H_2 as a key energy vector in integrated small scale distributed generation

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Prospect 2030 Replication Workshop

H_2: a long term perspective

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- In a long term perspective the energy scenario will be characterized by:
  - A high fraction of energy produced from renewable sources
  - A high fraction of non-ICE zero emission vehicles (EVs or FCEVs)
- The excess energy from renewables, otherwise lost, can be used to produce green H_2
- The H_2 can be used locally to produce electric energy, but mostly it will be fed into the pipeline to be distributed
- The exclusive use of local energy storage technologies would otherwise give a huge waste of clean energy

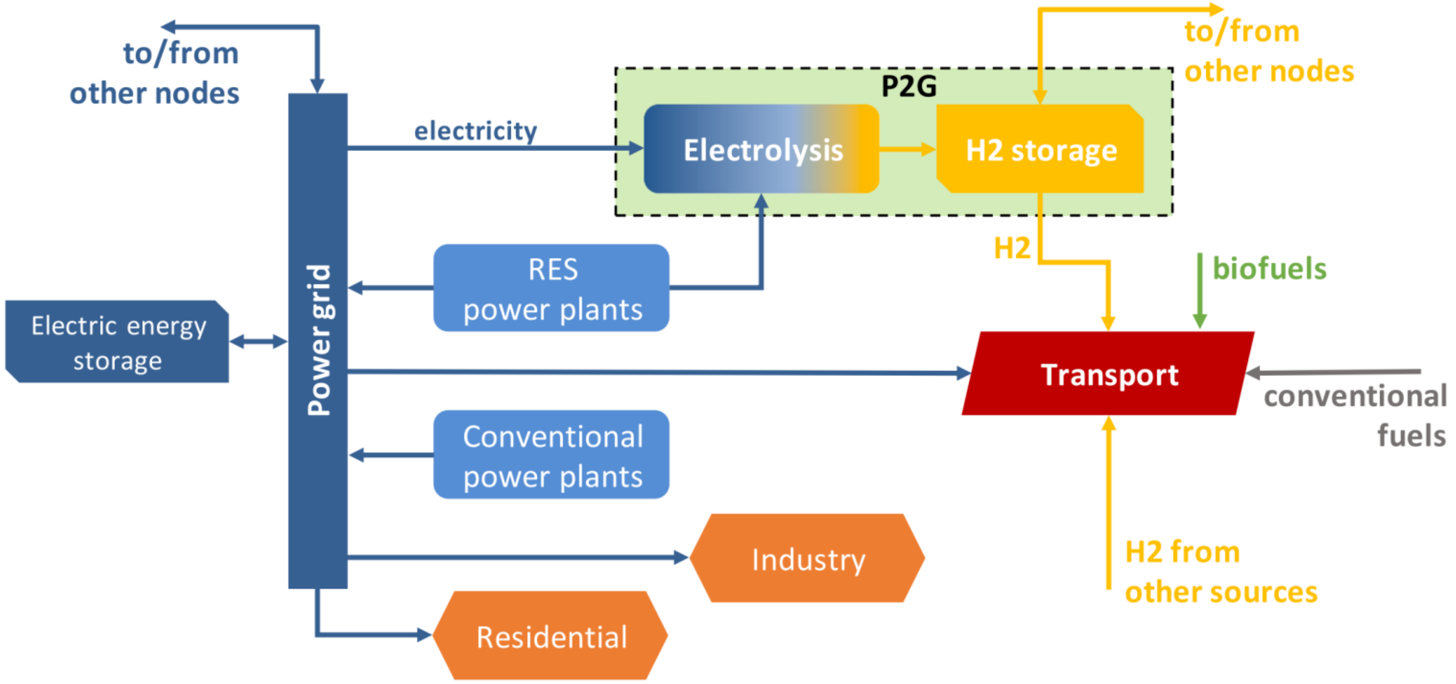
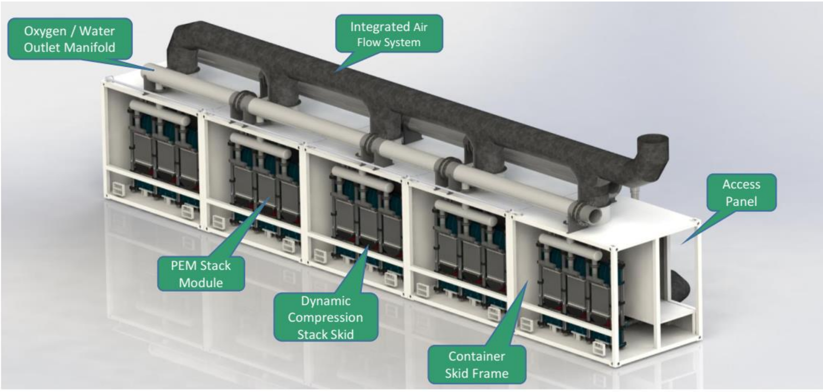


Fig. 1. Schematic of the energy flows within one nodal zone.

from Colbertaldo et al., Ren and Sust Energy Reviews, 133 (2020)

H_2 production technologies at the large scale

- Currently investments are mostly oriented to large scale projects for H_2 production
- The ultimate target is to reduce the cost of H_2 produced through water electrolysis
- The industrial standard is today natural gas reforming: we need to move to more sustainable processes from gray through blue H_2
- Production at the smaller scale is also feasible, and research activities are aiming at developing novel solutions also from diverse sources



REFHYNE
CLEAN REFINERY HYDROGEN FOR EUROPE

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

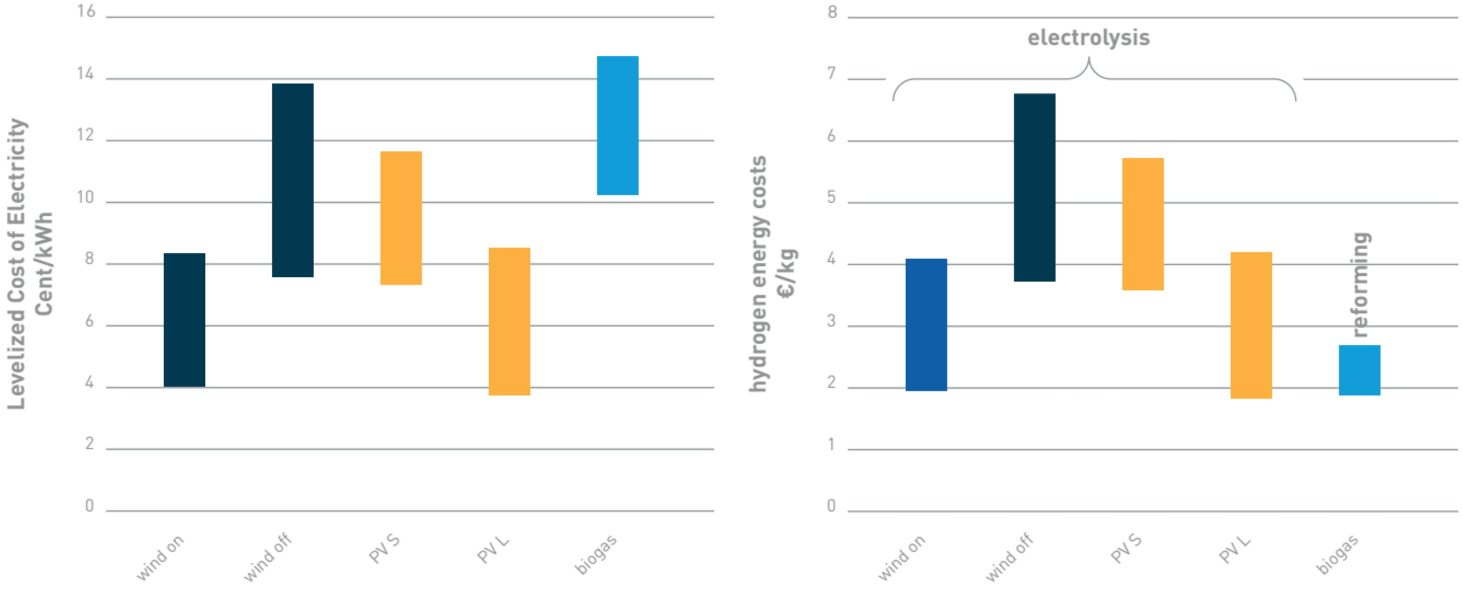
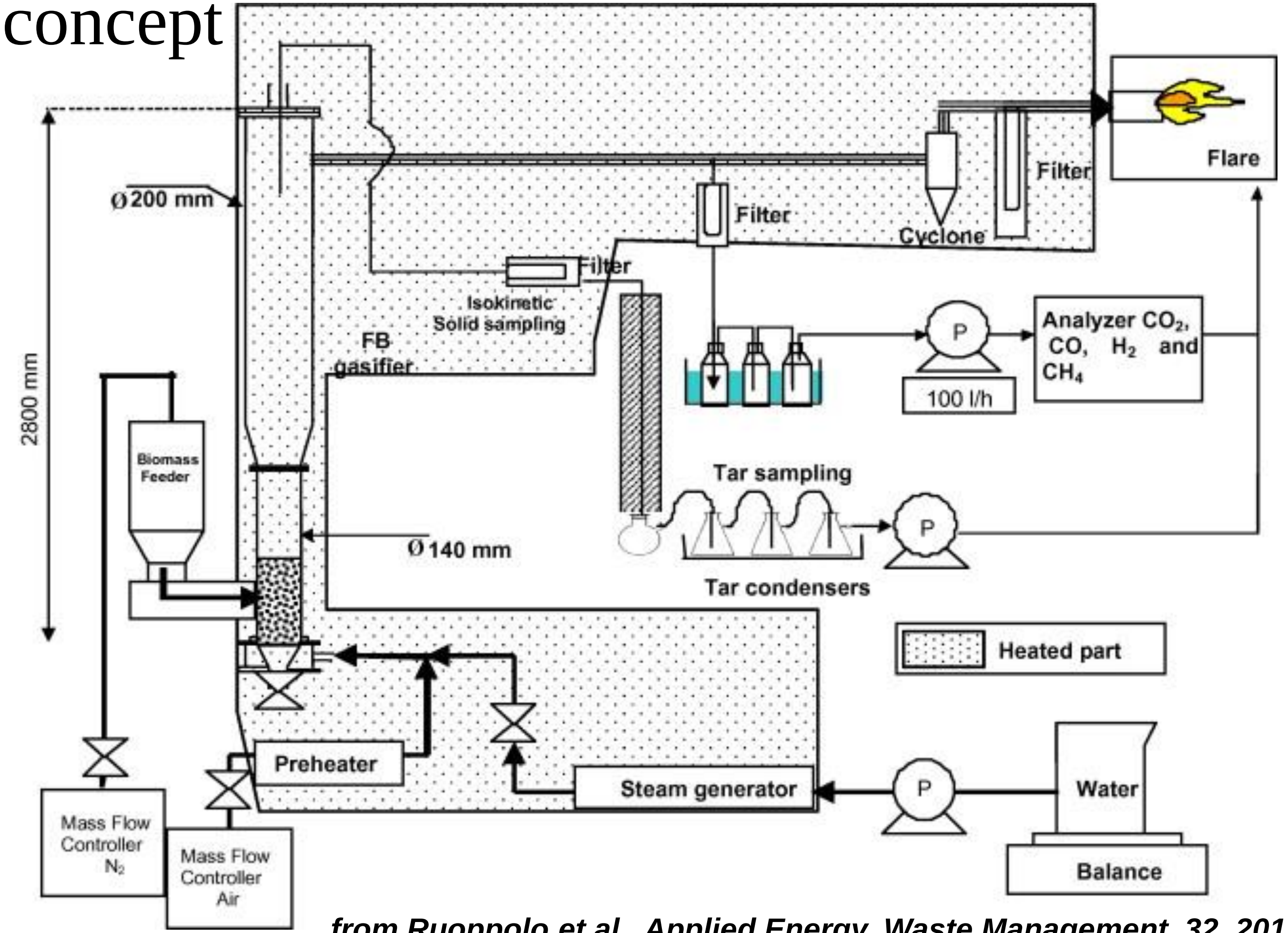


