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# Techno-Economic Analysis of a Hydrogen fueling Station for Rail Vehicle

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***January 30, 2024***



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# ***Modelling Multi-Energy Systems***



# MESS - Multi-Energy System Simulator

➤ Open-source software for the simulation of multi-energy systems

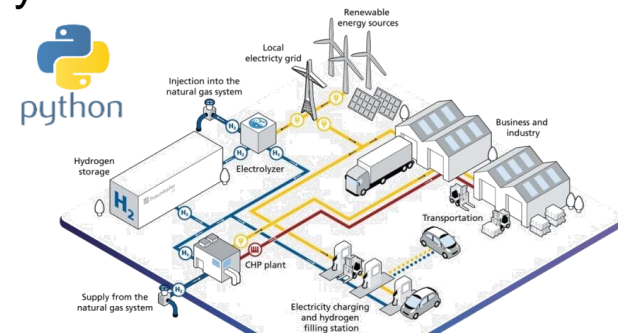
➤ Publicly available at: <https://github.com/pielube/MESSpy>

- Licensed under the European Union Public Licence (EUPL)



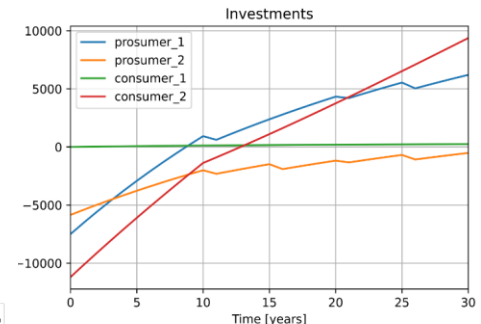
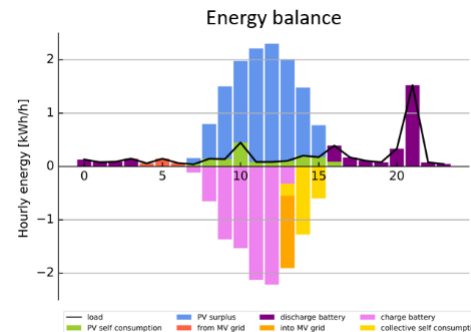
➤ Principali obiettivi del progetto

- Simulazione di sistemi multi-energetici con quote elevate di FER
  - Risorse energetiche rinnovabili distribuite, intermittenti
- Possibilità di analizzare più vettori di energia e la loro interazione
  - Elettricità, calore, idrogeno e combustibili



