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Assessment of key performance indicators in green Hydrogen Valleys

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2nd LATAM MEETING ON GREEN AMMONIA AND POWER-to-X

Objective and Contents

Objective:

The main goal of this work is to assess the monitoring roadmap for the key performance indicators (KPI) in green Hydrogen Valleys, especially focusing on green hydrogen production.

Introduction to Hydrogen Valleys

Overview of HVs under development worldwide and introduction to the North Adriatic Hydrogen Valley (NAHV).

Methodology: definition of the KPI monitoring roadmap and case study

Introduction to the crucial steps to outline the monitoring activities. Introduction to the case study regarding the green hydrogen production.

Application to the presented test case

Presentation of the results regarding the monitoring activities.

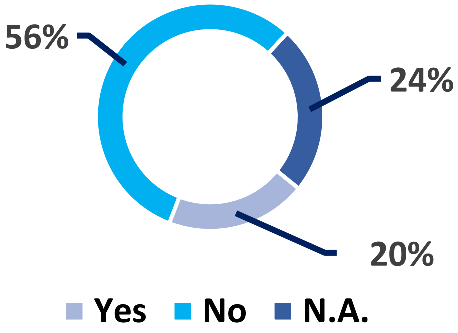
Concluding remarks and future developments

Findings overview, lack of the work and future developments.

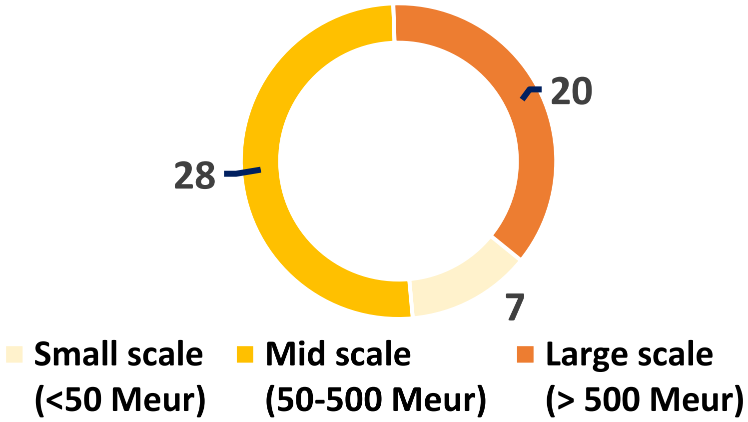
Introduction to Hydrogen Valleys: an overview

A hydrogen valley is a regional initiative that aims to develop a hydrogen ecosystem, including hydrogen production, storage, distribution, and utilization, within a defined geographical area. The idea behind a hydrogen valley is to create a localized cluster of companies, research institutions, and public authorities that work together to promote the use of hydrogen as a clean energy vector.

EU cross border HVs



EU HVs investment volume

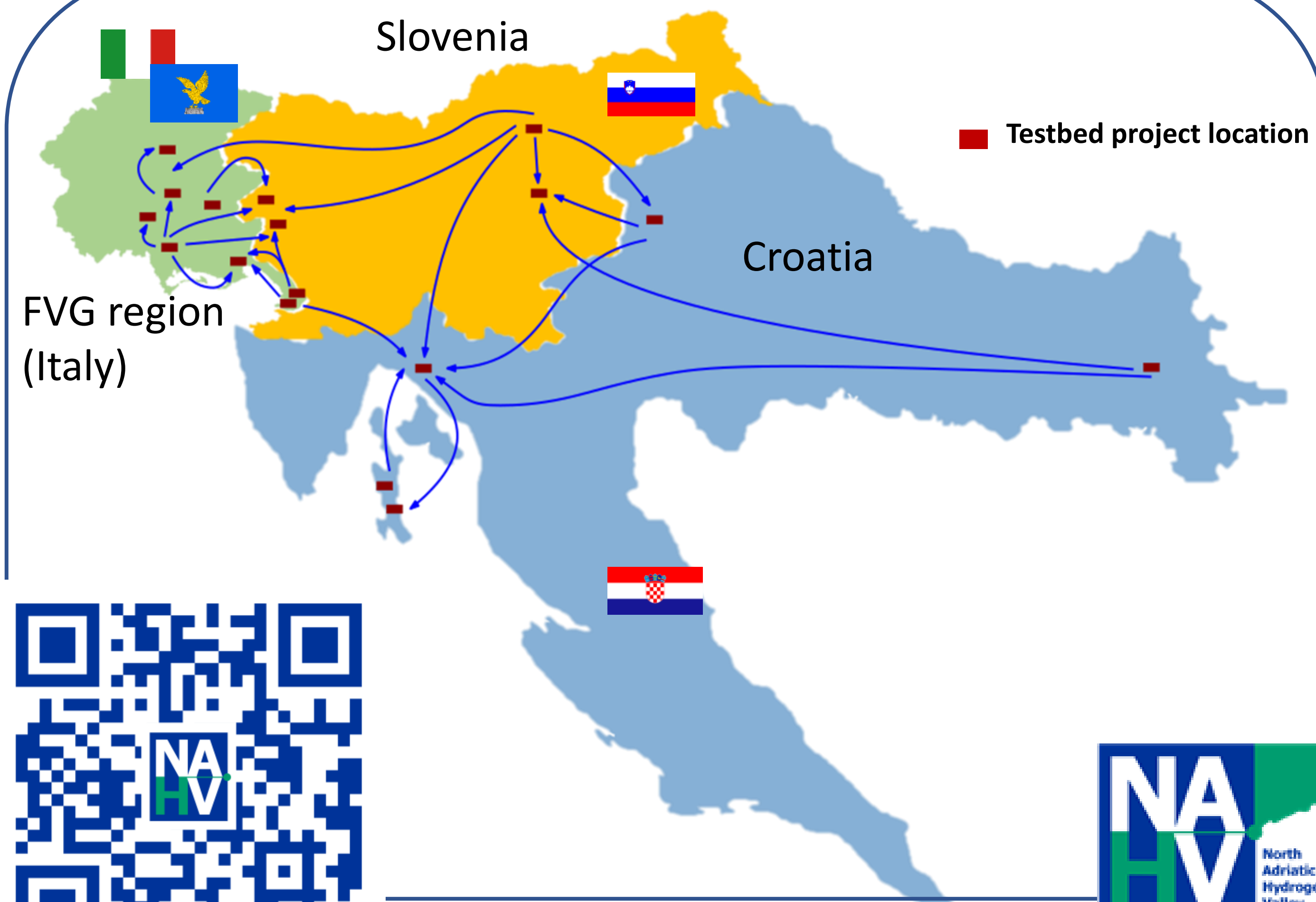


Distribution of Hydrogen Valleys in Europe

Sources:
Hydrogen Valleys platform: https://h2v.eu/hydrogen-valleys visited on October 2024

Introduction to Hydrogen Valleys: the North Adriatic Hydrogen Valley

Overview of the North Adriatic Hydrogen Valley



Involved EU regions:

- Slovenia
- Croatia
- Friuli – Venezia Giulia region (Italy)