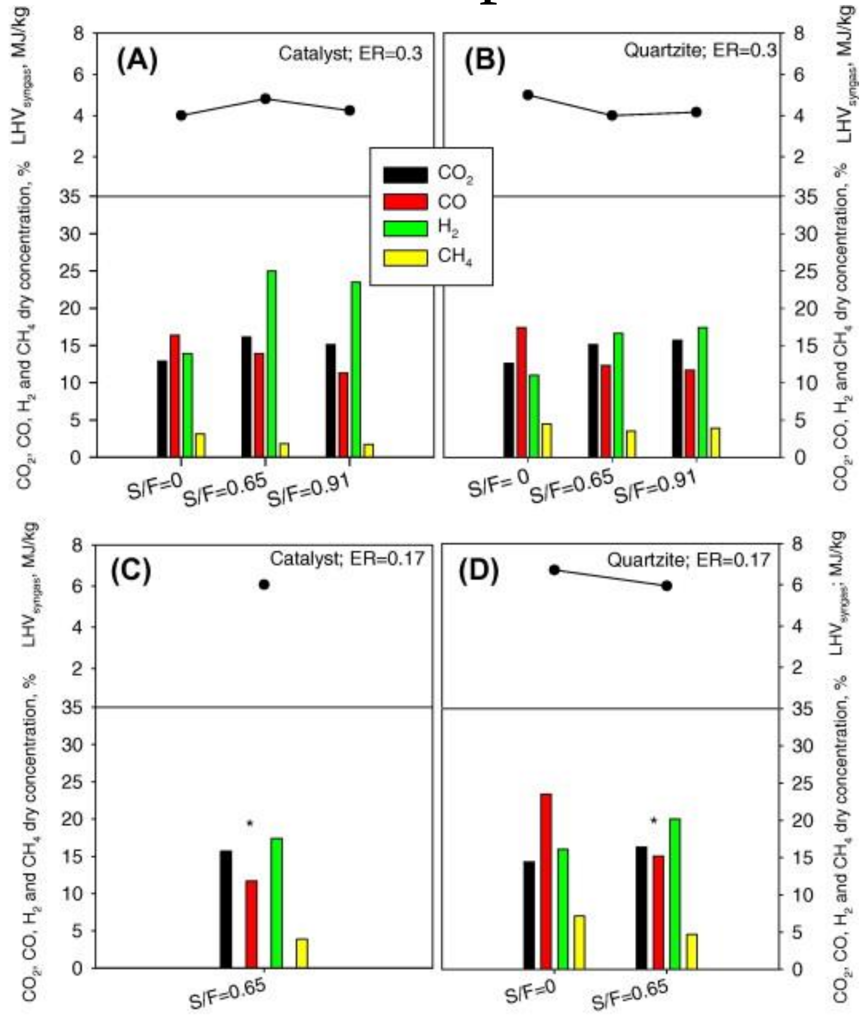
Fig. 3: (a) Levelized cost of electricity for new wind energy (WE), onshore and offshore, small and large PV systems and biogas in 2018; (b) hydrogen production costs calculated based on LCOE values [6]

from H_2 International, August 2020

- H_2 from biomass may be viable to implement a more distributed production concept



from Ruoppolo et al., Applied Energy, Waste Management, 32, 2012



H_2 utilisation technologies

- PEM or SOFC fuel cells are clean-noise-free systems, and they are relatively complex in their structure
- Durability is still an issue, as targets are at about 8000h for automotive systems and at least 40000h for stationary systems
- Fuel cell costs have been reduced by 60% in the last 10 years, depending mostly on the reduced use of catalysts (mainly Pt)
- On top of the study of new materials and new designs, the correct use of fuel cells in vehicles and systems is of utmost importance to avoid oversizing which is a typical practice of OEMs and maximize durability

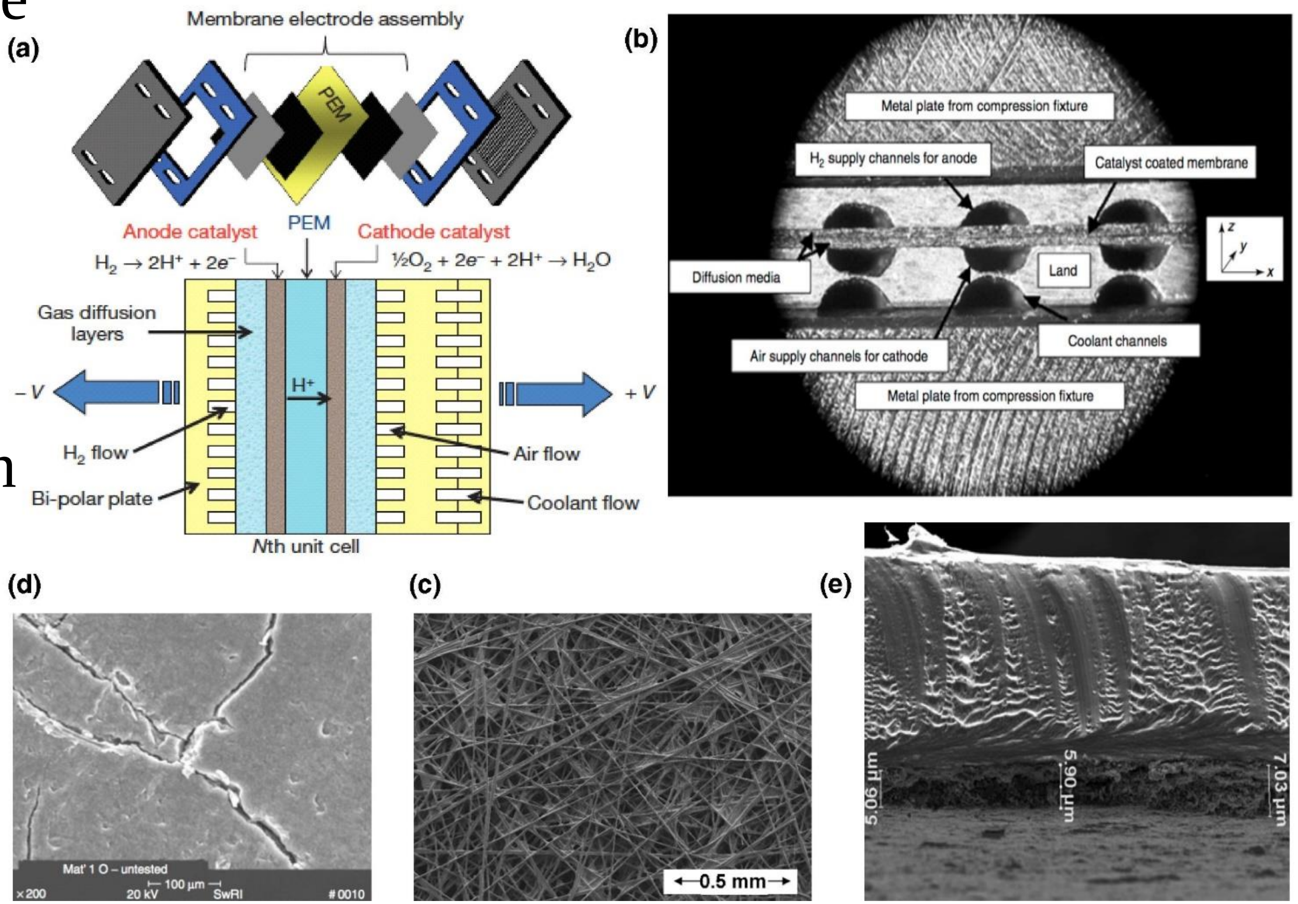


Figure 1. (a) PEM fuel cell structure, (b) cross-sectional view; (c) SEM (top view) of a gas diffusion layer; (d) SEM (top view) of a ELAT@ microporous layer; and (e) SEM (cross-sectional view) of catalyst layer and membrane [78], [148], [296], [306].