➤ Techno-economic assessment

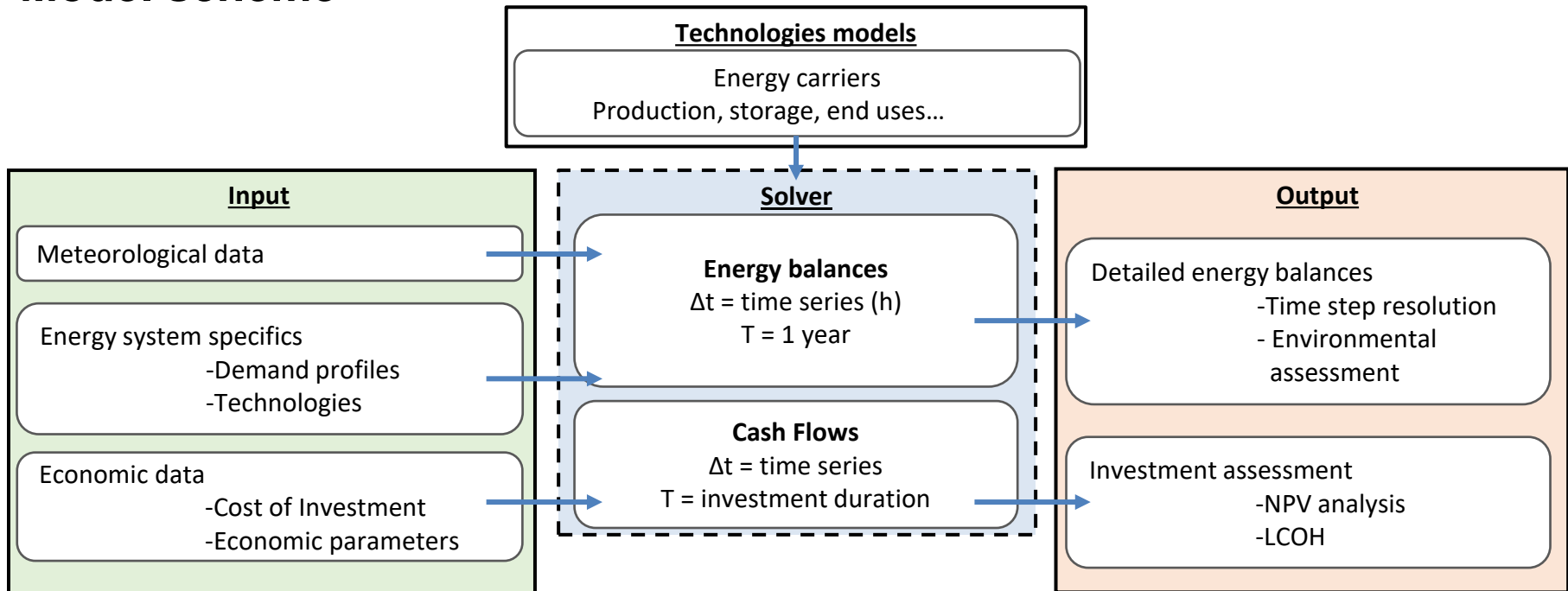
➤ Environmental analysis





# MESS - Multi-Energy System Simulator

## Model scheme



- Hourly energy balances resolved by reference year
  - ⇒  $\Delta t = 1 \text{ h}$ ,  $T_y = 8760 \text{ h/y}$

- Economic evaluation over investment period
  - ⇒ CAPEX, Investment costs, component replacement
  - ⇒ OPEX, sale, energy purchase
- Environmental assessment (GHG intensity)



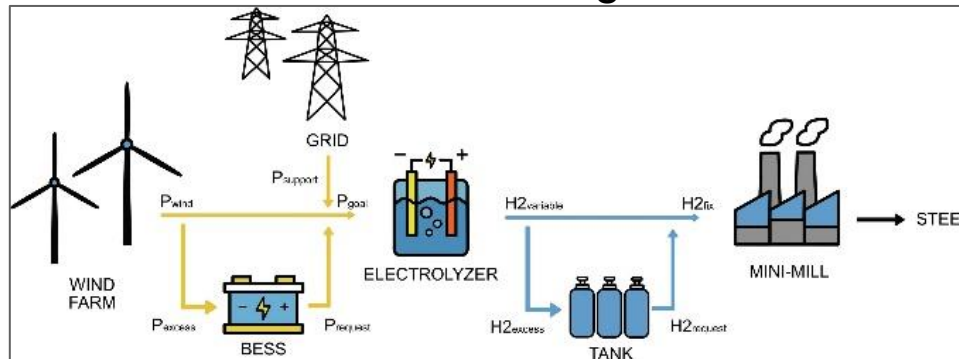
# MESS - Applications

## ➤ Flexibility in spatial resolution

⇒ One-to-many players

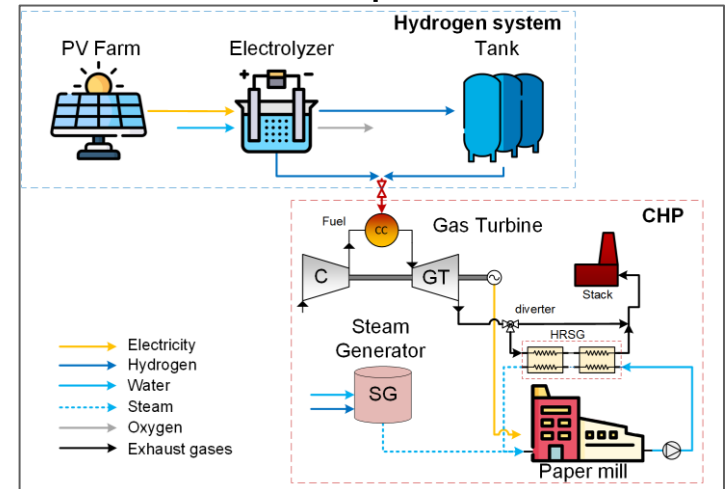
### Power plants and Industrial Hubs

#### Steelmaking



[3] F. Superchi, A. Mati, C. Carcasci, A. Bianchini, Techno-economic analysis of wind-powered green hydrogen production to facilitate the decarbonization of hard-to-abate sectors: A case study on steelmaking, *Appl. Energy*. 342 (2023) 121198. <https://doi.org/10.1016/j.apenergy.2023.121198>

#### Paper mill



[4] A. Mati, A. Ademollo, C. Carcasci, Assessment of paper industry decarbonization potential via hydrogen in a multi-energy system scenario: A case study, *Smart Energy*. 11 (2023) 100114. <https://doi.org/10.1016/J.SEGY.2023.100114>



# Treni ad Idrogeno

Coradia iLint

**ALSTOM**  
• mobility by nature •

- I treni ad Idrogeno sono una realtà
- ⇒ Fuel Cell



Mireo  
Plus H

**SIEMENS**

HydroFLEX



UNIVERSITY OF  
BIRMINGHAM



porterbrook



# Obiettivo

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- Fabbisogno di idrogeno
  - ⇒ Scenario energetico
  
- Hydrogen Refueling Station:
  - ⇒ Sviluppo delle infrastrutture
  
- Obiettivi :
  - ⇒ Ricerca e definizione di tratte ferroviarie non elettrificate:
    - ➔ Creazione curva di domanda di idrogeno;
  - ⇒ Costruzione di filiera di produzione di H<sub>2</sub> verde;
    - ➔ Stazione di rifornimento on-site autosufficiente:
  - ⇒ Analisi energetica ed economica.



# Caso Studio: Linea Faentina

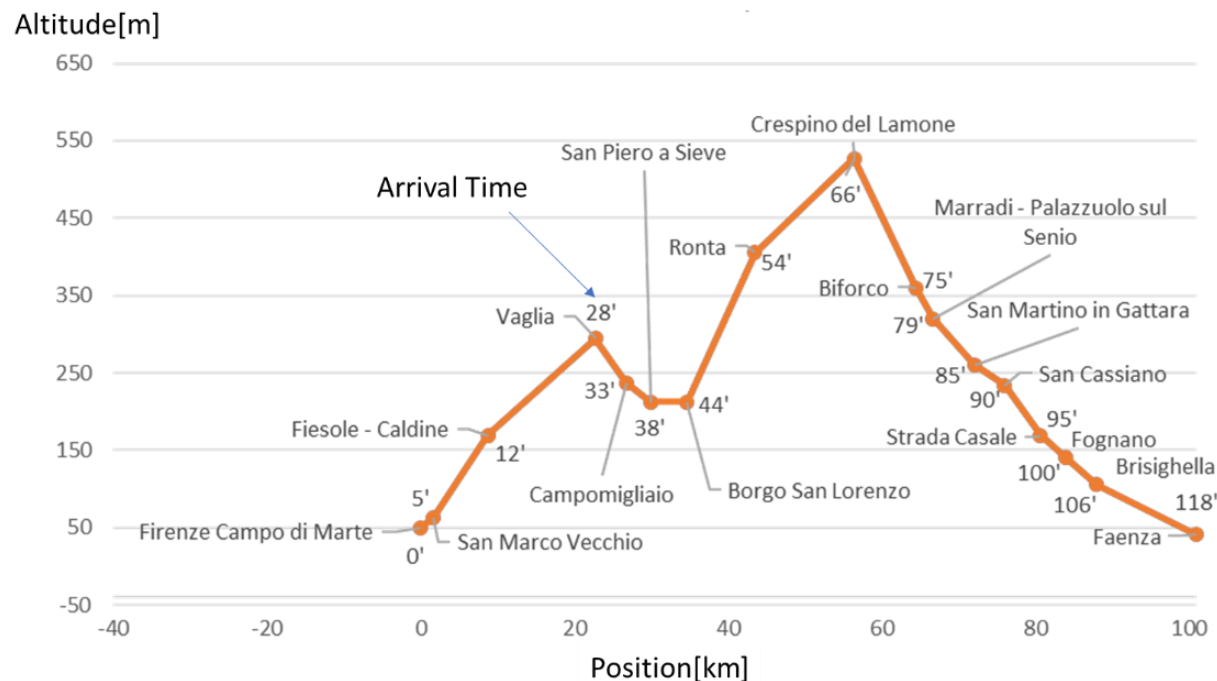




# Missione

- Linea attiva dal 1888
- 101 km
- forti dislivelli

Position [km+m]	Station/Plant(†closed)	Altitude[m]
(0+000)	Firenze Campo di Marte	53.
8+750	Fiesole-Caldine	169
14+397	PM Montorsoli	251.
15+984	Cercina †	276
19+751	Fontebuona †	330
22+735	Vaglia	292
29+853	San Piero a Sieve	211
34+615	Borgo San Lorenzo	212
38+098	Panicaglia †	281
43+438	Ronta	406
49+767	Fornello †	537
52+500	Max line Altitude	578
56+362	Crespino del Lamone	526
64+508	Biforco	360
66+619	Marradi-Palazzuolo sul Senio	319
68+958	Popolano di Marradi	296
72+082	San Martino in Gattara	261
75+945	San Cassiano	217
79+074	Sant'Eufemia di Brisighella †	191
80+647	Strada Casale †	169
83+960	Fognano	139
87+935	Brisighella	105
100+949	Faenza	34





## Tratta Firenze – Faenza

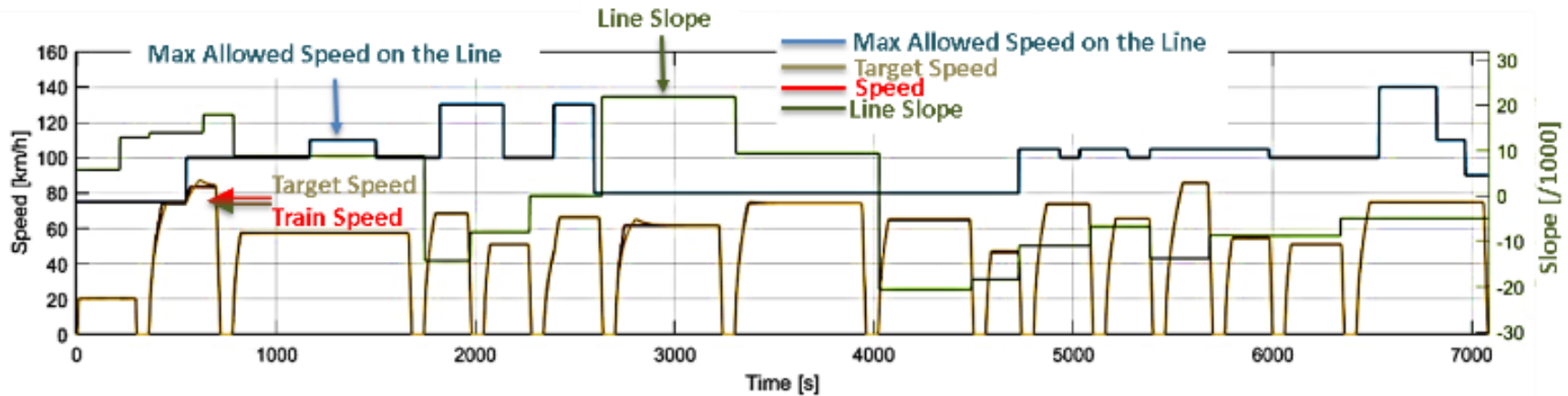
- 13 tratte per la sperimentazione di treni a H<sub>2</sub>.
- Firenze – Faenza;
  - ⇒ Elevato numero di passeggeri;
  - ⇒ Attraversa borghi storici dell'Appennino;
  - ⇒ 12 viaggi giornalieri coperti da 4 treni.
  - ⇒ Presenza di gallerie;
  - ⇒ Elettrificazione complessa
- Fabbisogno giornaliero della flotta:
  - ⇒  $demand=582,64 \text{ kg}_{\text{H}_2}/\text{d}$



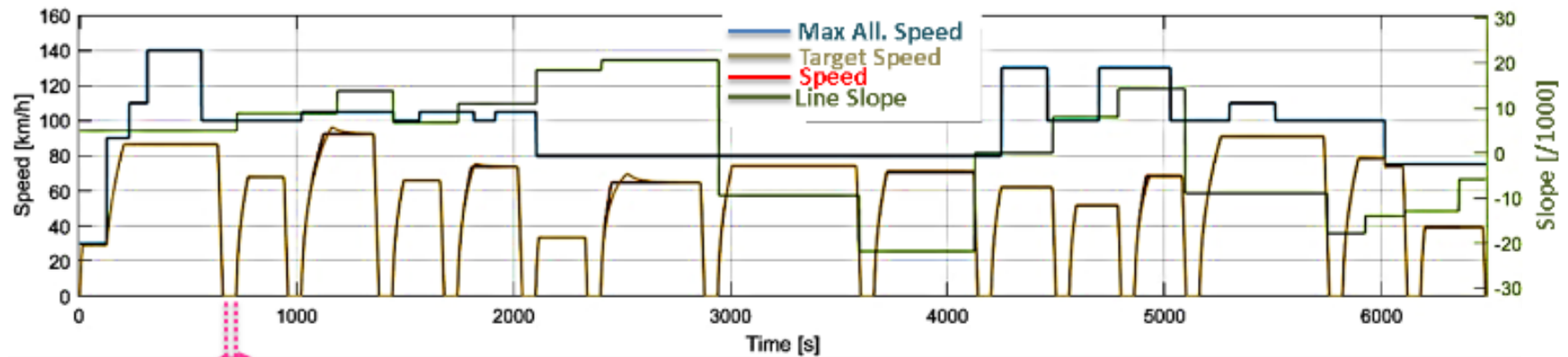


# Constrained Train & Kinematics

## Simulated Outward Run



## Simulated Return Run



Duration of Train Stops is also Simulated



# Modellazione HRS

## ➤ HRS:

⇒ Modellazione tramite il software MESSpy;

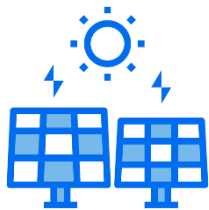
➔ Simulazione per time – step (orarie) per un dato arco temporale;

### Input

- › Domanda
- › PV Size
- › PEME Size
- › Tank<sub>LPH</sub> (P, Capacity)
- › Compressore
- › Tank<sub>HPH</sub> (P, Capacity)
- › Zona Geografica
- › Costi
- › Anni

### Output

- › LCOH
- › LOC Tank
- › Bilanci energetici



PV



PEME



Tank<sub>LPH</sub>



Compressore



Tank<sub>HPH</sub>



Dispenser



# Simulazione compressore

## HRS – Compressore:

$$m_{H_2} = 100 \text{ kg/h};$$

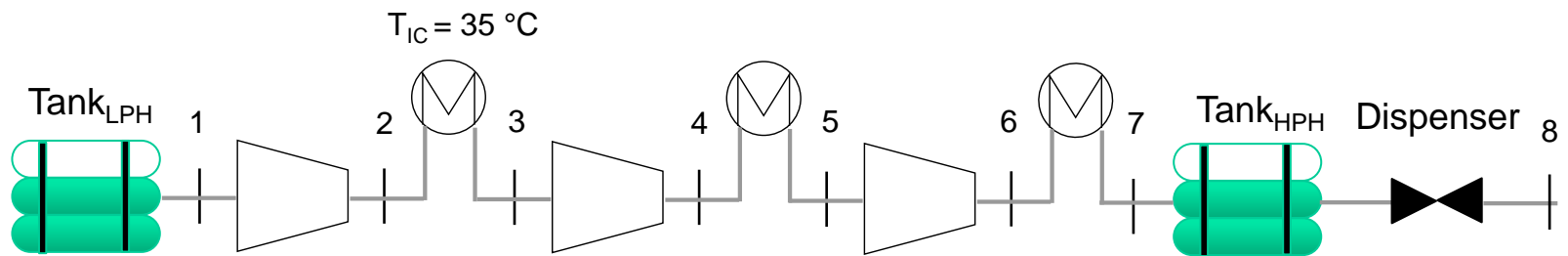
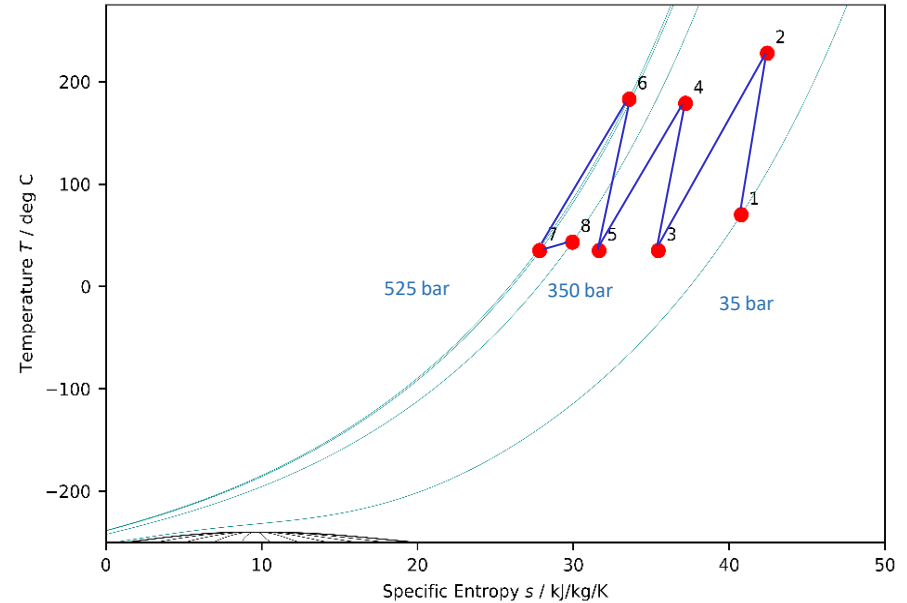
$$\beta_{id} = 15;$$

- $W_{comp} = 192,87 \text{ kW}$
- $Q_{IC} = 198,30 \text{ kW}$

Verifica della T durante il rifornimento:

- $T < 85 \text{ °C}$ .
- Espansione isoentalpica 7- 8 a 350 bar:

- $T[8] = 316,48 \text{ K} = 43,33 \text{ °C}$



$$P_{in} = P_{LPH} = 35 \text{ bar}$$

$$T_{in} = T_{out, PEME} = 70 \text{ °C}$$

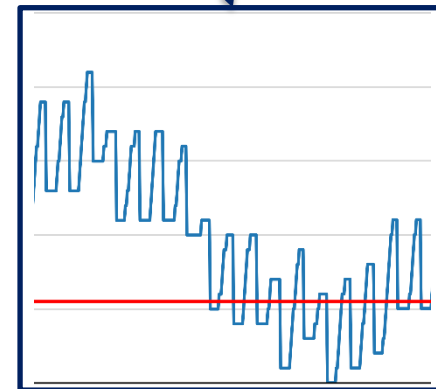
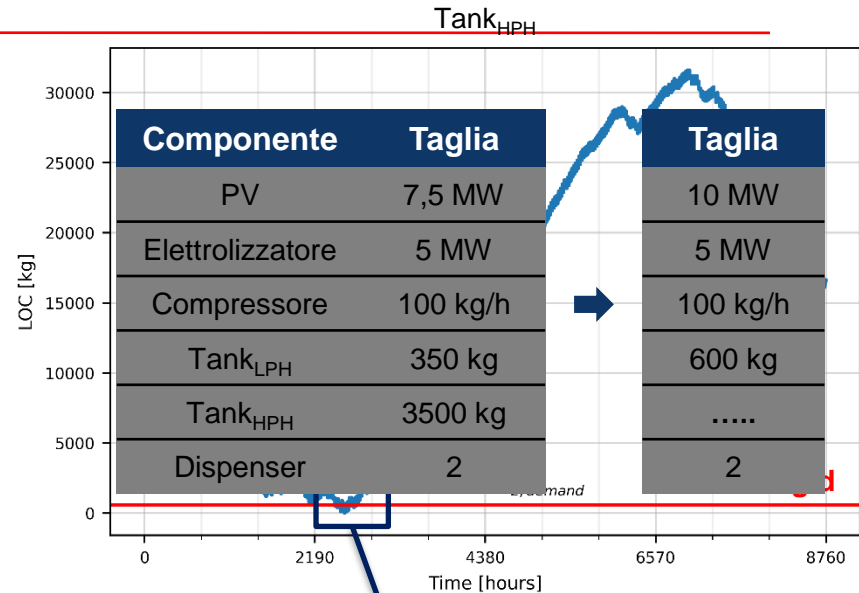
$$\eta_{pol} = 0,70$$

$$P_{out} = P_{HPH} = 525 \text{ bar}$$

$$T_{lim} = 85 \text{ °C}$$

# Ridimensionamento HRS

- Taglia PV: 10 MWp
- Capacità Tank<sub>LPH</sub>:
  - ⇒ Ha solo il compito di «buffer»:
  - ⇒ TankLPH = 600 kg;
- Capacità Tank<sub>HPH</sub>:
  - ⇒ almeno di 32 t.

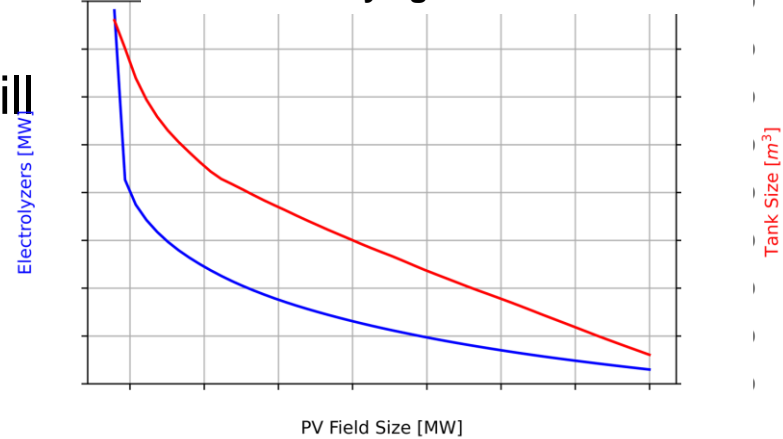




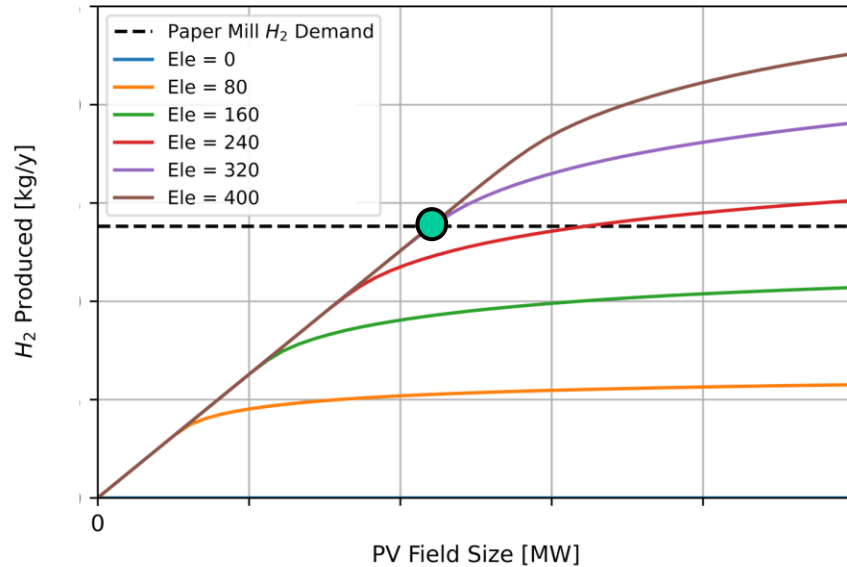
# Possible Combinations – PV & Electrolyzers

- Coupling of different solutions
  - ⇒ Satisfying H<sub>2</sub> Demand of the Paper Mill
  - ⇒ PVsize vs Electrolyzersize

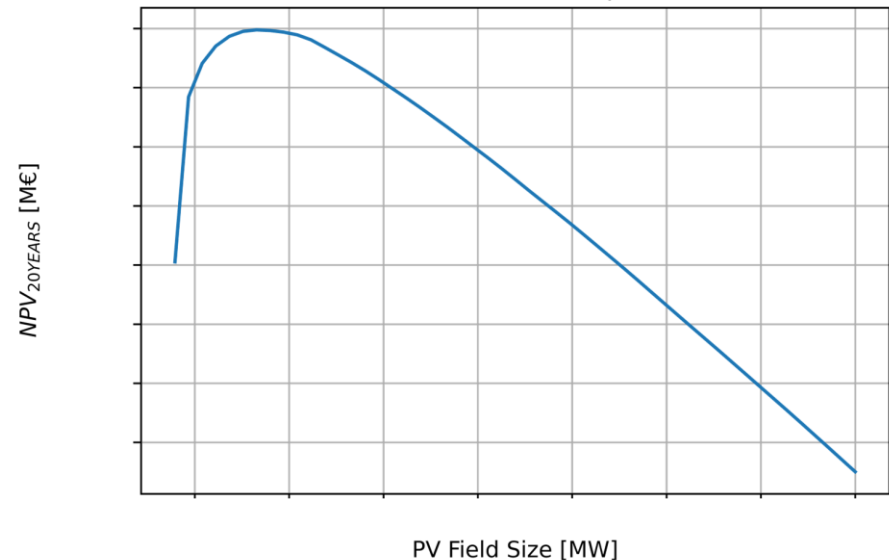
Solutions varying PV Field Size



Operation Map - Solar Energy



Net Present Value - Optimum





## Risultati Economici

➤  $LCOH_{overall} = 18,78 \text{ €/kg}_{H_2}$ ;

⇒  $CAPEX = 42,7 \text{ M€}$

→ Il  $Tank_{HPH}$  è il componente più costoso.

– 27,2 M€.

→  $CAPEX_{comp}$  poco superiore all'1% dell'investimento totale.

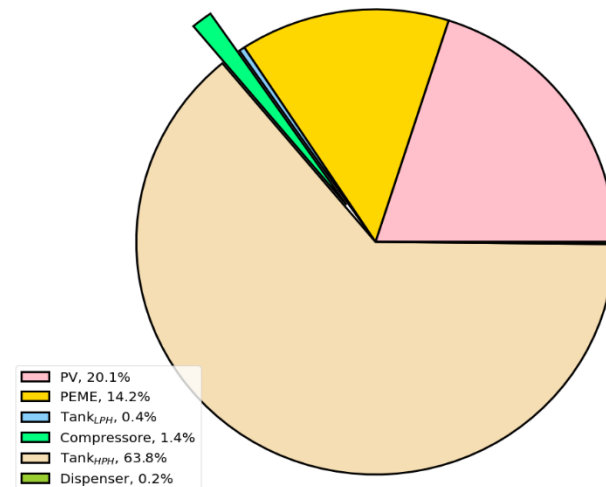
–  $c_{spec,comp} = 4500 \text{ €/kW}$ ;

Componente	Taglia
PV	7,5 MW
Elettrolizzatore	5 MW
Compressore	100 kg/h
Tank <sub>LPH</sub>	350 kg
Tank <sub>HPH</sub>	3500 kg
Dispenser	2



Taglia
9,1 MW
5,5 MW
70 kg/h
600 kg
32000 kg
2

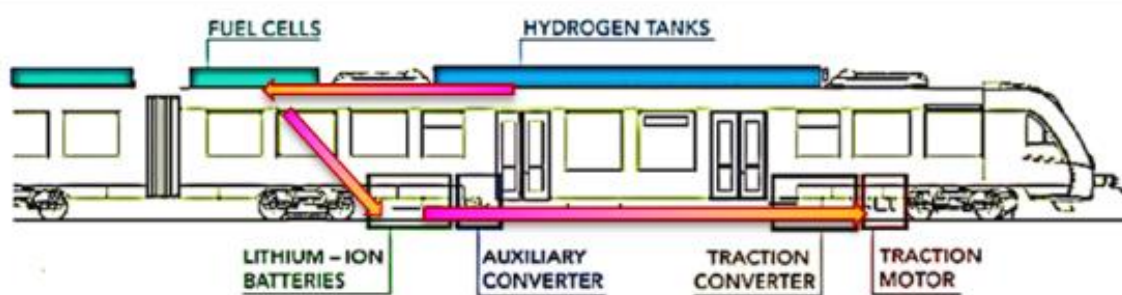
CAPEX





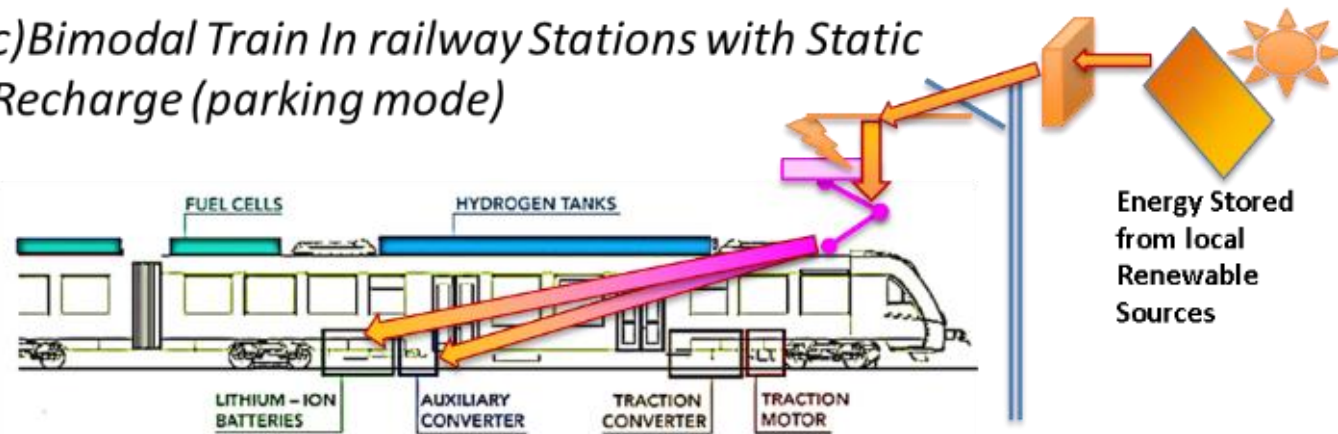
# Modalità di funzionamento

## b) Bimodal Train on Not Electrified Lines



Everything is supplied by H<sub>2</sub> Fuel Cells

## c) Bimodal Train In railway Stations with Static Recharge (parking mode)



Batteries Are Recharged & Auxiliaries are supplied

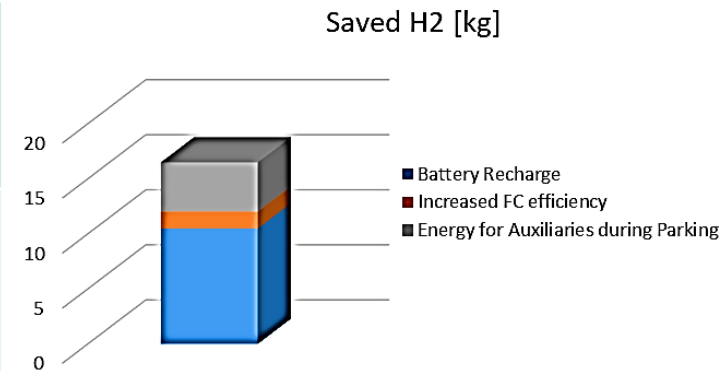


# Consumi con e senza ricarica della batteria

Conventional Solution      Fast Recharge in Station



Parameter	Value	Value	Difference
Consumed H <sub>2</sub>	44,82[kg]	31.5[kg]	-35%
Mean Consumption of H <sub>2</sub>	About 0.25[kg/km] (0.18[kg/km]declared)	0.16[kg/km]	-35%
Autonomy	About 750 km (1000km declared)	1150-1200[km]	+50%
Mean Efficiency of Fuel Cells	50.15%(Outward Run) 49.93(Return Run)	52.5%(Outward) 51.8%(Return)	+2%
Initial Battery SOC	70%	70%	0
Min. Battery SOC during the mission	36.9%	47.4%	+11%
Final SOC at end of mission	80..06%	85%	+5%





## Conclusioni

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- Analisi termo-economica della stazione di rifornimento a idrogeno:
  - ⇒ Valutazione del fabbisogno della tratta;
  - ⇒ Modellazione sistema di compressione;
  - ⇒ Dimensionamento dell'HRS.
- I risultati mostrano un  $LCOH_{overall}$  (18,78 €/kgH<sub>2</sub>) alto poiché:
  - ⇒ H<sub>2</sub> prodotto in loco e «green»;
  - ⇒ Si necessita di TankHPH di grandi dimensioni;
  - ⇒ Incidenza economica del compressore molto bassa.
- Valutazione soluzioni alternative



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