Partners ecosystem

- 3 Public institutions
- 16 industrial partners
- 5 R&D organization s
- 3 SME

Testbed Projects

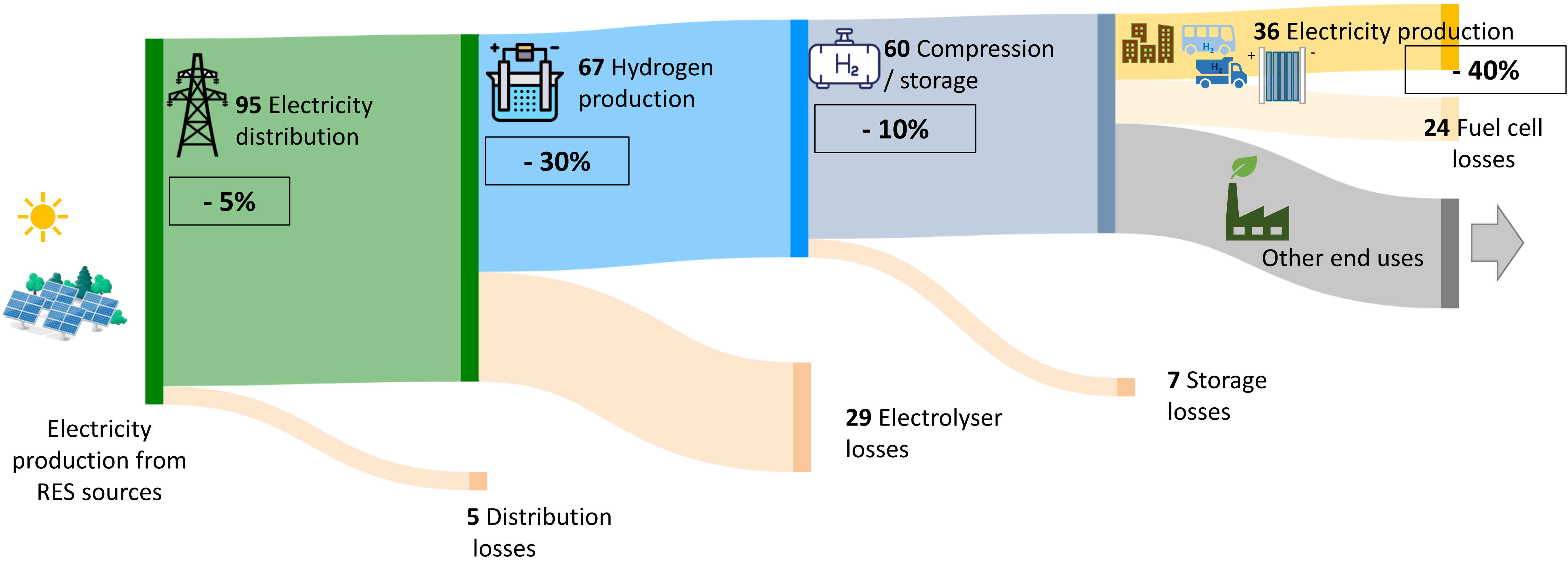
- 17 pilot projects
- 3 sectors: industry – energy - transport
- 5000 t/y H_2 production

Source: www.nahv.eu

Co-funded by the European Union

The project is supported by the Clean Hydrogen Partnership and its members. It has received funding from the European Union's Horizon Europe research and innovation programme under the Grant Agreement No. 101111927.

Introduction to Hydrogen Valleys: the NAHV value chain



Methodology: assessment of the monitoring roadmap in green hydrogen production

Plant equipment:

Definition of the equipment for real-time monitoring of the hydrogen production systems.

KPI baseline definition:

Definition of specific KPIs at plant level aligned with the EU 2030 targets.

Integration of systems optimization tools:

Utilization of advanced tools to track progress in real-time and to simulate the systems operations.

Periodic reporting:

Establish and outline a monitoring and reporting framework

Methodology: case study

Trieste Hydrogen Hub scenario

Hydrogen Hub H_2 Trieste

AcegasApsAmga

58.000 m^2 PV plant
4.8 MWp

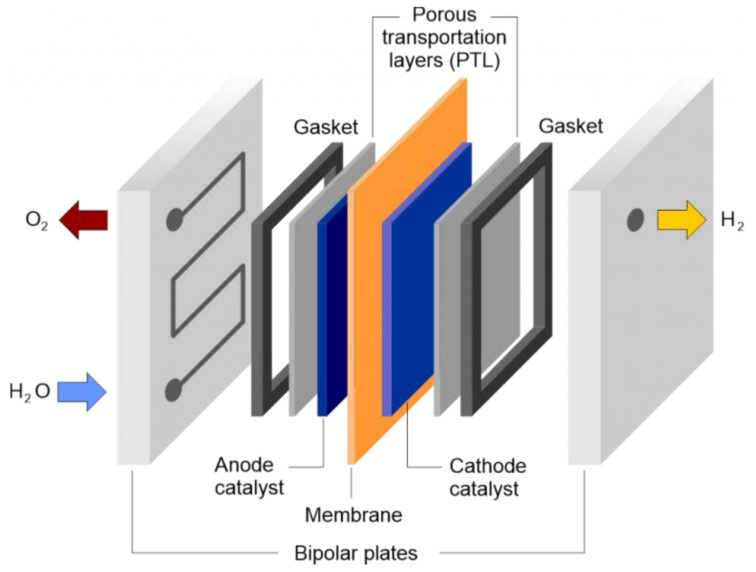
5MW electrolyser
400 ton/year H_2 production

Public transport
Port area logistic
Industrial vehicles

The H_2 plants monitoring activities in the NAHV framework is coordinated by University of Trieste.

Methodology: case study

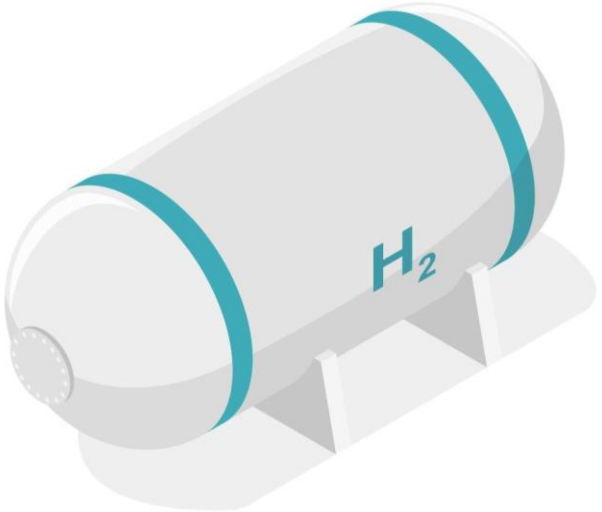
Electrolysis and storage specifications



Electrolyser

- Power: 5 MW
- Stack power rating: 625 kW
- Number of stacks: 8
- Number of cells: 245
- Production: 90 kg/h
- Cell area: 1000 cm^2

- Annual operation of 5889 hours for 400 ton/year of H_2 production.
- Minimum uptime of electrolyzer: 7.5 h
- Maximum uptime of electrolyzer: 36.5 h