from Wang et al., Materials Today, 2020

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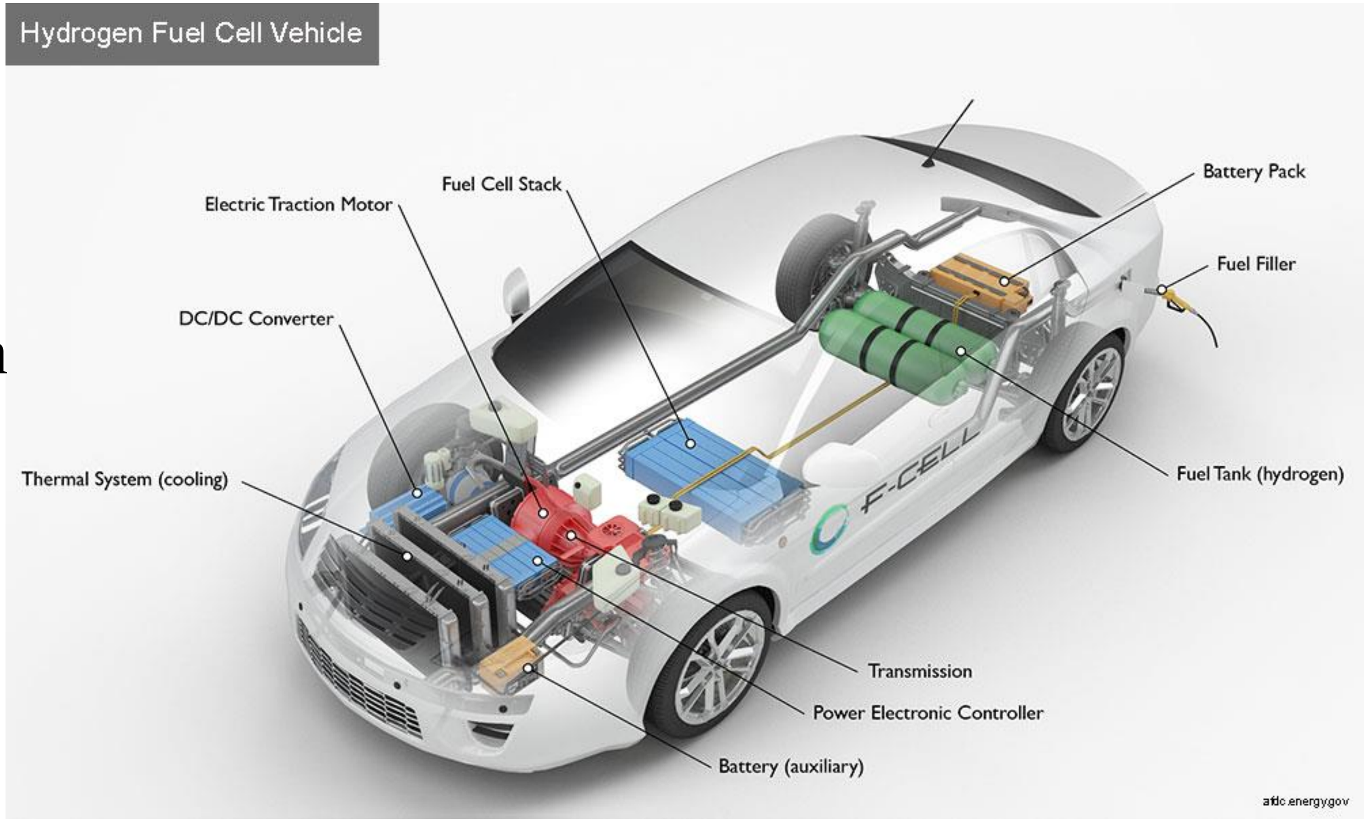

from afdc.energy.gov

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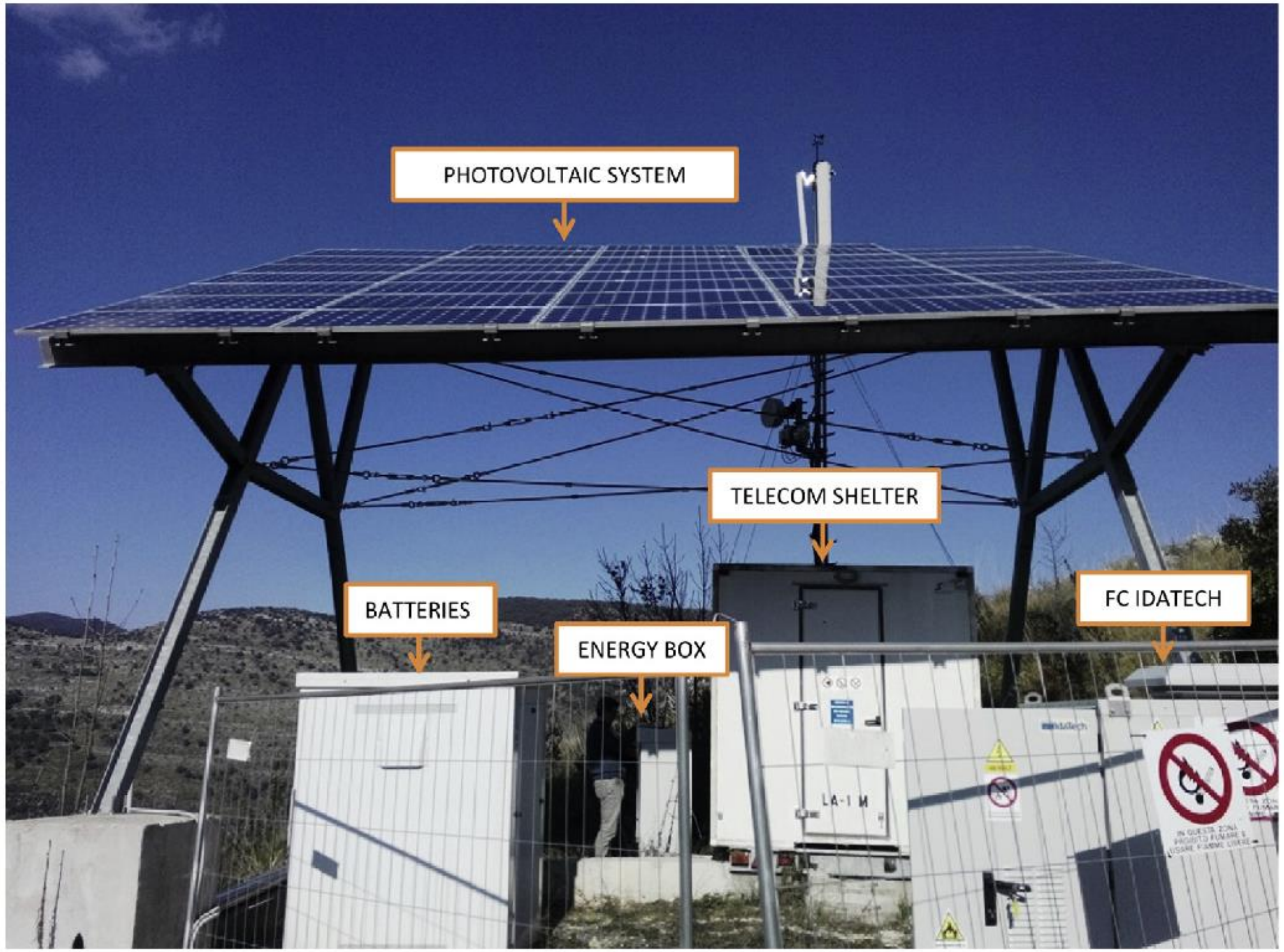

from Cordiner, Mulone et al., Applied Energy, 192, 2017

SCERG@TorVergata: main collaborations

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H_2 small scale systems –Lab@Tor Vergata

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The experimental setup includes:

- Proton Exchange Membrane Fuel Cell systems:
  - Ballard Europe system 3 X 1.7 kW stack (DBX2000)
  - Ballard system 1.2 kW
- VR Lead Acid Battery packs:
  - 720 Ah @48V
- Electronic Loads up to 12 kW
- Power Supply to emulate programmable power sources and the electric grid, up to 16 kW
- Alkaline Electrolyzer up to 0.3 Nm^3/h
- Weather station with 10s sampling rate, data collected in the last 10 years

FCH2poweredRBS

- **Starting Date**: 01/01/2012
- **Duration**: 48M
- **Budget**: € 10,591,649
- **Funding**: € 4,221,270
- **Partners**: 6 partners
- **Countries**: Belgium, Denmark, Italy, Switzerland
- **Coordinator**: Ericsson
- **2** systems tested in R&D centers for benchmarking
- **11** real RBS station power generation systems in selected sites field trials.

Scope:

- Demonstrate the advantages of a FC stationary application in term of Total Cost of Ownership in telecom off-grid radio sites
- Assess the market readiness of the FC technology vs the telecom reliability demanding targets.

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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Project Partners

ERICSSON — Project Coordinator

Dantherm Power

MES S.A.

European Commission JRC's Institute for Energy and Transport

Dipartimento di Ingegneria Industriale Università degli Studi di Roma "Tor Vergata"

GREENHYDROGEN.DK

Telecom Operators involved

TIM

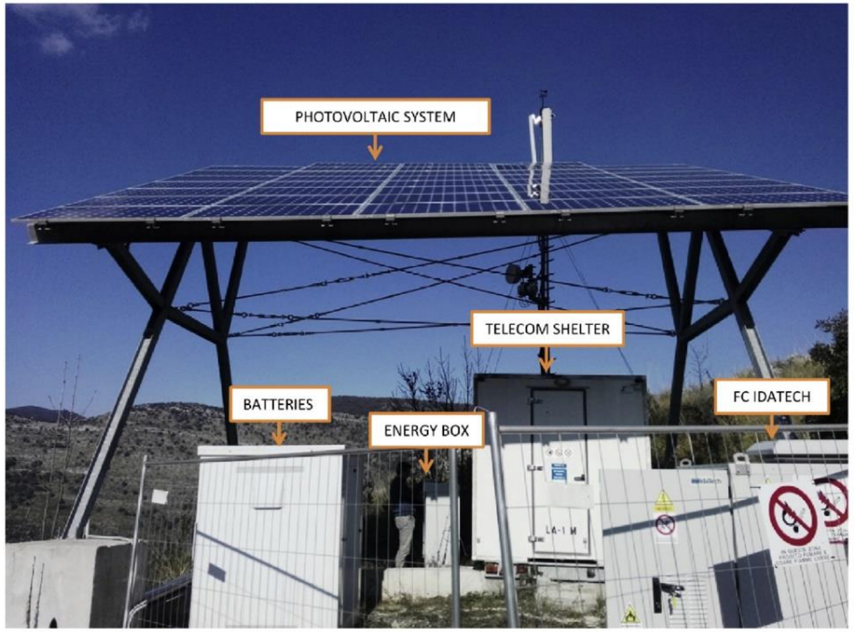
3

Analysis of system performance over one year

Design characteristics of the 6 sites installed in Lazio (central Italy).

	Site #1 (Baschi)	Site #2 (Fiano Romano)	Site #3 (Colle Turchina)	Site #4 (Sasso)	Site #5 (Campoleone)	Site #6 (Sonnino)
PV system power	5 kWp	5 kWp	3 kWp	5 kWp	2.5 kWp	5.5 kWp
PV canopy tilt angle	10–25 deg	10 deg	10 deg	10–25 deg	10–25 deg	30 deg
Fuel cell technology	1.7 kW Dantherm H_2 fed	1.7 kW Dantherm H_2 fed	1.7 kW Dantherm H_2 fed	1.7 kW Dantherm H_2 fed	1.7 kW Dantherm H_2 fed	2.5 kW Ballard Methanol fed
Lead-acid battery System	640 Ah at 48 V	640 Ah at 48 V	380 Ah at 48 V	640 Ah at 48 V	320 Ah at 48 V	640 Ah at 48 V
Average power at the RBS load	1.31 kW	1.28 kW	0.35 kW	0.72 kW	0.87 kW	0.65 kW

Installation of the FC system in Fiano Romano (site #2)

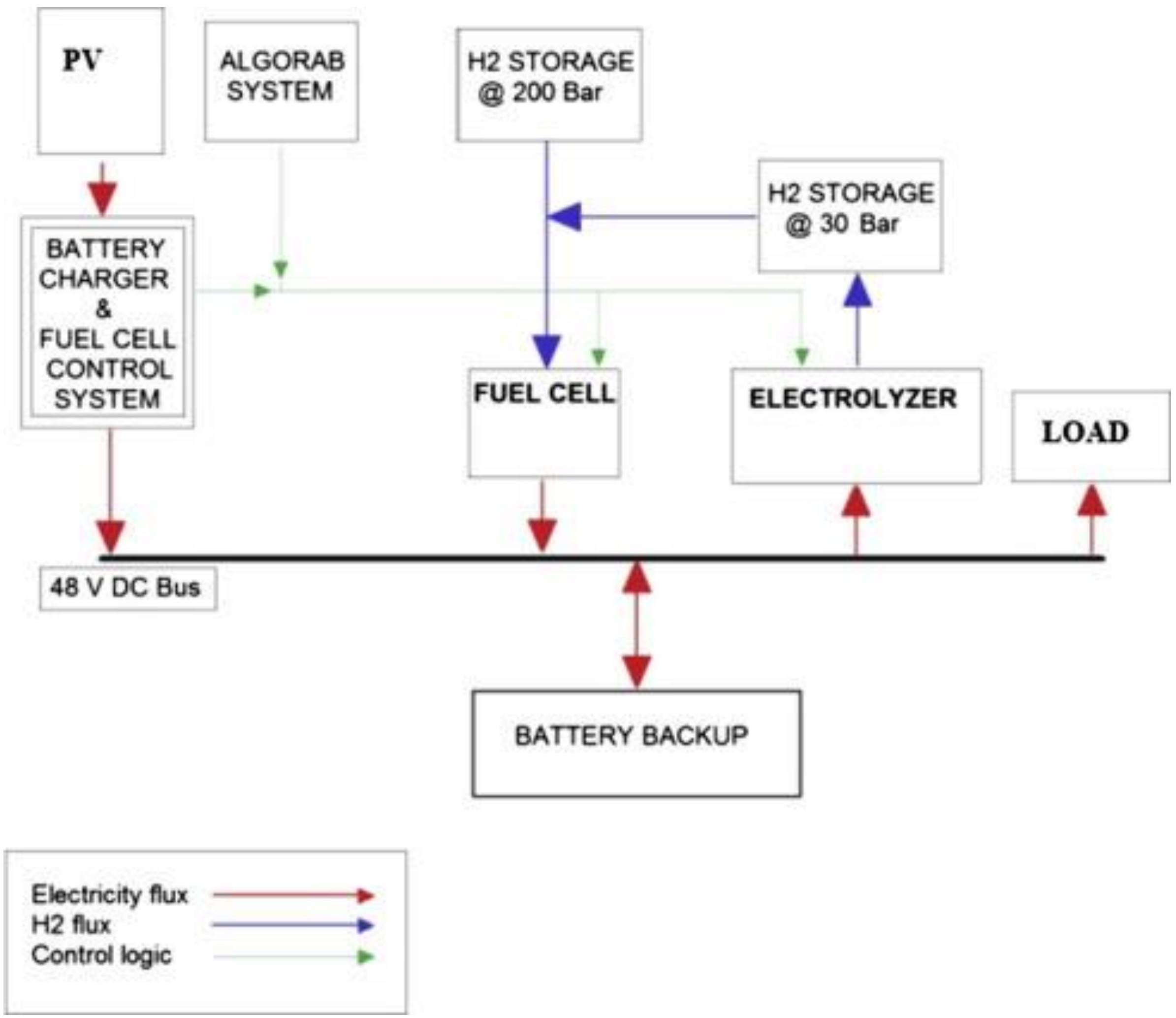


Installation of the FC system in Sonnino (site #6)

from Cordiner, Mulone et al., Applied Energy, 192, 2017

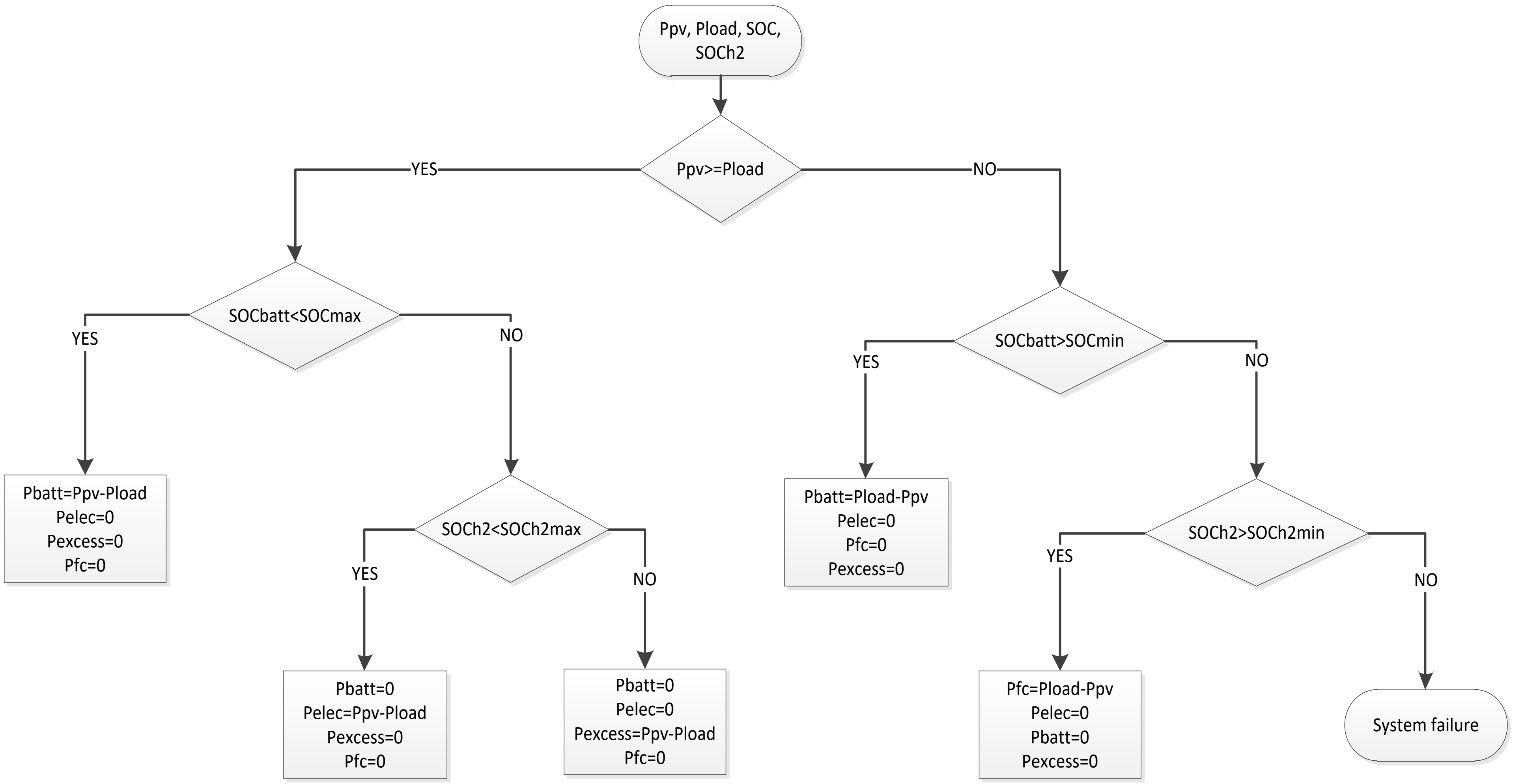
Technical challenges

- Site dependant solutions in terms of: geographical locations, load, energy storage design
- The design procedure must be flexible and scalable
- Development of a solutions with few components and reliable toward high availability



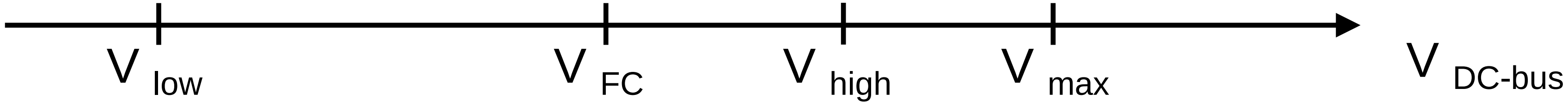
from Cordiner, Mulone et al., Applied Energy, 192, 2017

Technical challenges: ...the ideal control strategy...

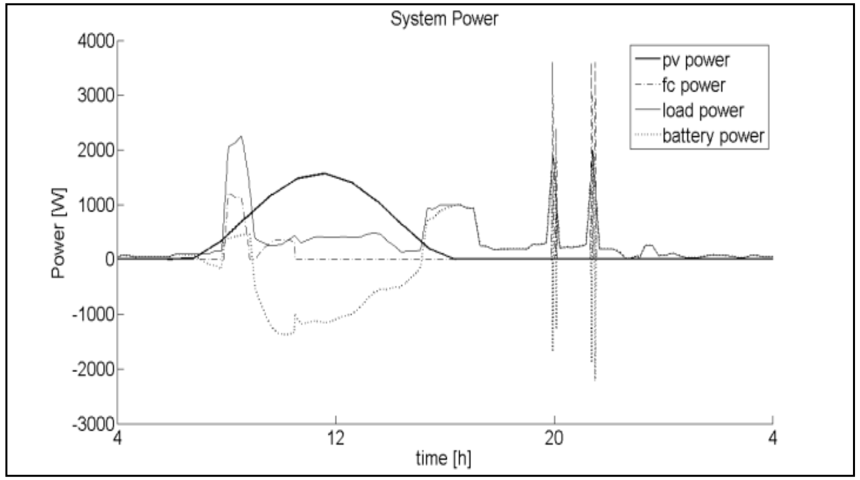


Control strategy is defined based on the bus voltage threshold values to simplify the system

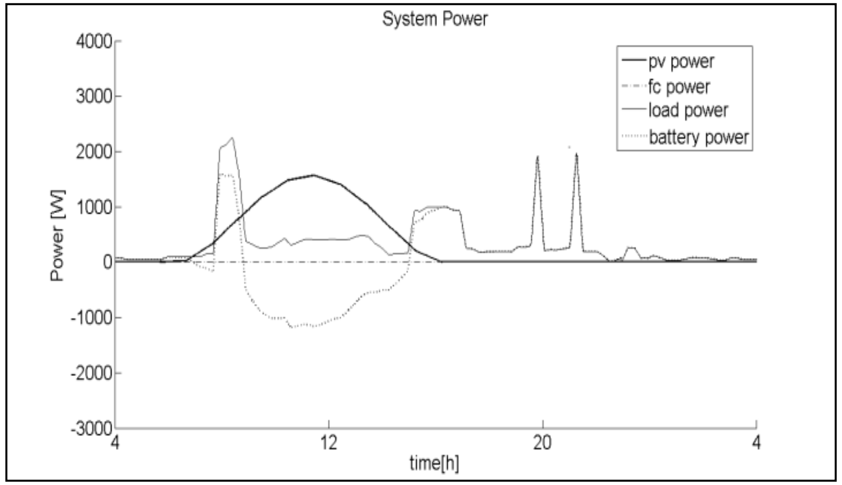
- V_{low} → FC start
- V_{FC} → FC operation
- V_{high} → FC stop
- V_{max} → Recharge battery voltage



LOW Vlow/Vhigh ratio



HIGH Vlow/Vhigh ratio



Power splitting depending on weather conditions

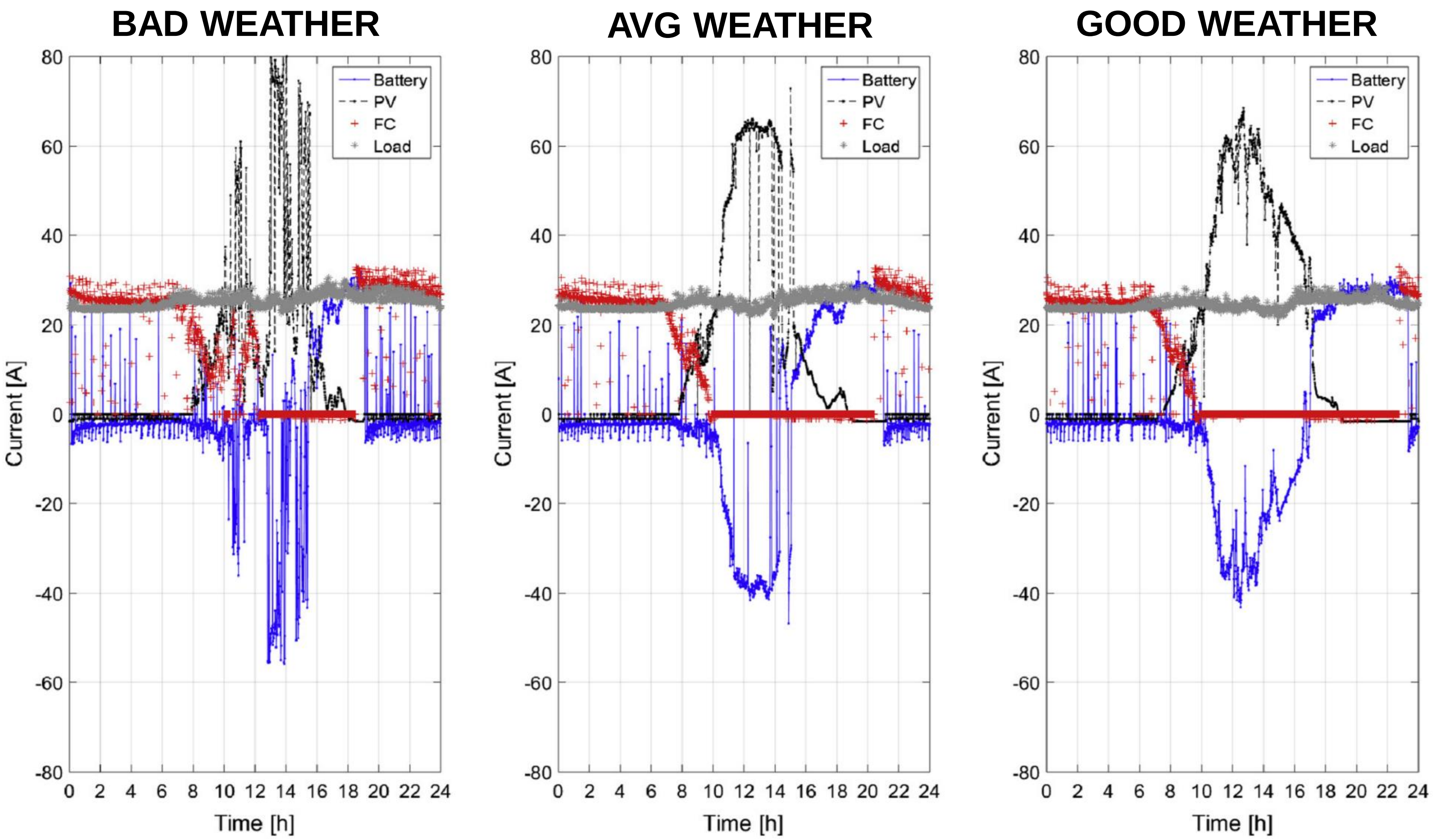
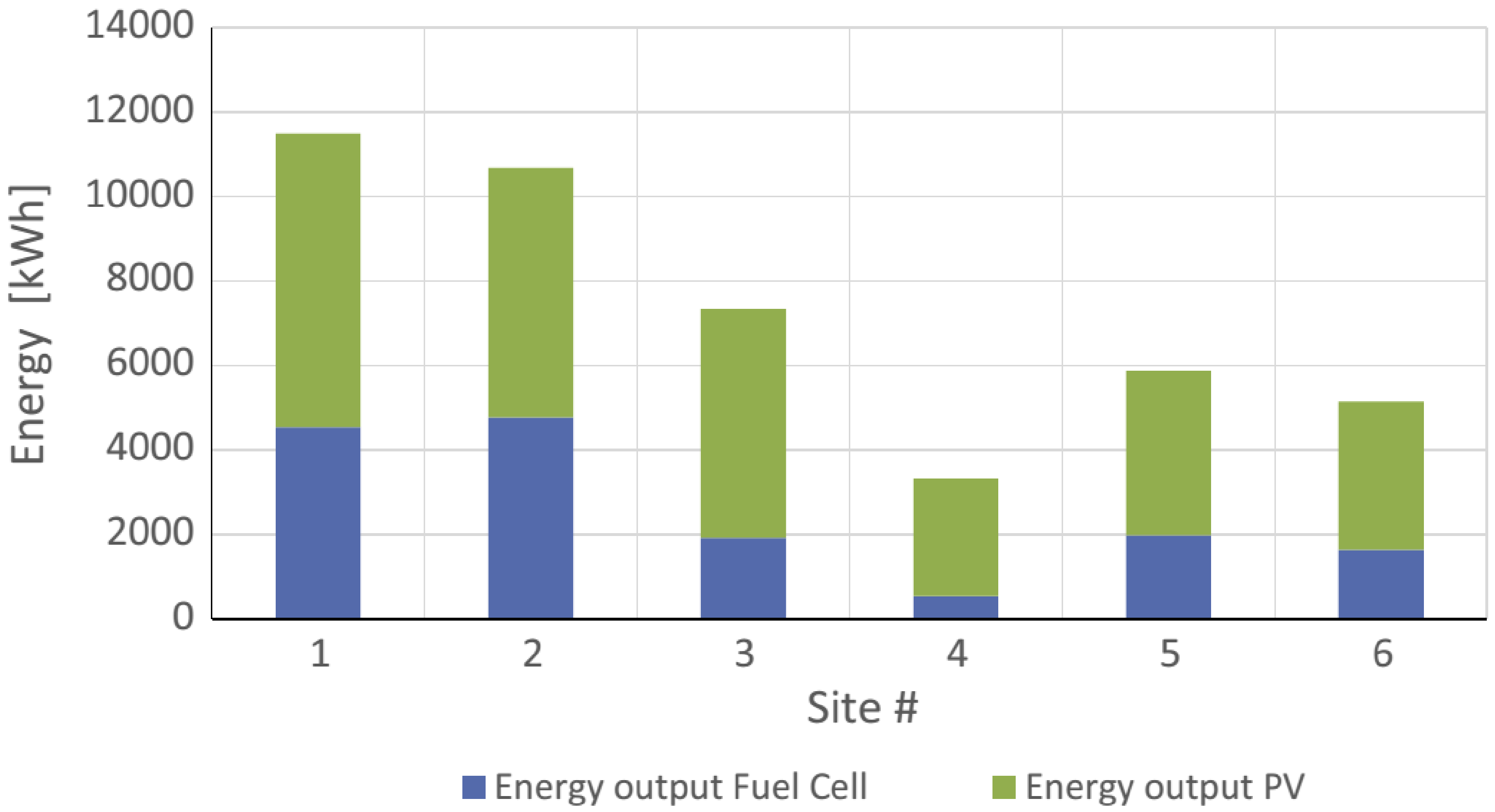


Fig. 9. Current output of PV system, battery, Fuel Cell and load during three representative days in the month of September 2015, Fiano Romano site (#2).

from Cordiner, Mulone et al., Applied Energy, 192, 2017

Energy consumption at the sites over the year



- Energy at the load is provided from renewables (PV) and through Fuel Cells (H_2 or methanol)

From Cordiner, Mulone et al., Applied Energy, 192, 2017

System performance parameters

- System performances may be evaluated via efficiency, whose value depends heavily on subsystem power sizings
- The greater the PV power, the closer η_{sys} would be to η_{PV}
- The lesser the PV power, the closer ηsys would be to $\eta_{FC}\eta_{REF}$
- System performance then can be also measured through the ratio E_{fes}/E_{res} evaluating the effectiveness of the system toward indepedence on fossil (external) sources, and thus in terms of CO_2 emission savings

$$I_{size} = \frac{E *_{load}}{E *_{RES}}$$

Class size index

$$\eta_{sys} = \frac{E_{load}}{E_{RES} + E_{FES}}$$

System efficiency

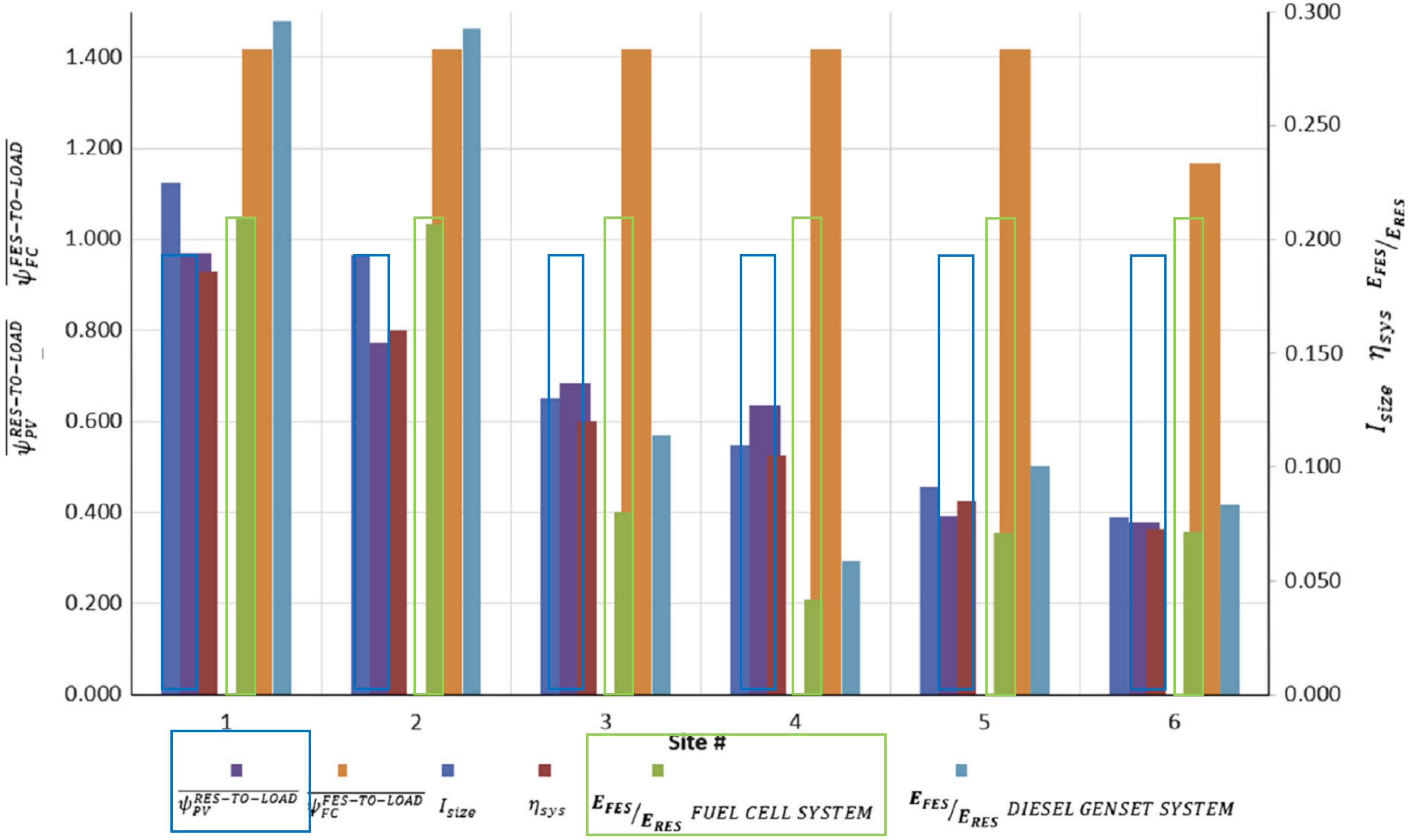
$$\eta_{sys} == \frac{\left(\overline{\psi_{PV}^{RES-TO-Load}}\ \eta_{PV}^{DIRECT\ *}\right) E_{RES} + \overline{\psi_{FC}^{FES-TO-Load}}\ \eta_{GENSET}^{*}\ E_{FES}}{E_{RES} + E_{FES}}$$

$$\overline{\psi_{RES-TO-LOAD}} = \frac{\bar{\eta}_{PV}}{\eta_{PV}^{DIRECT*}}$$

$$\overline{\psi_{FES-TO-LOAD}} = \frac{\bar{\eta}_{FC}\eta *_{REF}}{\eta_{DIESEL} *}$$

Performance coefficients of subsystems

Analysis of performance parameters at the sites over the year



From Cordiner, Mulone et al., Applied Energy, 192, 2017

Looking at a comparison with a site with the electrolyzer...

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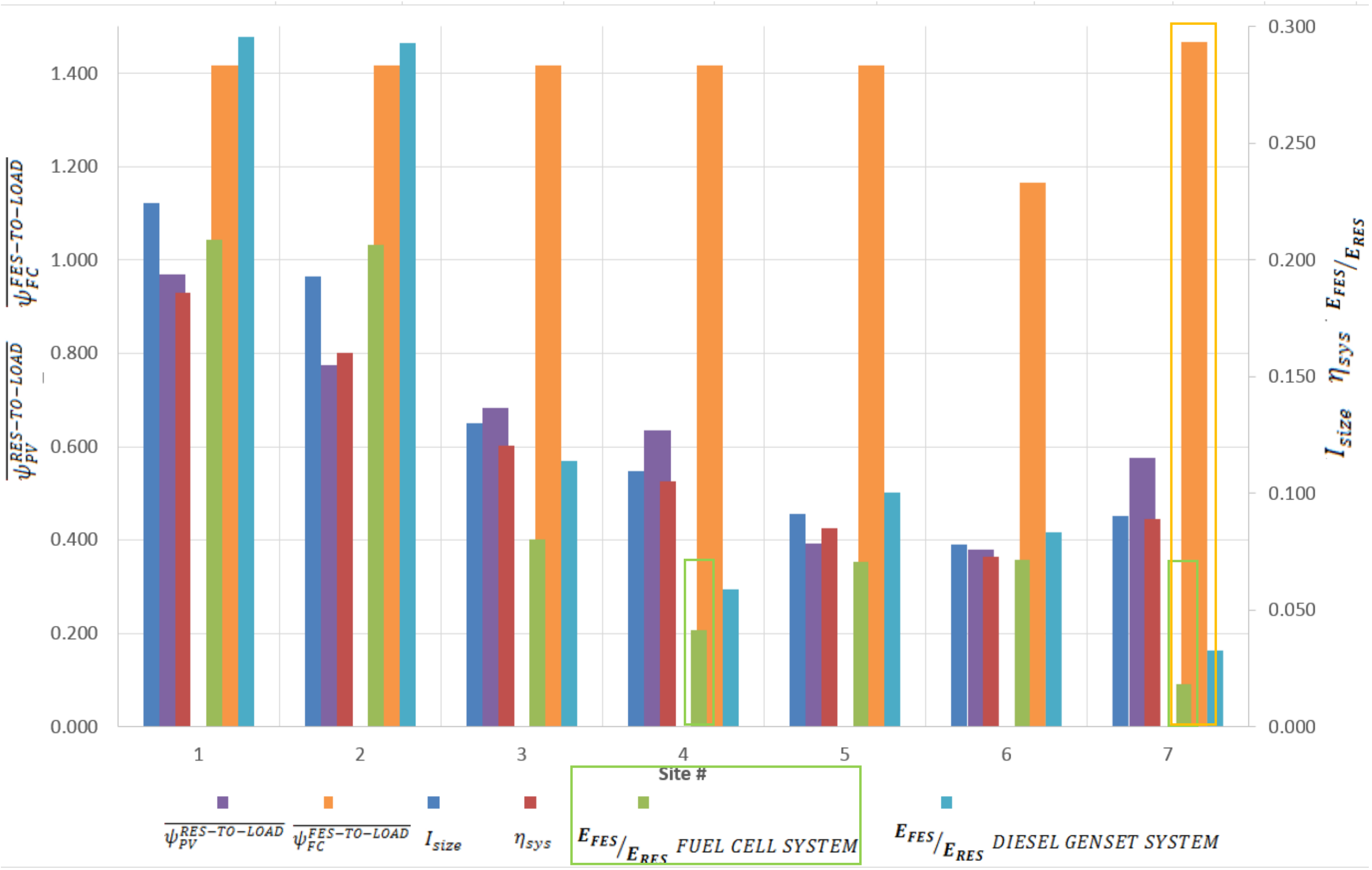


Site #7 is equipped with

- 7 kW_p PV
- 1 kW load power
- 1 Nm^3/h alcaline electrolyzer
- 640Ah@48V battery

From Cordiner, Mulone et al., Applied Energy, 192, 2017

Showing the commercial value proposition in tel. market

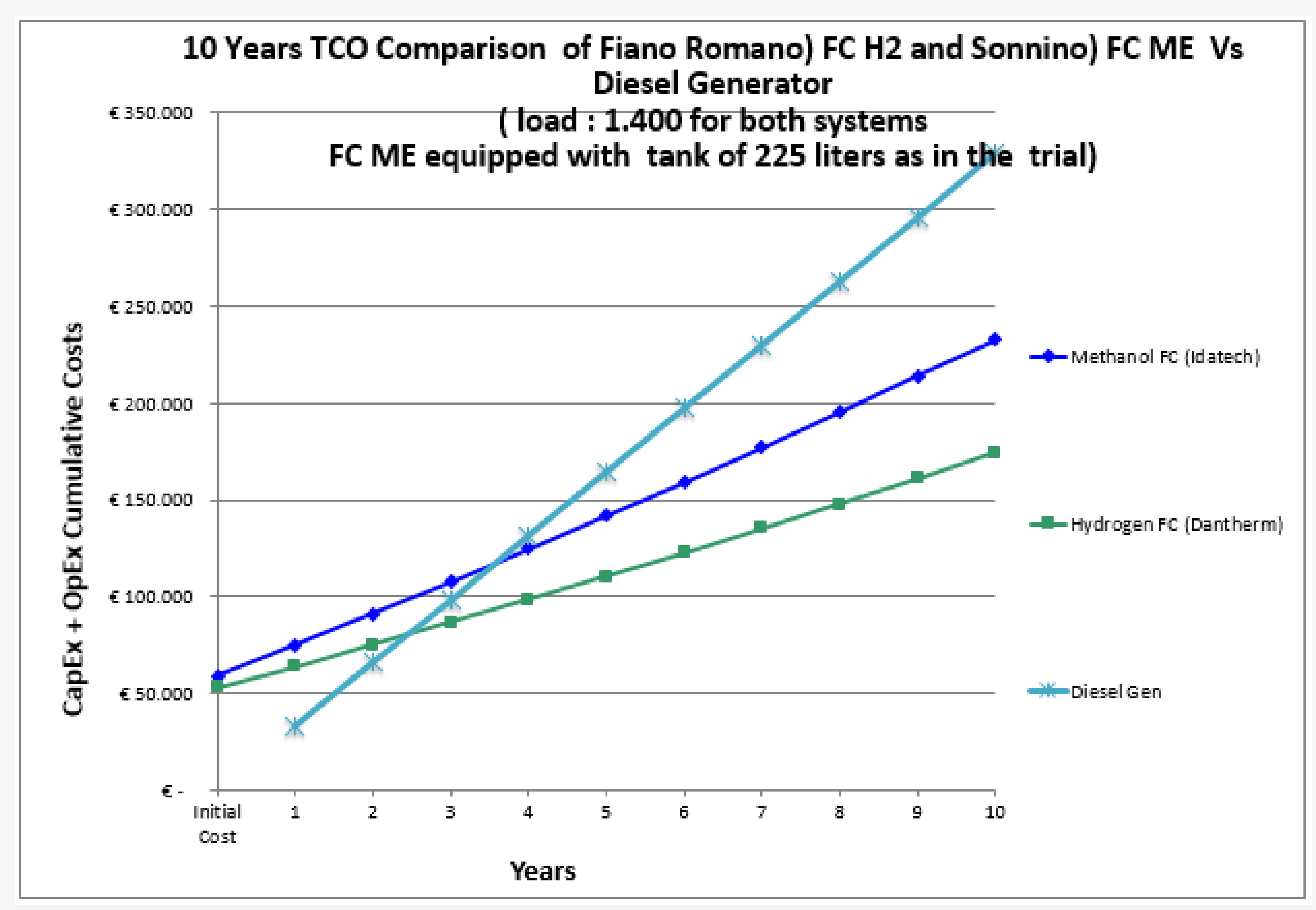
- Fuel Cells technologies meeting the demanding requirements from Telecom (technical, permitting, etc.), widely demonstrated in real conditions at operators radio sites: reliability greater than 95% and durability of more than 2 years

- The hybrid solution has highlighted high conversion efficiency with extended intervals of unattended operation (low fuel consumption) with consequently cheap maintenance costs and very low CO_2 emissions

- Total Cost of Ownership analysis over 10 years (TCO: upfront investments and operational costs) to benchmark economically the FC hybrid systems vs off-grid radio sites today solution (i.e. diesel generator rent and refueling service)

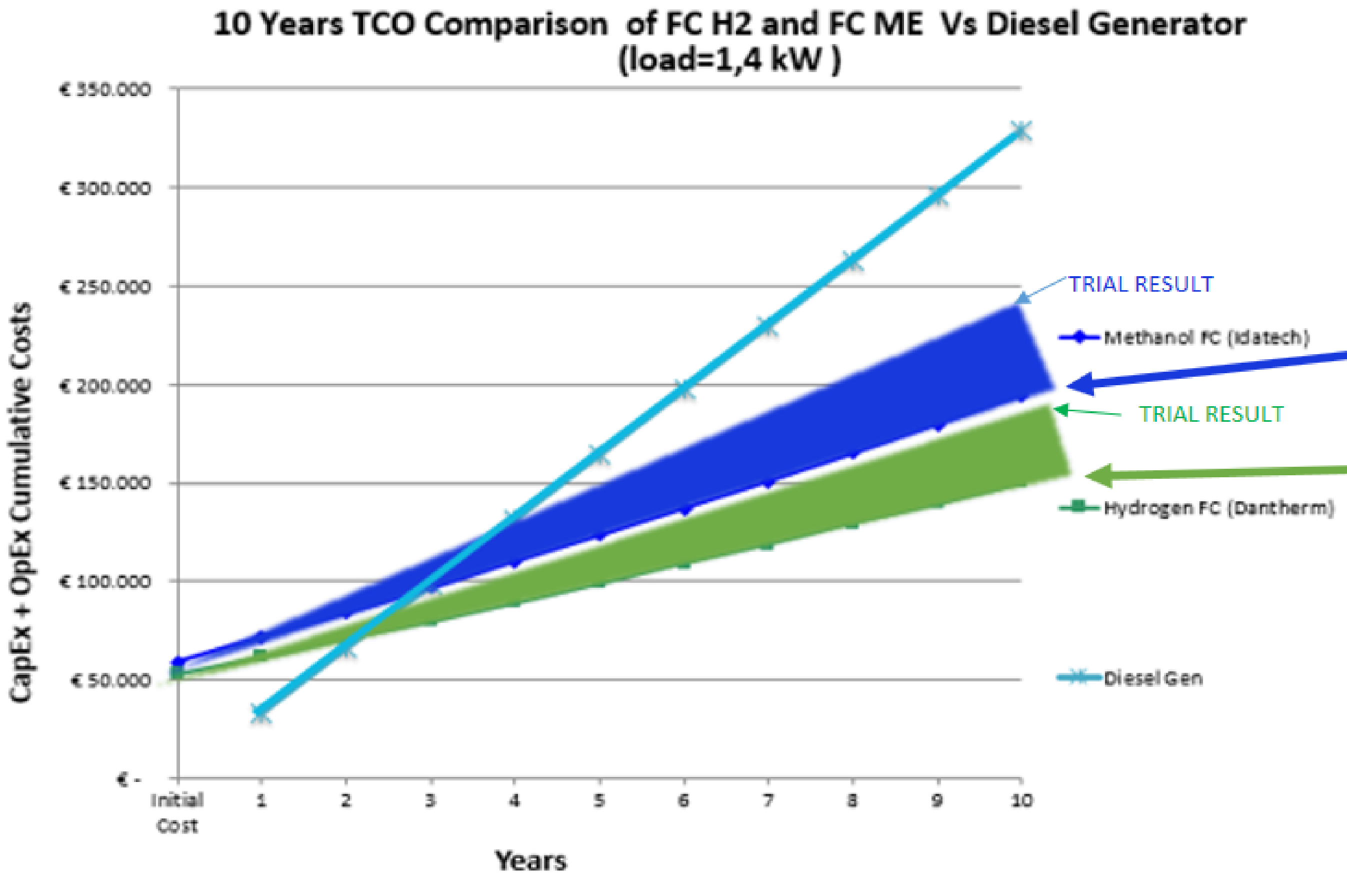
TCO analysis results

- Break-even time calculation results from the on-field tests:
  - FC H_2 vs diesel gen: break-even time in 2,5 years
  - FC Methanol vs diesel: break-even time in over 3.5 years
  - Increasing saving after break-even time



TCO analysis results

- Sensitivity analysis



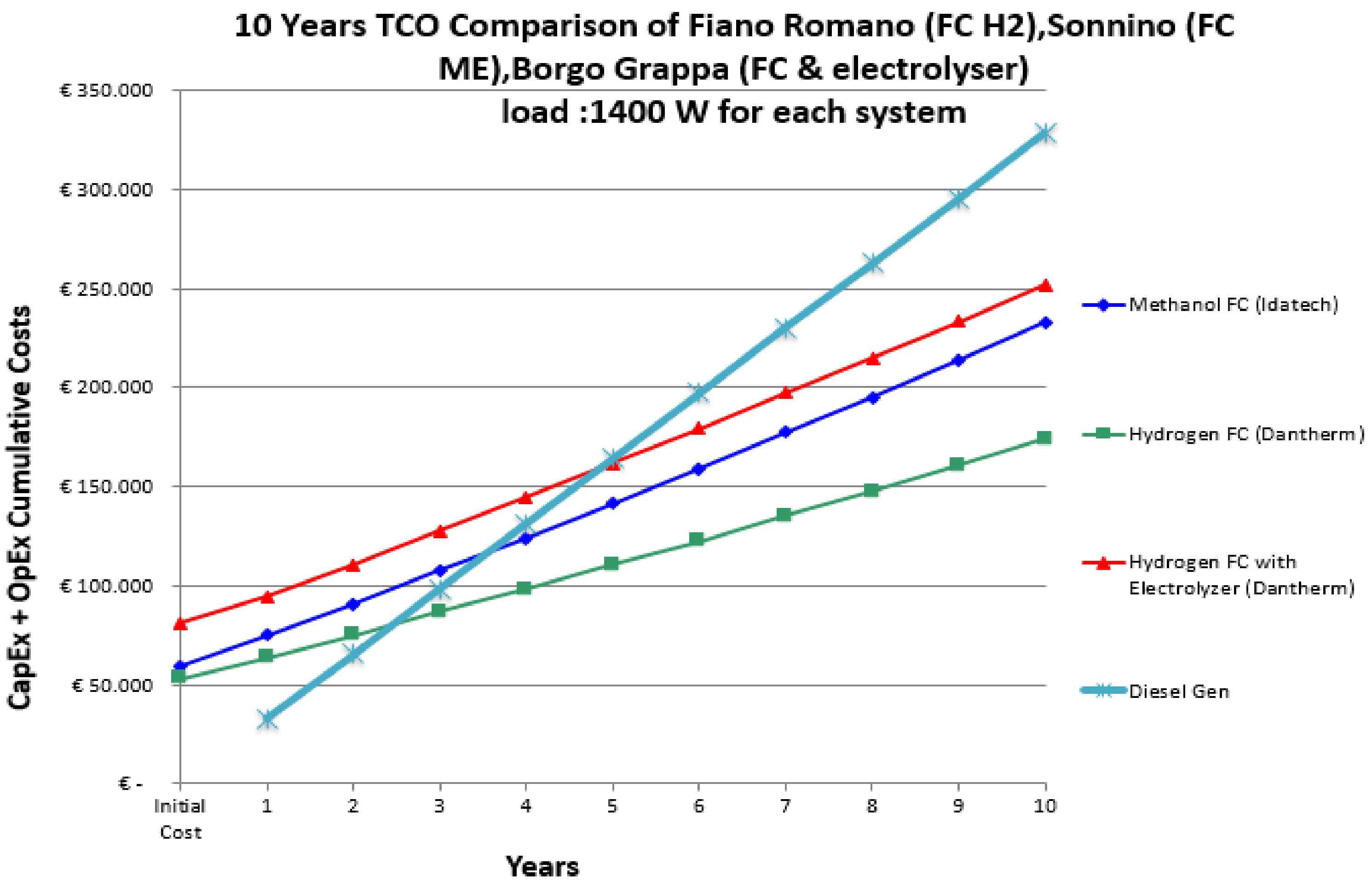
The most effective actions aimed to improve TCO :

Increase of sizing methanol tank from 225 to 450 liters

H2 reduction cost:-30% thanks to a massive deployment of FC H2 (i.e. 100 sites in country like Italy)

TCO analysis results

- Sensitivity analysis



ÖBB

Università di Roma
Tor Vergata

Hy2Rail

Development of a Modular, Hybrid Zero Emission Propulsion System to Replace Diesel Power Trains in Railway Vehicles

MESH4U ERA-NET EU project

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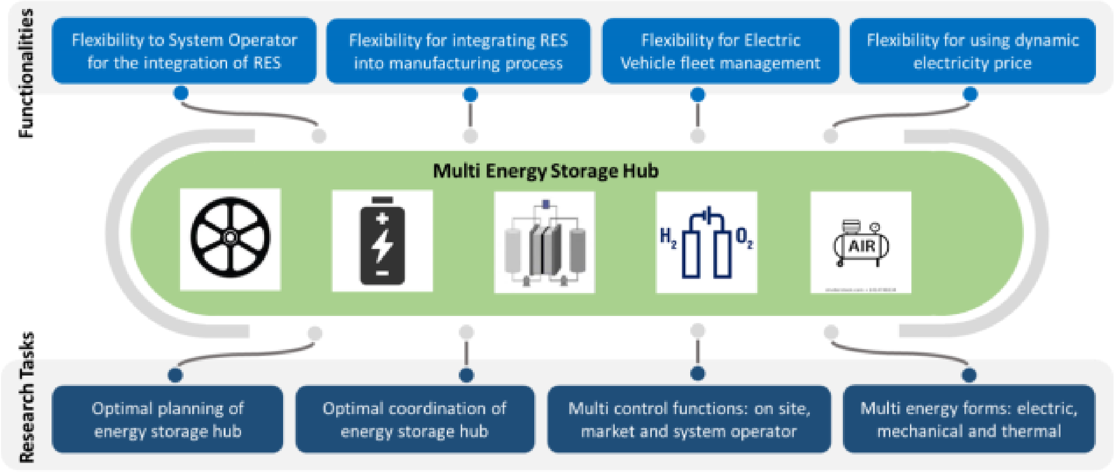

- Funded in May 2020
- