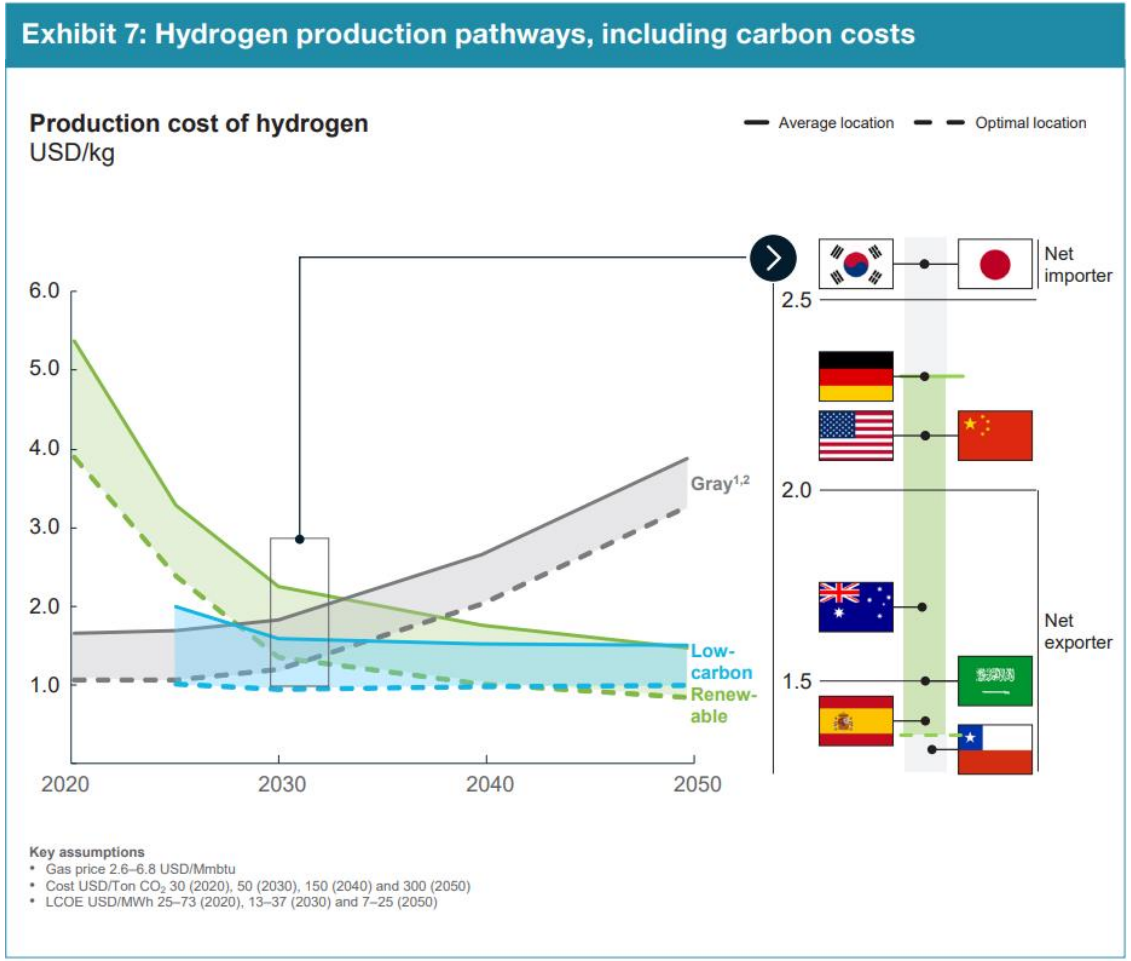
2020 — PacificGreen Energy Storage Technologies

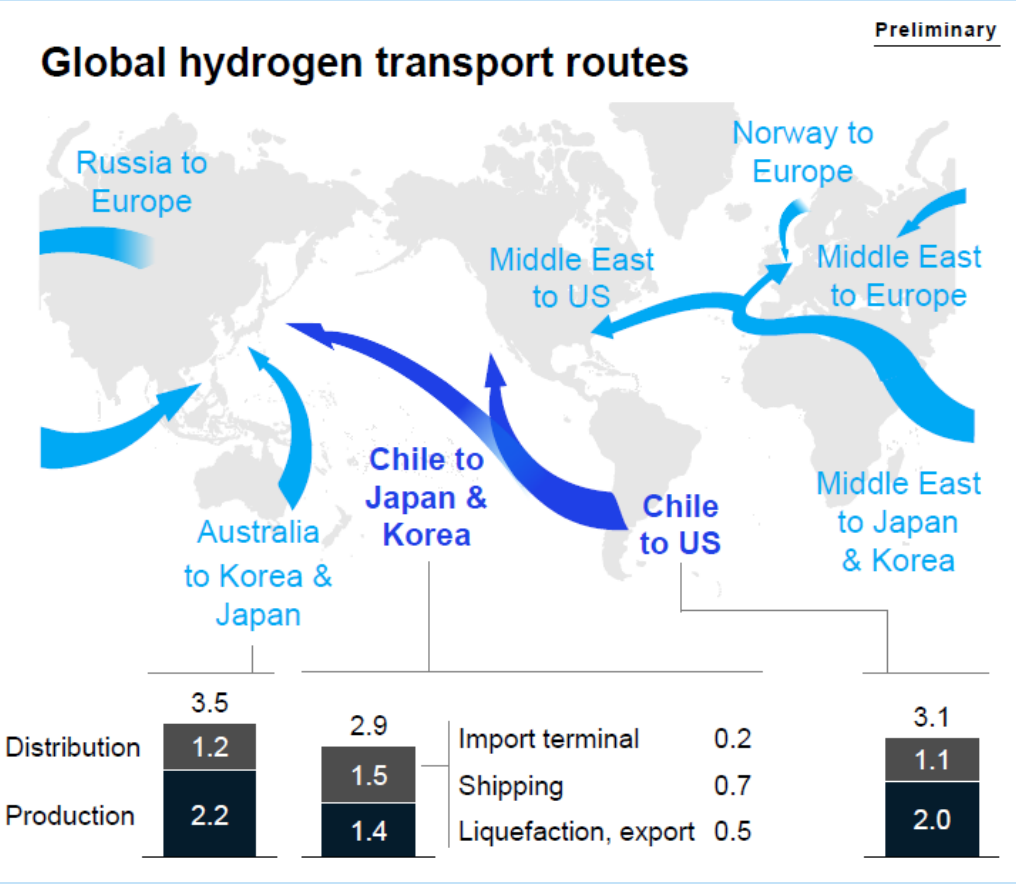
Battery Energy Storage Systems

2021 — PacificGreen Hydrogen Technologies

Hydrogen Production

Context – Huge hype for Green Hydrogen





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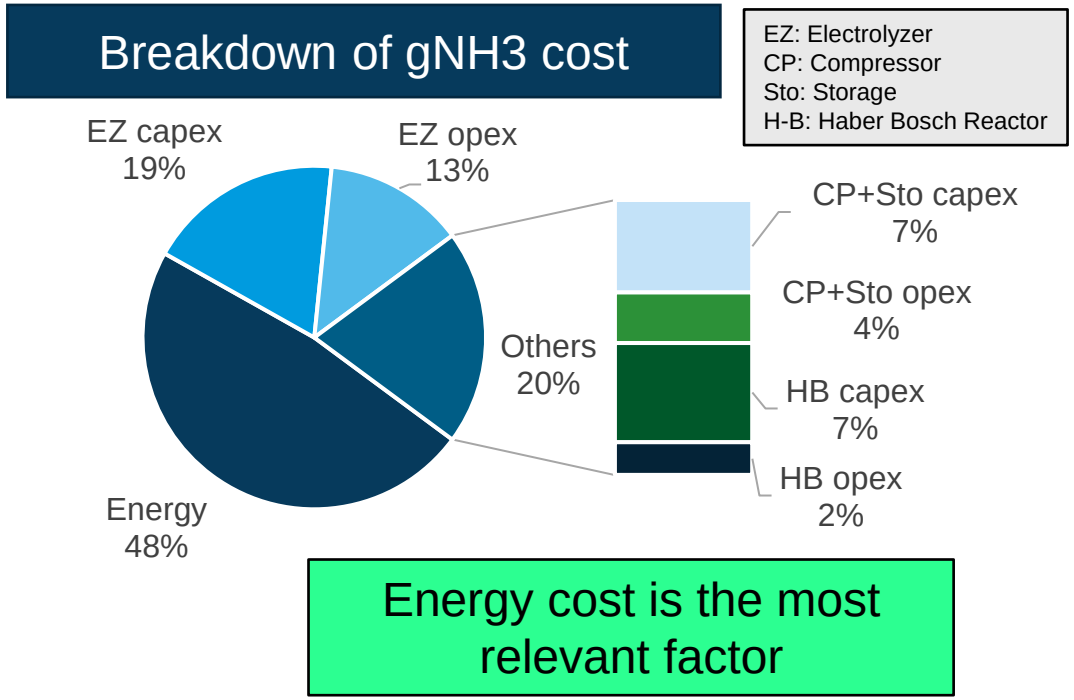
[1] Mckinsey & Company, 2021. Hydrogen Insights, 2021.
[2] Ministerio de Energía de Chile, "National Green Hydrogen Strategy."

Context – From Green Hydrogen to Green Ammonia

- Ammonia production is mainly made by a Haber-Bosch Reactor
- Ammonia is one of the most demanded chemical in the industry
- It has the potential to be used as an energy carrier of the Hydrogen



Energy cost is the most relevant factor

How to make the H_2 and NH_3 Green with Solar?

The best option is **PV+CSP technology**.

How a hybrid CSP+PV plant can reduce the LCoA?

What could be the CSP role on gH2 and gNH3 industry?

How we design a CSP considering the profile requirements of the ammonia industrial plant?

System Description – CSP+PV Generation Plant and H2+NH3 Industrial Plant

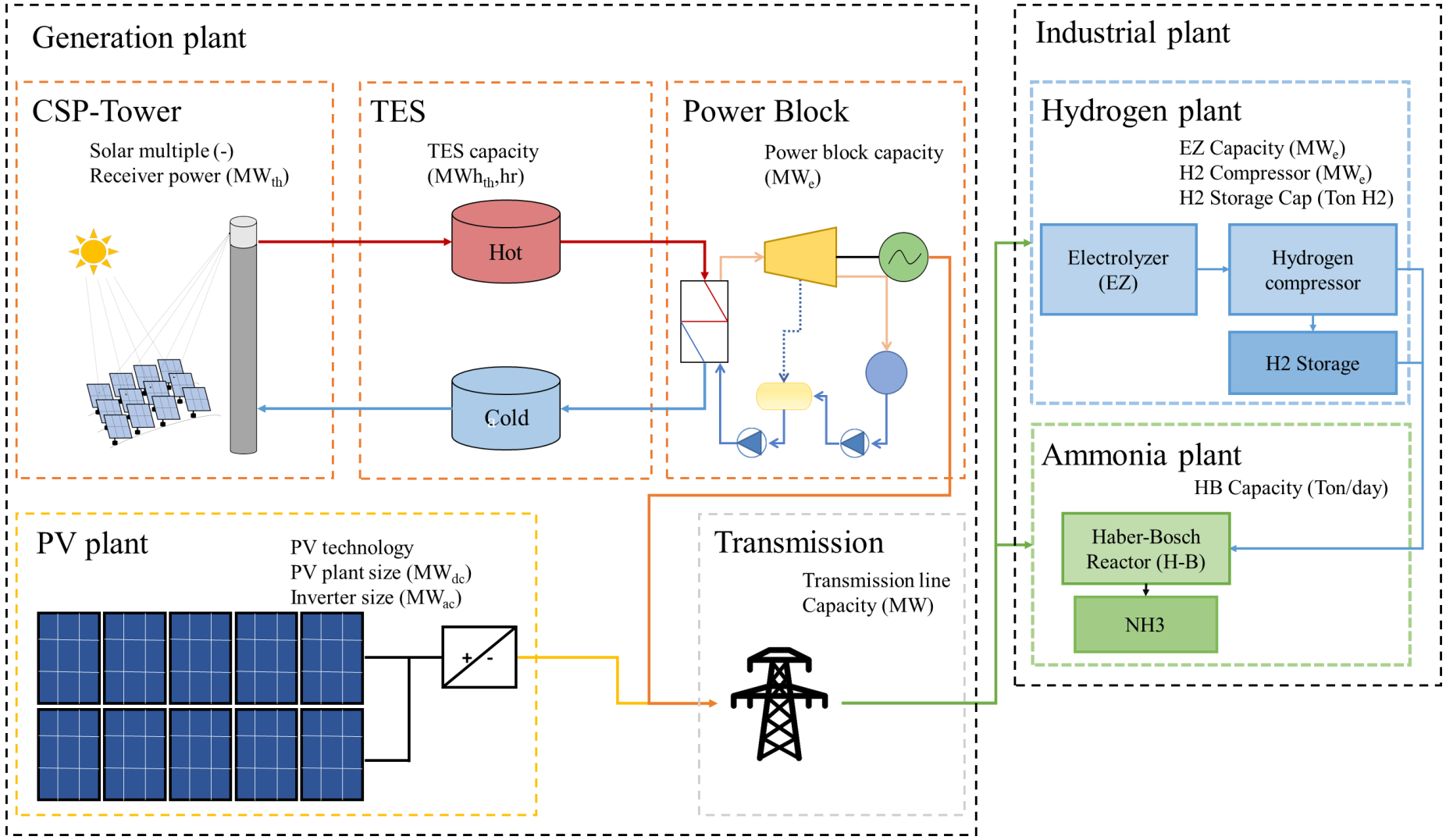
Main system

Generation plant:

- CSP Tower [MW]
- PV plant [MW]

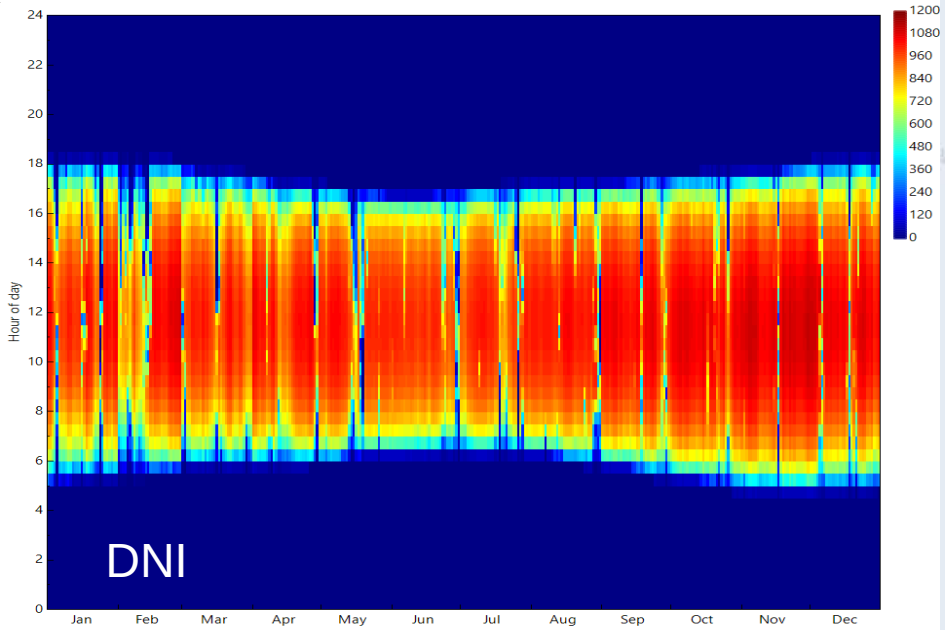
Industrial plant

- Electrolyzer [MW]
- H2 Compressor [MW]
- H2 Storage [Ton]
- Haber-Bosch Reactor [Ton/d]

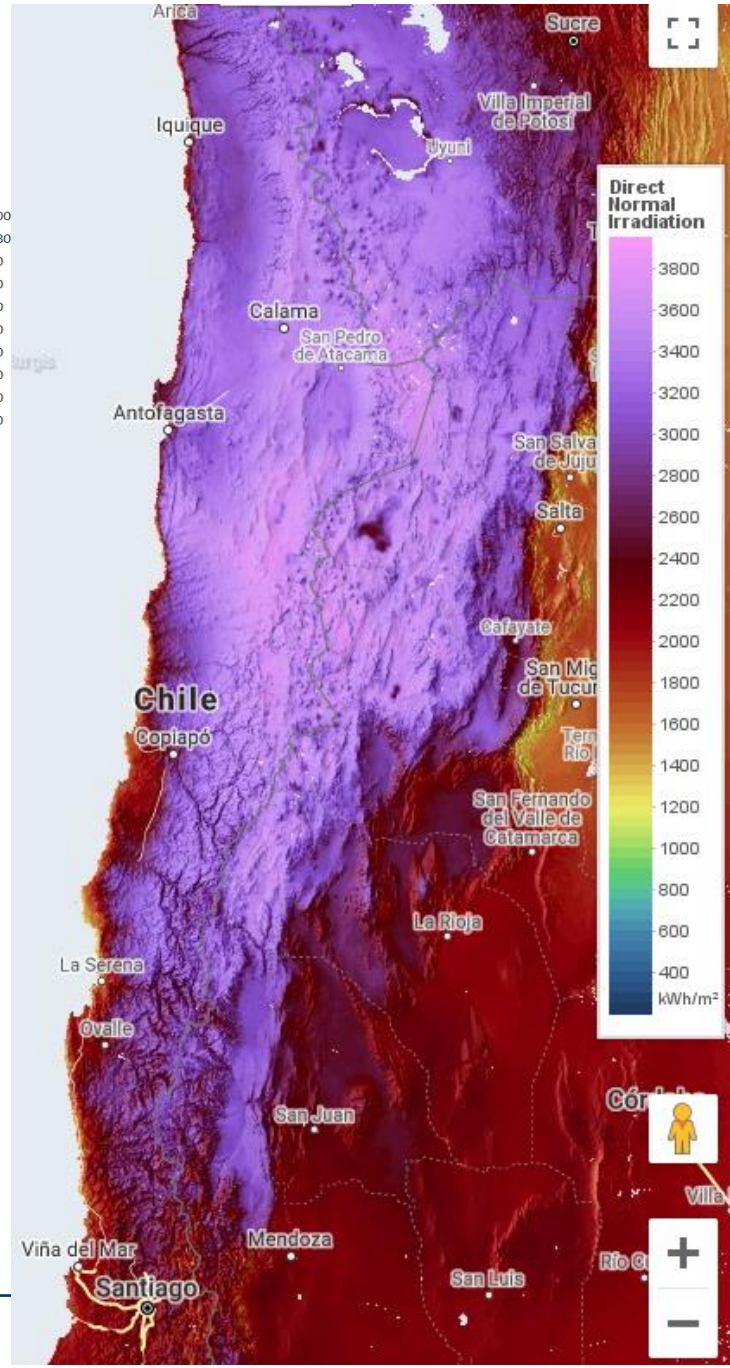


Case of Study – Chile Atacama Desert

- Analysis performed for northern Chile - Atacama Desert conditions.
  - DNI: **3500** kWh/m^2-yr
  - GHI: **2670** kWh/m^2-yr
- Decision variable:
  - **PV Capacity**
  - **CSP Capacity**
  - **EZ Capacity**
- **H-B capacity** of 1,000 Ton/d
- KPI:
  - LCOE
  - LCOH
  - **LCOA**
  - **NH3 production**

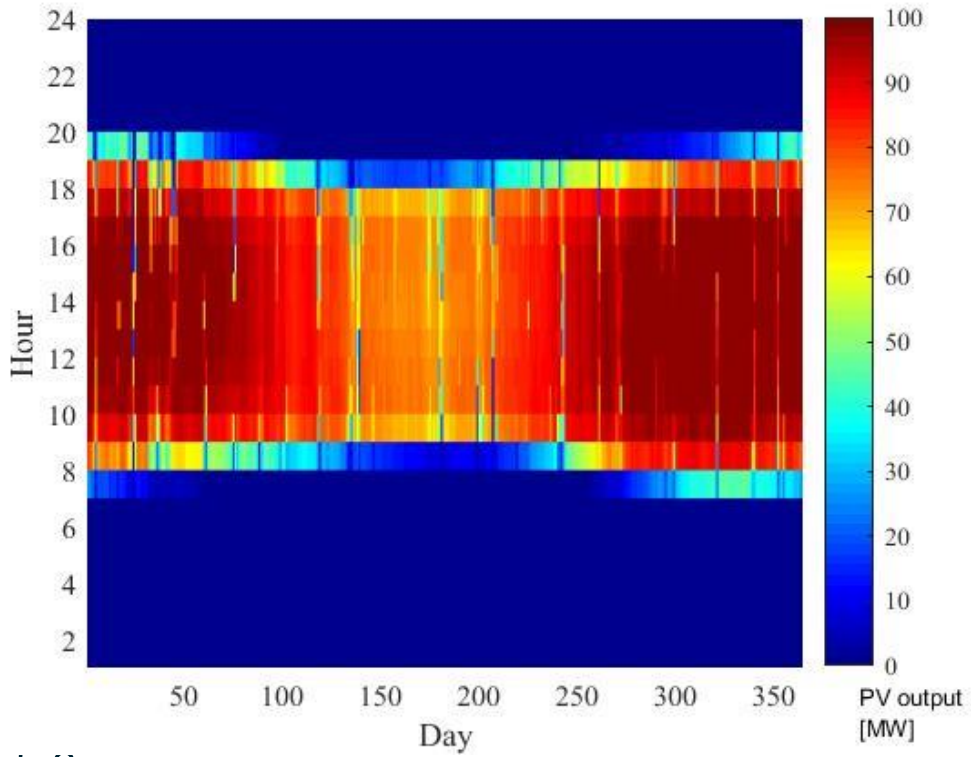


Capacity	Unit	Ref	Min	Max
PV	MW	800	500	1,500
CSP	MW	200	0	400
EZ	MW	600	500	1,500
H-B	Ton/d	1,000	-	-

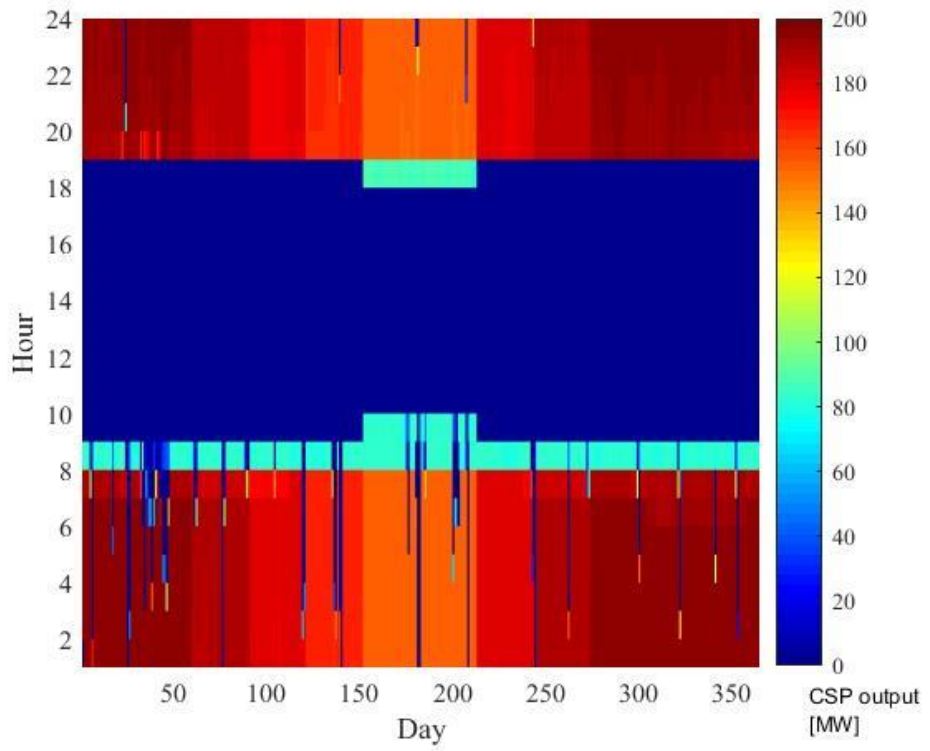


Generation Plant – Power Profiles

- PV profile: full operation during the daylight hours.
- Main H2 production with PV.

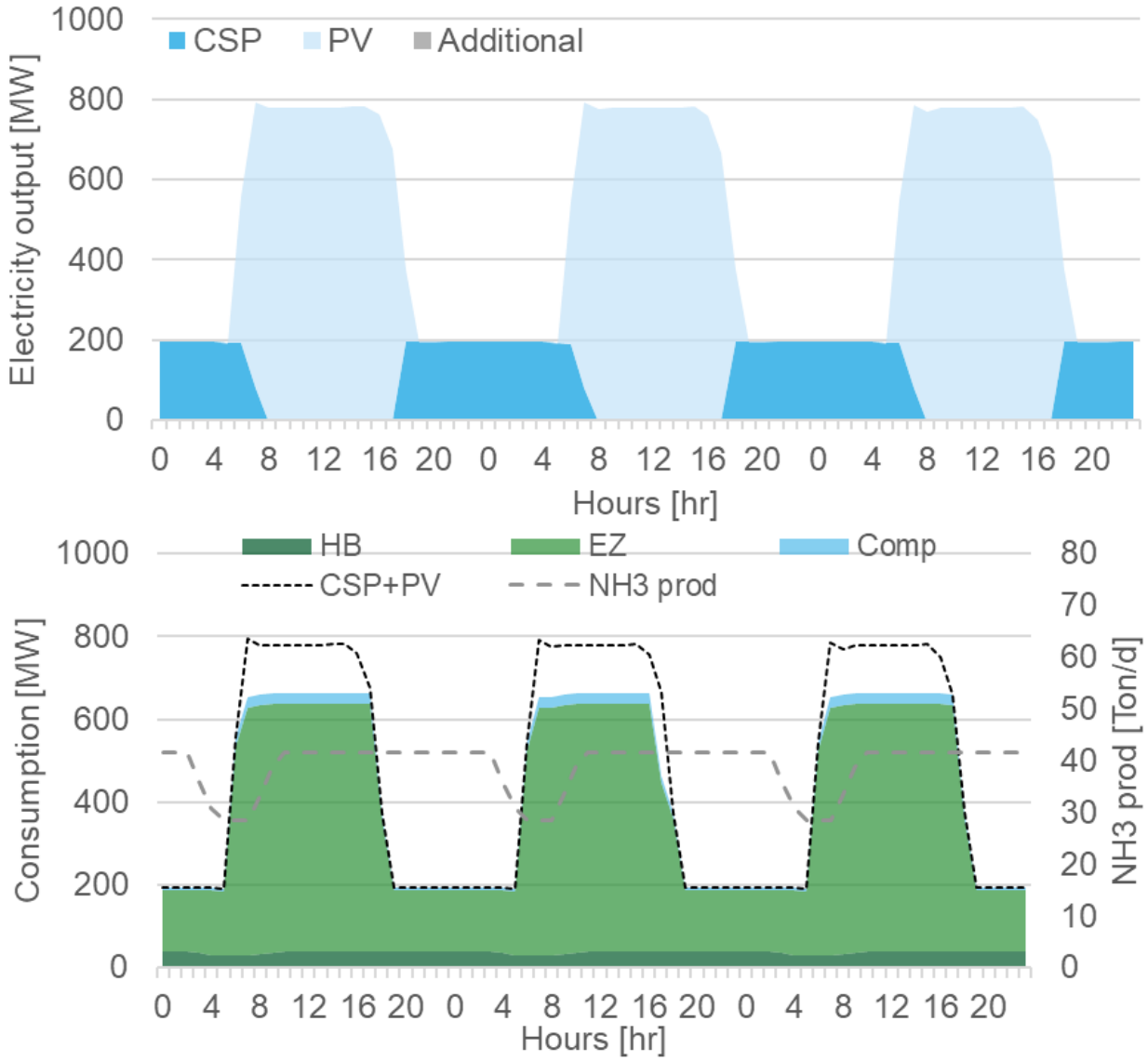


- CSP profile: focused on night operation.
- Optimize profile to deliver stable power considering a part-load operation.

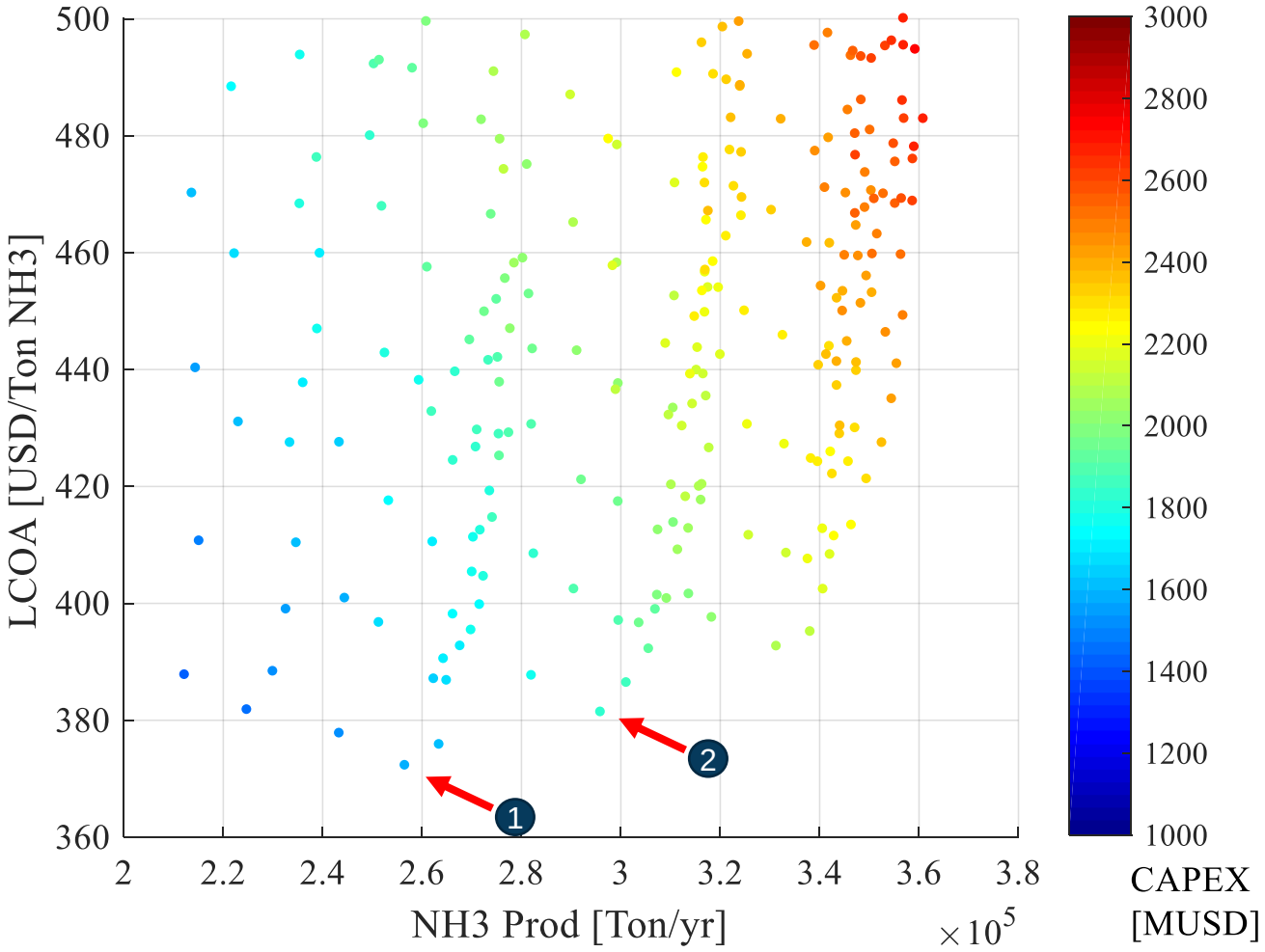


Industrial Plant – Hourly Profile and Operation

- Electrolyzers operates in two modes:
  - Main **H2 production with PV** in daylight hours
  - **CSP support** the H2 production during the night
- **Hydrogen storage management** is key point.
- **H-B operates** in terms of the H2 production and the available H2 stored.
- Critical H-B operation limitation
  - Ramping and part-load operation.
  - Avoid shut-down.



Results - Optimization



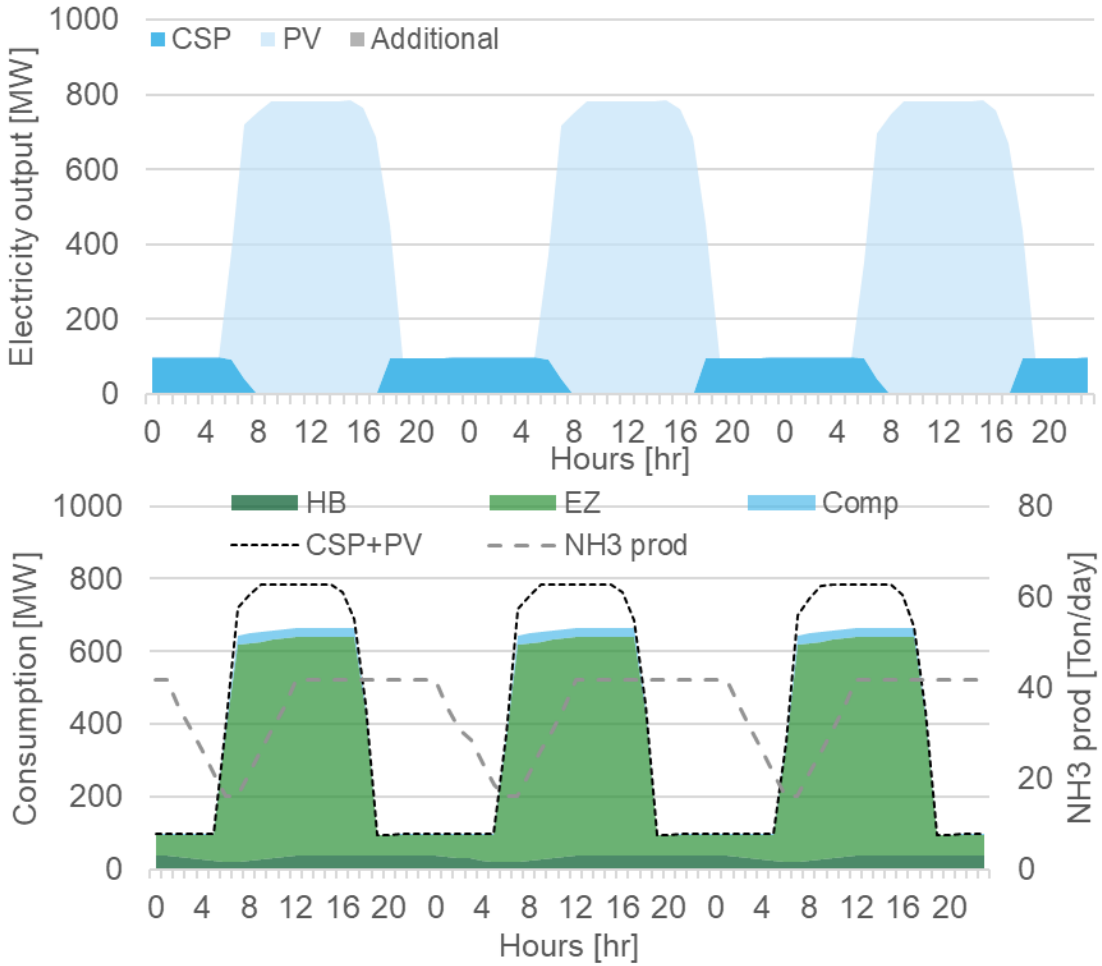
		Opt 1	Opt 2
CSP	MW	100	200
PV	MW	800	800
EZ	MW	600	600
HB	Ton/d	1,000	1,000
LCOE PV	USD/MWh	11.5	11.5
LCOE CSP	USD/MWh	41.9	41.5
LCOE (Combined)	USD/MWh	16.2	19.3
LCOH	USD/kg H_2	1.53	1.62
LCOH (Stored)	USD/kg H_2	1.77	1.84
LCOA	USD/Ton NH_3	372.2	381.3
NH_3 production	NH_3 Ton/yr	257,451	296,924
H_2 production	H_2 Ton/yr	45,701	52,717
Total Generation	GWh	2,836	3270

2%

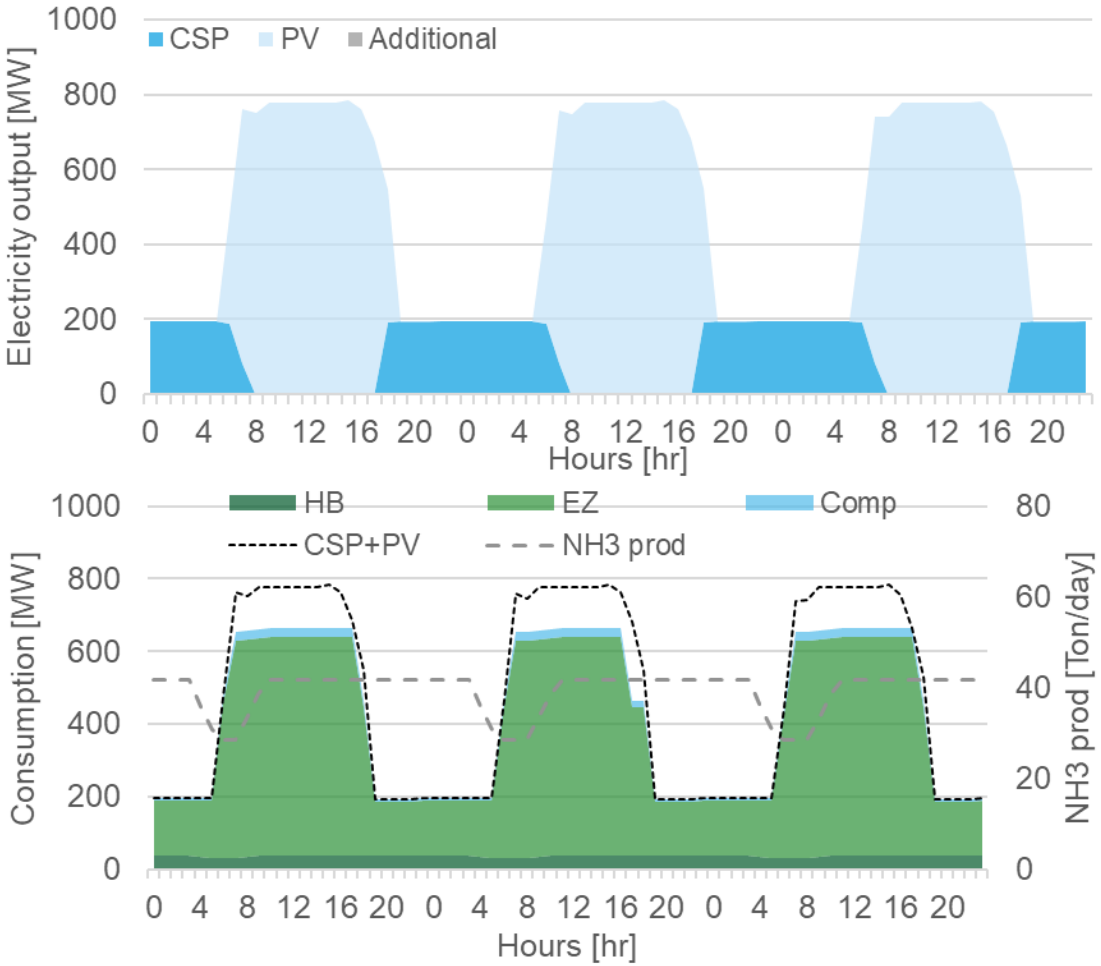
15%

Results – Optimum profiles

Layout 1 case profile

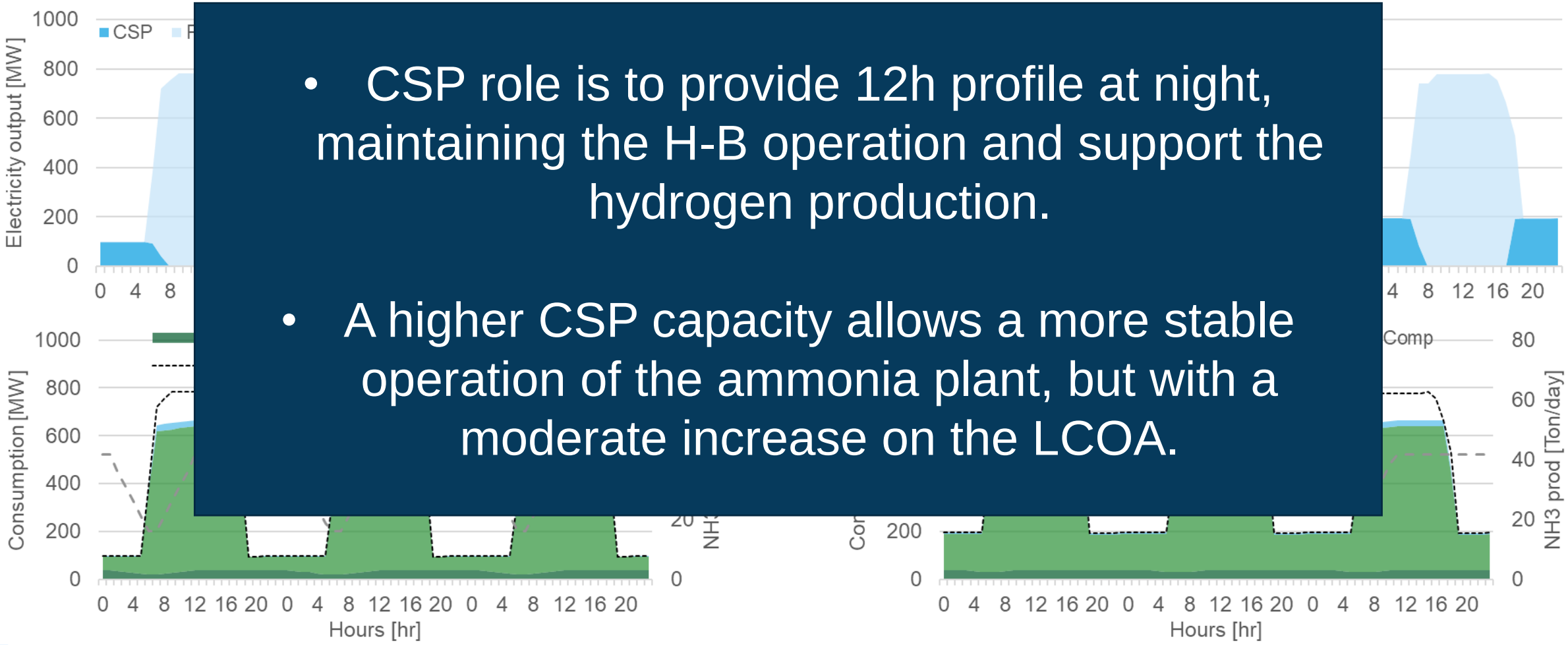


Layout 2 case profile



Results – Optimum profiles

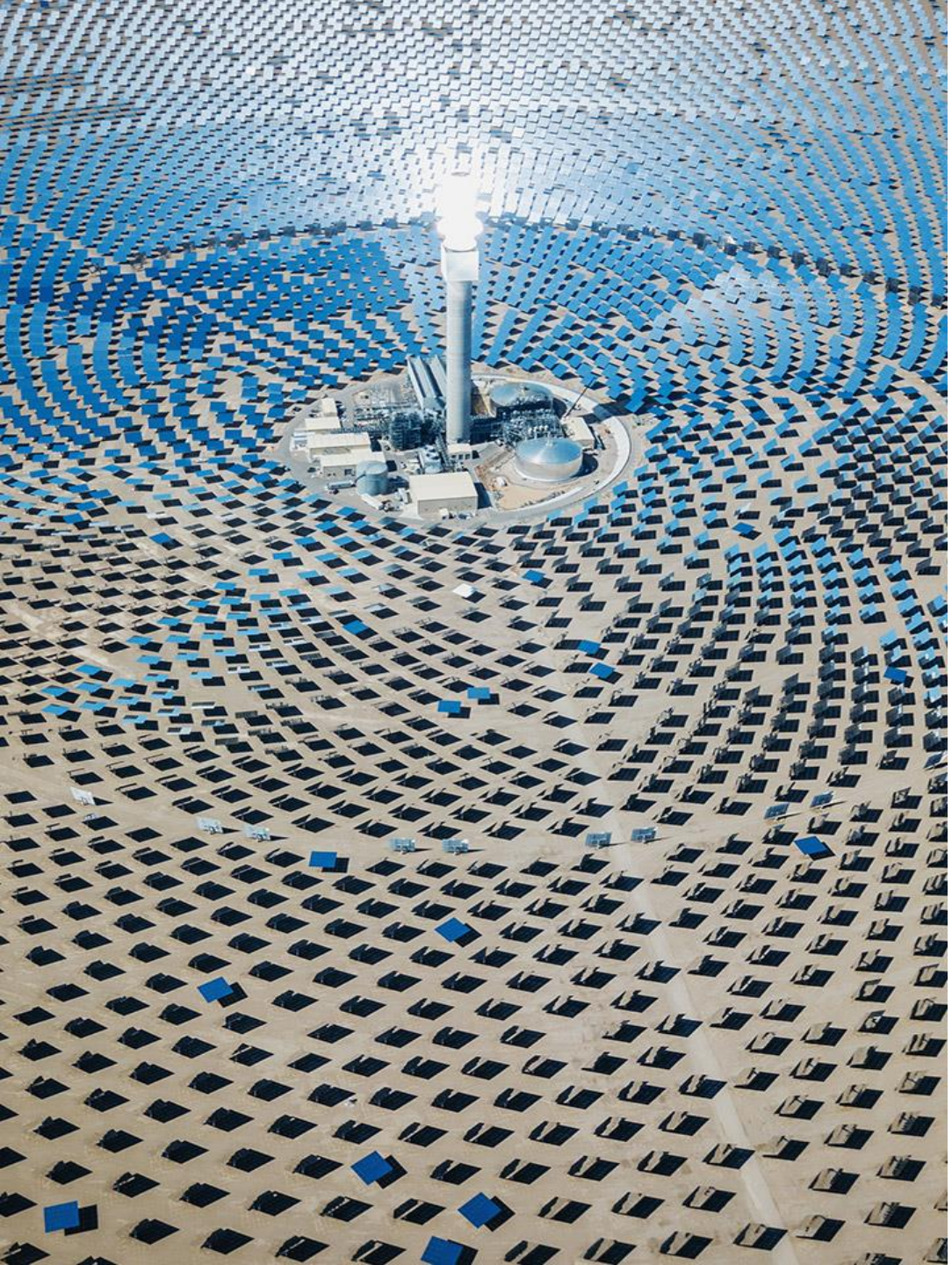
- Opt 1 case profile
- Opt 2 case profile



- CSP role is to provide 12h profile at night, maintaining the H-B operation and support the hydrogen production.
- A higher CSP capacity allows a more stable operation of the ammonia plant, but with a moderate increase on the LCOA.

Conclusions

- CSP have an important role in the green hydrogen and ammonia industry.
- PV provide the low energy cost to produce H_2.
- The CSP design must provide stable power during 12h to the H-B reactor and complement the H_2 production at night.
- The operational limitation of the H-B and H_2 storage are crucial to define the limitation of the CSP+PV power profile.
- The CSP capacity is defined by the H-B capacity. A 1000 Ton/d H-B may require from 100 to 200 MW of CSP.



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