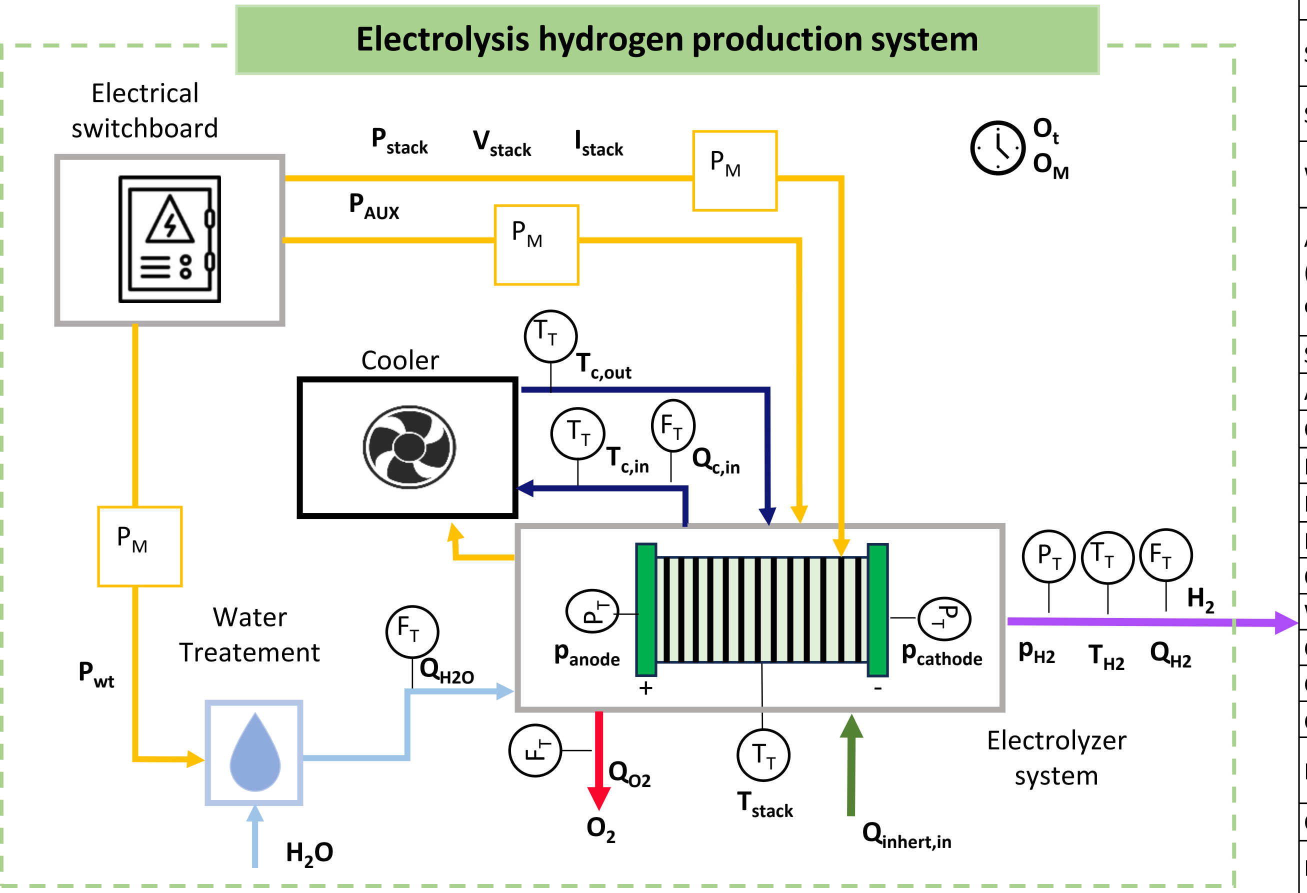


Storage

- Pressure: 500 bar -> 1980 kgH_2
- Pressure: 200 bar -> 500 kgH_2

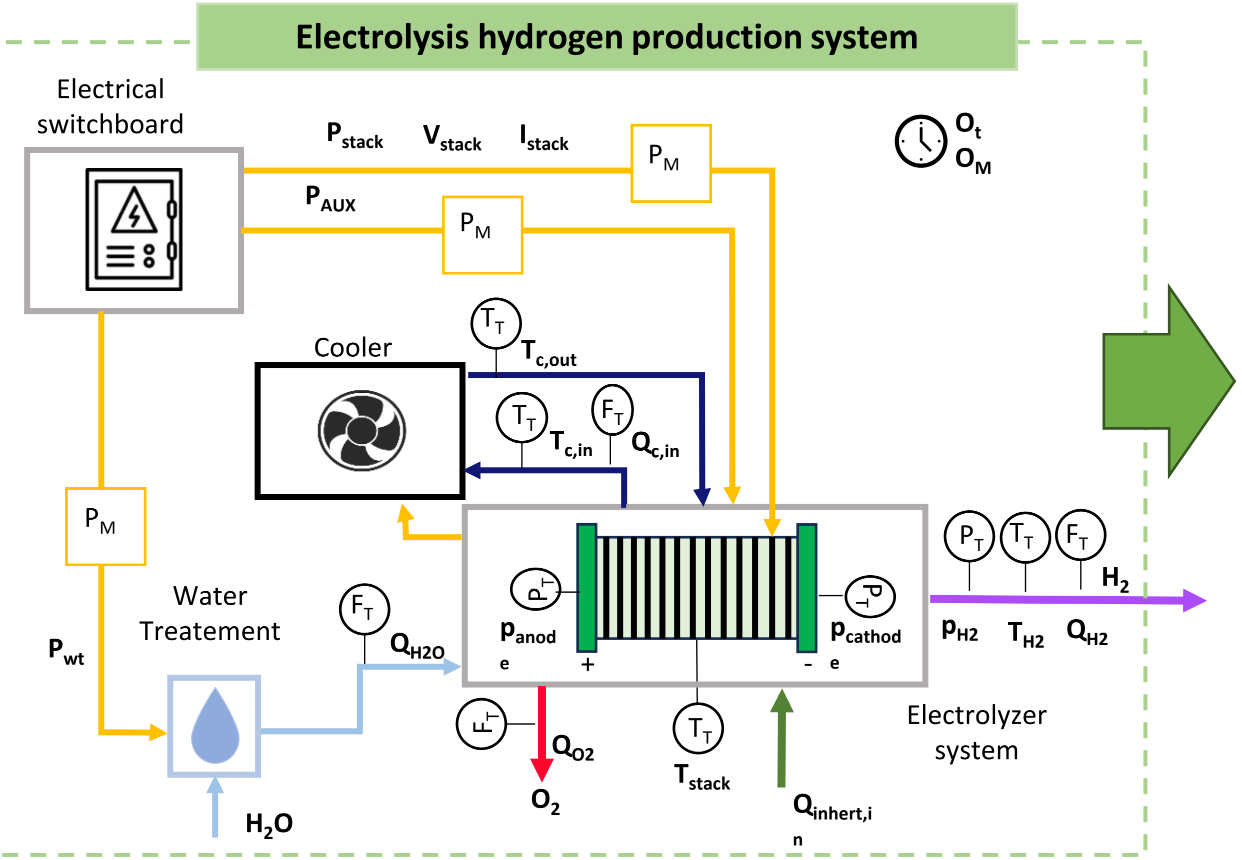
Data from NEPTUNE V electrolyser manufactured by ITM power: https://itm-power.com/products/neptune-5

Results: plant monitoring equipment definition



Electrolysis hydrogen production system				
Parameter	**Unit**	**Symbol**	**Component**	**Monitoring purpose**
Stack current	A	I_{stack}	Power meter	Assess stack energy inputs and energy consumption
Stack voltage	V	V_{stack}		
Stack power	kW	P_{stack}		
Water Treatement power	kW	P_{wt}		Water Treatement power consumption
Auxiliaries Power (e.g. cooling pumps, control units)	kW	P_{AUX}		Other uxiliaries power consumption
Stack temperature	°C	T_{stack}	Temperature transmitter	Stack operations
Anode pressure	bar	p_{anode}	Pressure transmitter	
Cathode pressure	bar	$p_{cathode}$	Pressure transmitter	
Hydrogen Pressure	bar	p_{H2}	Pressure transmitter	H_2 flow assessment
Hydrogen Temperature	°C	T_{H2}	Temperature transmitter	
Hydrogen Flow rate	m_3/h	Q_{H2}	Flow meter	
Oxygen Flow rate	m_3/h	Q_{O2}	Flow meter	O2 production rate
Water Flow rate	l/h	Q_{H2O}	Flow meter	Water consumption
Cooling flow temperature	°C	$T_{C,in}$	Temperature transmitter	Assessment of stack cooling
Cooling flow temperature	°C	$T_{C,out}$		
Cooling flow rate	m_3/h	$Q_{c,in}$	Flow meter	
Inhert fas flow rate	m_3/h	$Q_{inhert,in}$	flow meter	Assessment of inhert gas utilization
Operational time	h	O_t	Run - time / maintennce time meters	Assessment of operational and maintenance time
Maintenance time	h	O_M		
Ambient temperature	°C	T_{amb}	Weather station with integrated sensors	Ambient conditions
Wind speed	m/s	w_s		
Ampient pressure	bar	p_{amb}		
Ambient humidity	%	H_{amb}		

Results: KPI baseline definition



Parameter	Unit	Equation
Specific stack energy consumption	kWh/kg	$SC_{el,stack} = \frac{P_{stack} \cdot \tau_k}{\rho_{H2} \cdot (Q_{H2} \cdot \rho_{H2})/3600}$
Specific system energy consumption	kWh/kg	$SC_{el,sys} = \frac{P_{sys} \cdot \tau_k}{\rho_{H2} \cdot (Q_{H2} \cdot \rho_{H2})/3600}$
Stack efficiency	%	$\eta_{el,stack} = \frac{\rho_{H2} \cdot (Q_{H2}/3600) \cdot LHV}{P_{stack}}$
Electrolysis system efficiency	%	$\eta_{el,sys} = \frac{\rho_{H2} \cdot (Q_{H2}/3600) \cdot LHV}{P_{sys}}$
Auxiliary power efficiency	%	$\eta_{AUX} = \frac{P_{stack}}{P_{stack} + P_{AUX}}$
Stack voltage efficiency	%	$\eta_{voltage} = \frac{V_{ideal}}{V_{stack}}$
Hydrogen production	kg	$V_{H2} = \sum_{k}^{rp} (\frac{Q_{H2}}{3600}) \cdot \rho_{H2} \cdot \tau_k$
Oxygen production	kg	$V_{O2} = \sum (\frac{Q_{O2}}{3600}) \cdot \rho_{O2} \cdot \tau_k$
Annual operational time	$O_{t,annual}$	$O_{t,annual} = \sum O_t$
Annual maintenance time	$M_{t,annual}$	$M_{t,annual} = \sum M_t$
Annual Operation and Maintenance cost	$O\&M_{cost,annual}$	$O\&M_{cost,annual} = \sum^{p} O\&M_{cost}$
Volume of Oxygen selled or used	kg	$S_{O2} = \sum (Q_{O2,sell}/3600) \cdot \rho_{O2}$
Fraction of selled/used oxygen over the all production	%	$FS_{O2} = \frac{S_{O2}}{V_{O2}}$
Water utilization	l	$M_{H20} = \sum Q_{H2O} \cdot \tau_k$
Specific system energy for hydrogen production @ nominal capacity	kWh/kg	$SP_{H2,sys-@nom} = \frac{P_{sys}}{Q_{H2} \cdot \rho_{H2}}$
System efficiency @ nominal capac	%	$\eta_{sys\,@\,nom} = \frac{\rho_{H2} \cdot (Q_{H2}/3600) \cdot LHV}{P_{sys}}$

Results: Integration of systems optimization tools

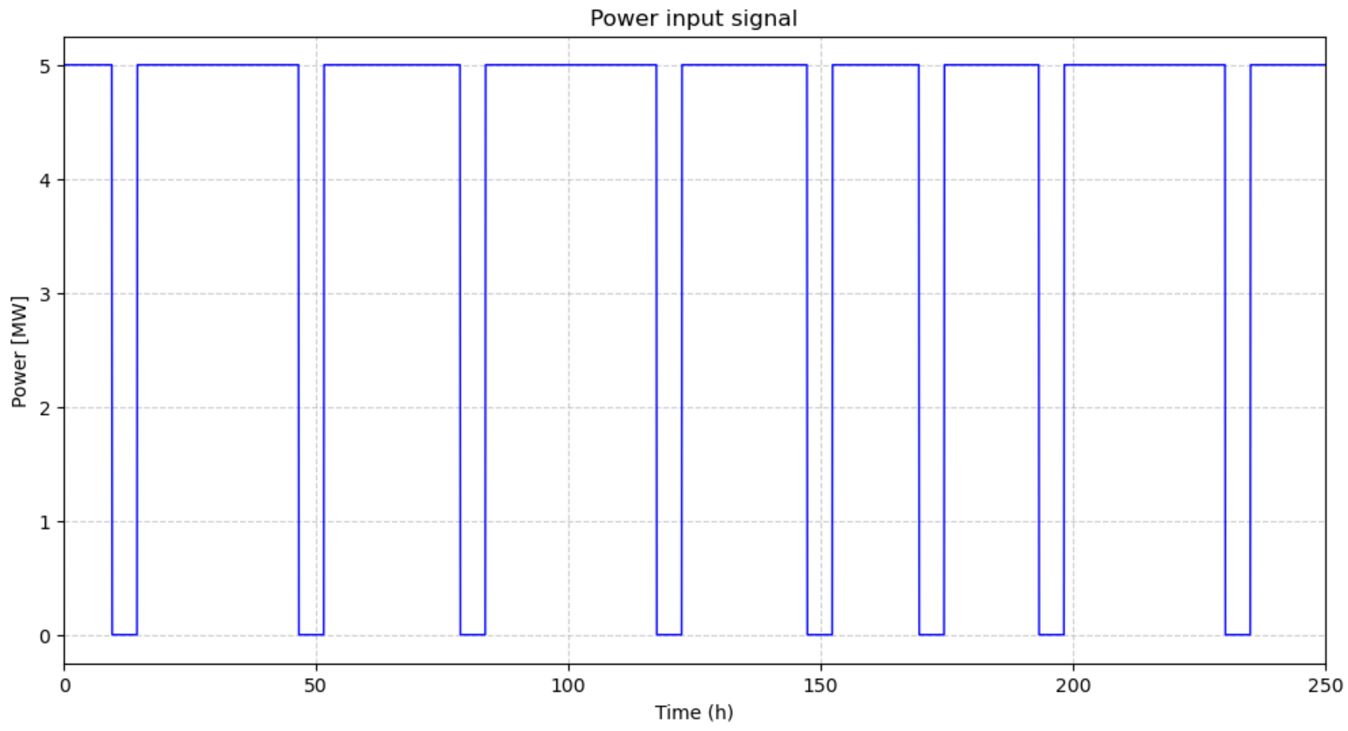
Digital Twins has been defined as promising technology to track progress in real-time, simulate and control the electrolyser systems operations.

A preliminary model of Digital Twin is under development, and the first release will be based on data derived from a electrolyser numerical model.

The numerical model contains the specifics of the Trieste Hydrogen Hub.

Hydrogen Hub Trieste AcegasApsAmga

Randomic power input signal for the electrolyzer system



The work is under development at the University of Trieste ENESYS Lab, also in collaboration with PhD Davide Pivetta, PhD Marco Bogar and MSc Eng. Marco Russo Cirillo.

Results: Integration of systems optimization tools

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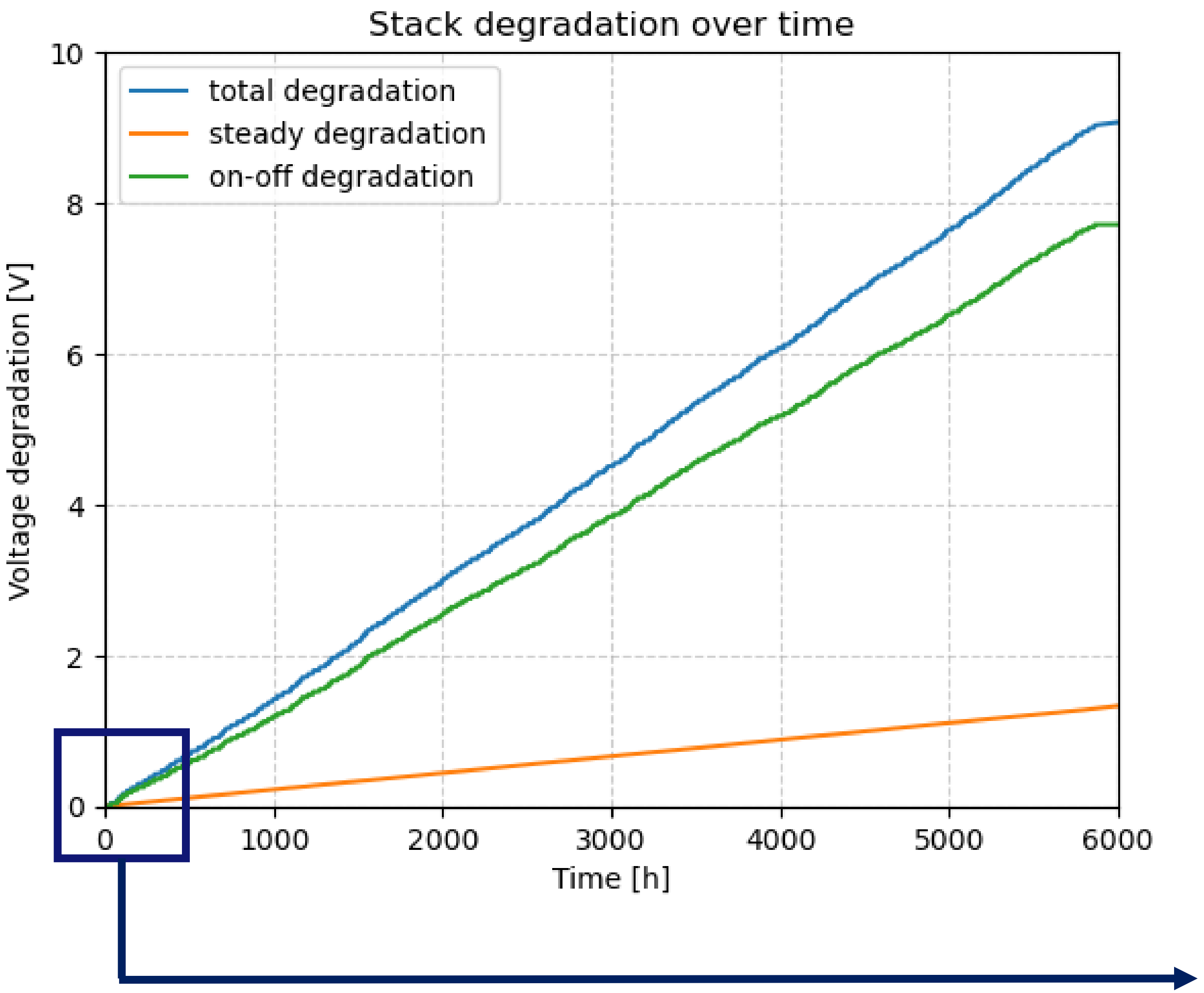
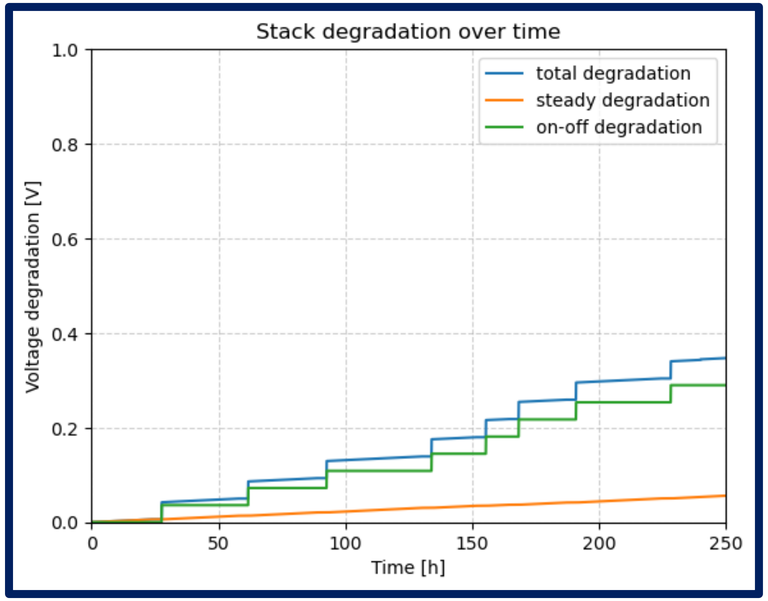
Simulation of one year electrolyzer degradation for a production of 400 t/year of hydrogen.





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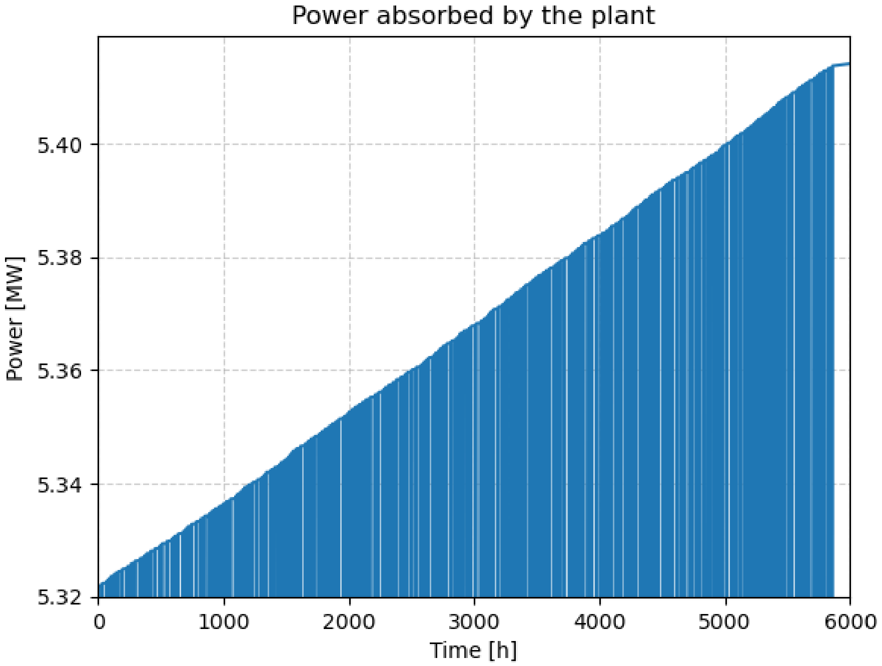

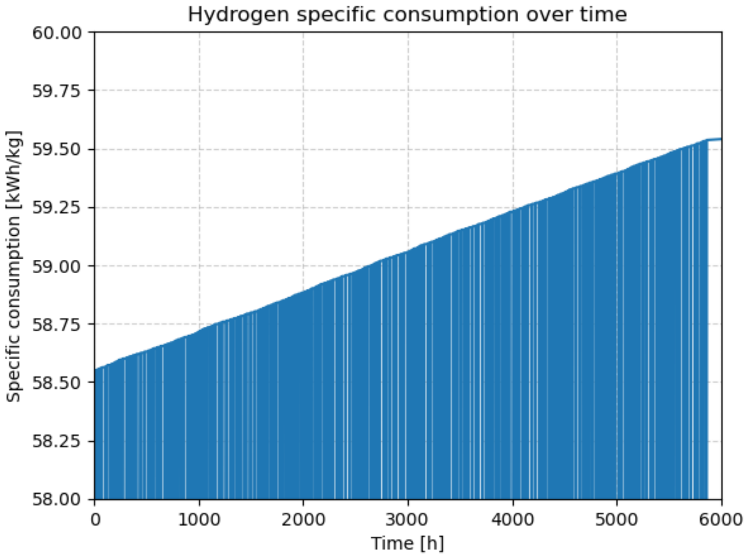

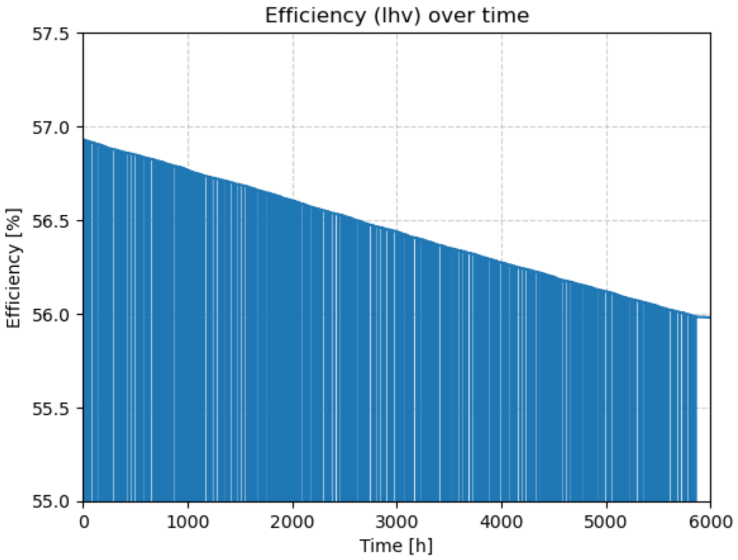

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Concluding remarks and future developments

- Regulation & Standards defining a set of KPI to be monitored within a hydrogen production plant at commercial level has not yet been definied.
- KPIs in a Hydrogen Valley environment could be defined by considering the entire value chain of hydrogen produced.
- For a power density of 1.25 A/cm^2 the model estimates an increase of power absorbed by the electrolyser equal to 11 kW every year. This leads to an increase of power absorbed by the entire system equal to 1.2 MW after 80.000 hours of electrolyser operations.
- Future advancements of the numerical model will include also the effect of the load and current density over the electrolyser degradation to generate the first training set of the Digital twin model.
- Future developments of this work will focus on deploying the neural-network based DT model in hydrogen production facility. The deployment process will involve close collaboration with industrial stakeholders taking part in in the North Adriatic Hydrogen Valley project.

Thank you for your attention!

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- Backup slides

The city of Trieste

Castello di Miramare
(*Miramare castle*)

Piazza Unità d'Italia
(*Unity of Italy square*)

Barcolana
(*Sailing race competition*)

The city of Trieste

Port of Trieste:

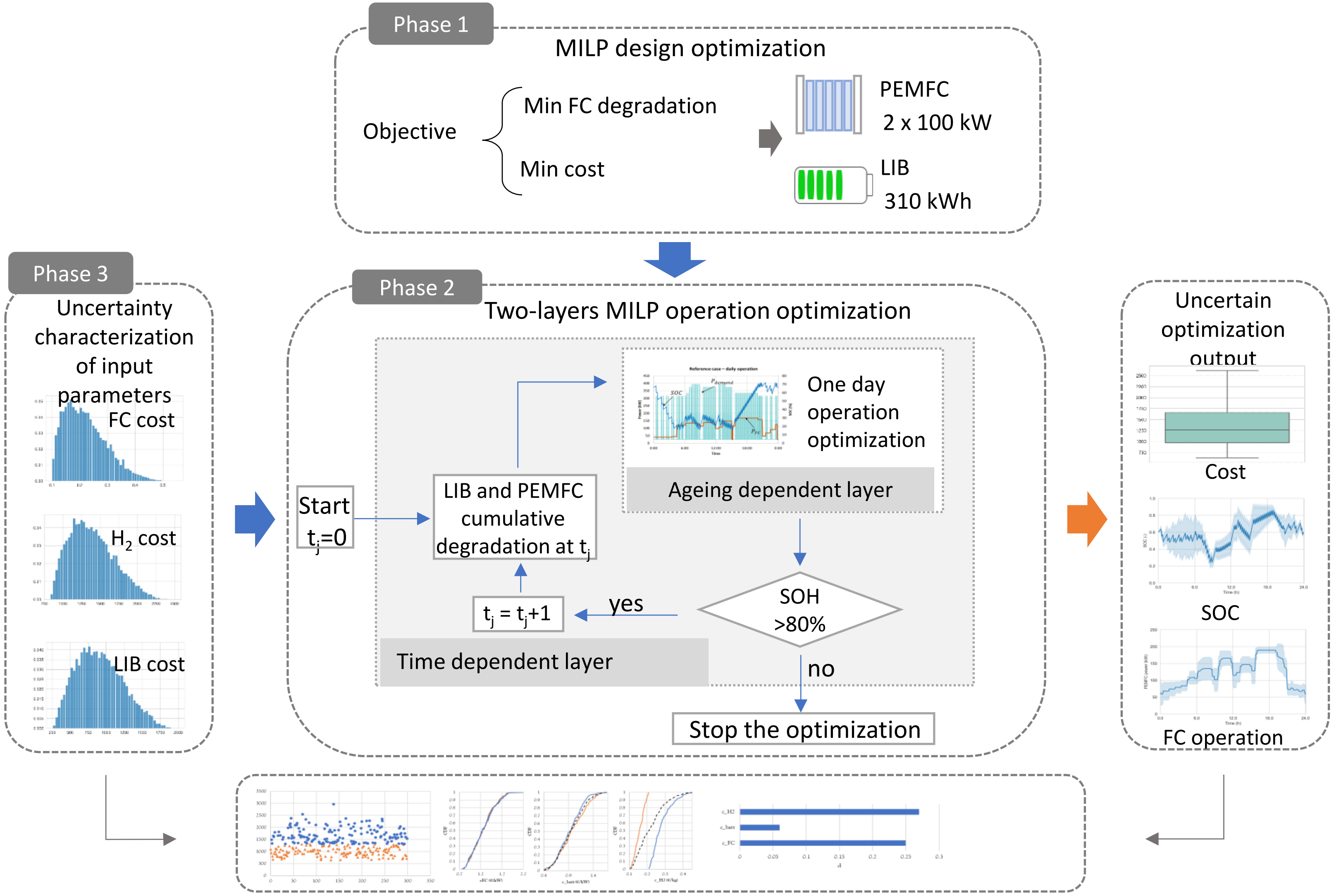
- 880 thousand 20-foot equivalent units (TEUs)
- 37.5 million cargo tonnage (solid and liquid bulk)
- 56% cargo transported via railway

Industries in Trieste:

Trieste hosts a variety of strategic industries. These industries include energy, steel, chemical and paper industries. Additionally, the city is home to businesses involved in shipbuilding, cruise tourism, and marine industries.

Data retrieved from: AdSPMAO and Supair

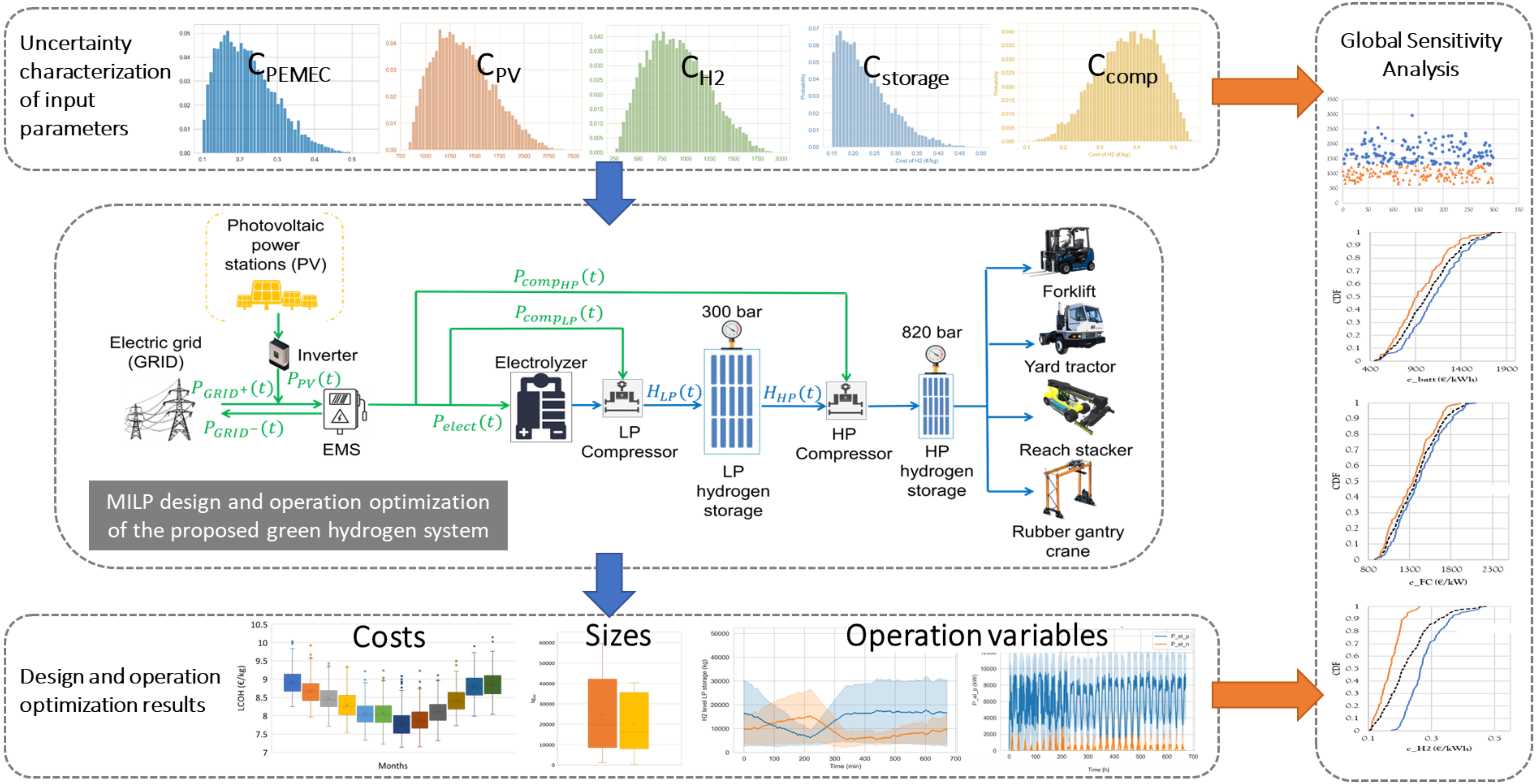
Digital models for hybrid fuel cells and battery system



https://nuovavenezia.gelocal.it/venezia/cronaca/2022/12/18/news/lido_venezia_gara_trasporti_ferry_boat-12419903/

C. Dall'Armi, D. Pivetta, R. Taccani, Uncertainty analysis of the optimal health-conscious operation of a hybrid PEMFC coastal ferry, International Journal of Hydrogen Energy, Volume 47, Issue 21, 2022, https://doi.org/10.1016/j.ijhydene.2021.10.271.

Digital models for H_2 production, storage and use



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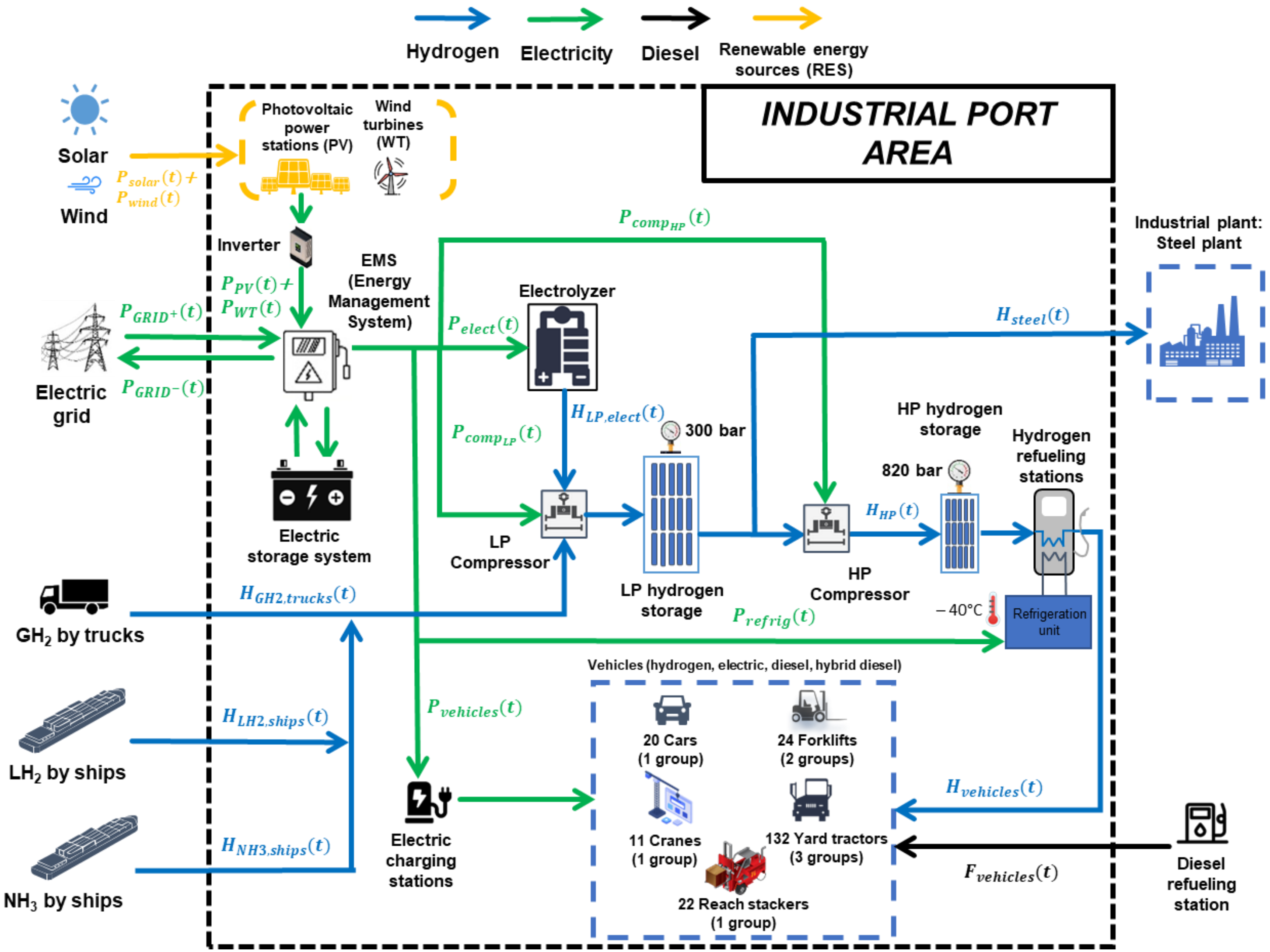
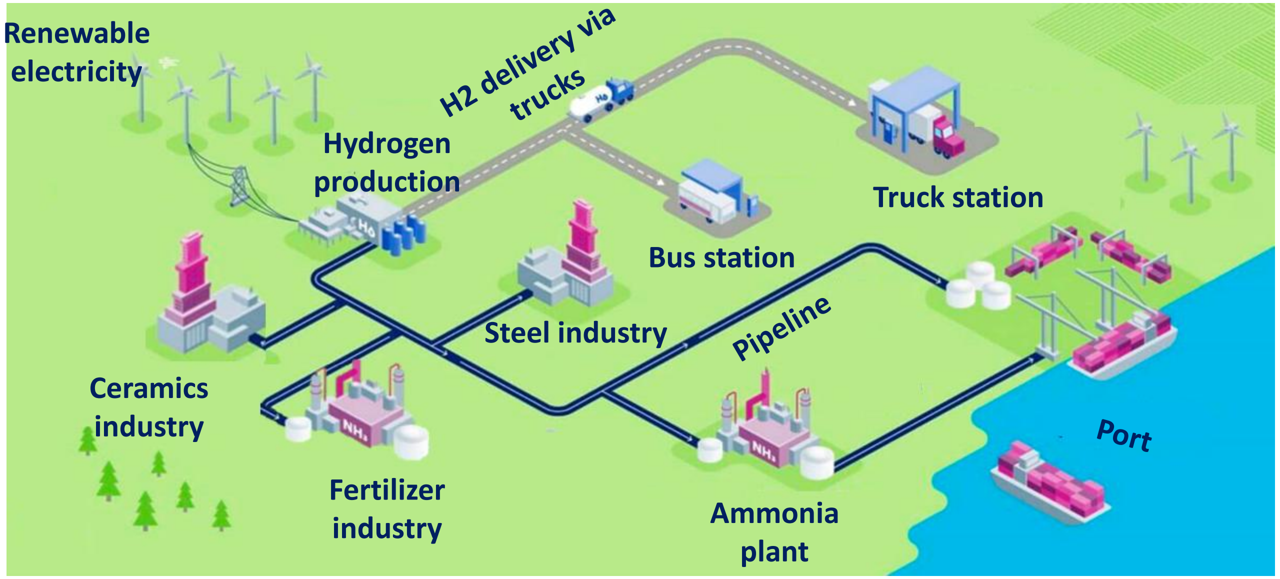
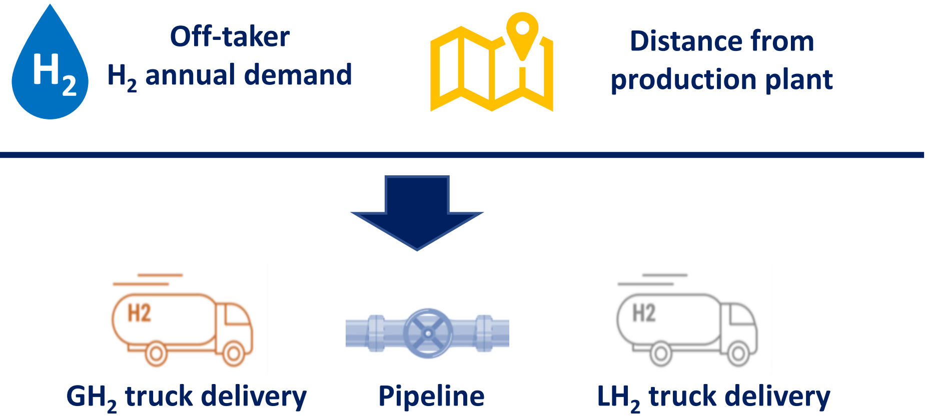


Davide Pivetta, Alessio Tafone, Stefano Mazzoni, Alessandro Romagnoli, Rodolfo Taccani, A multi-objective planning tool for the optimal supply of green hydrogen for an industrial port area decarbonization, Renewable Energy, Volume 232, 2024, https://doi.org/10.1016/j.renene.2024.120979.

Digital models for H_2 distribution infrastructure configuration

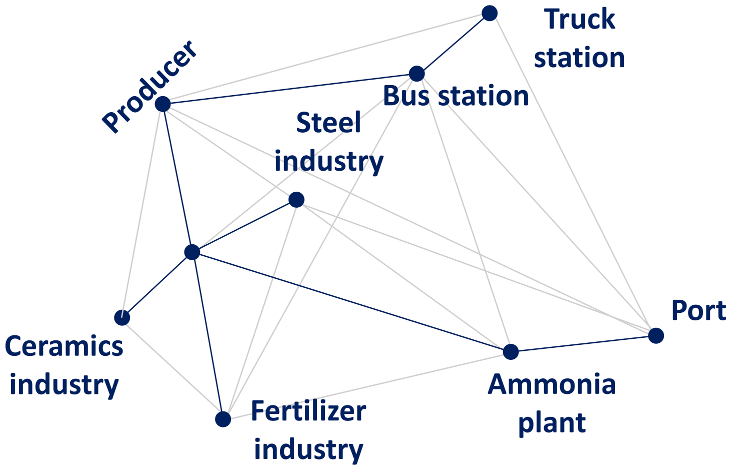
Inland distribution of Hydrogen





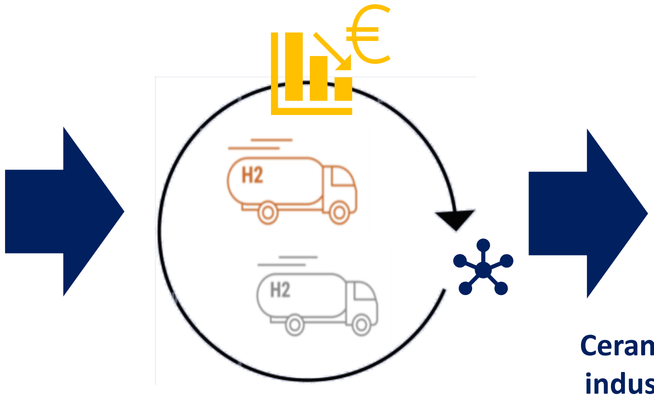
Support of decision making in hydrogen distribution infrastructure

Initial distribution pipeline layout

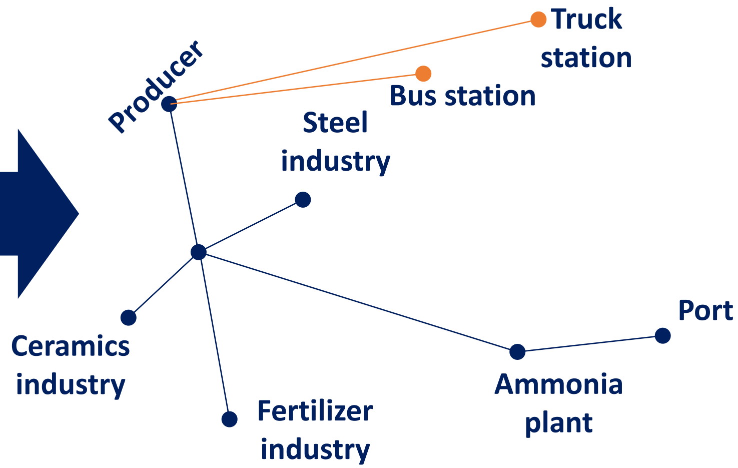


Minimum spanning tree distribution based on pipeline minimum length

Integration



Result



F. Del Mondo ed al, Investigation on hydrogen distribution infrastructure and cost reallocation. In Press.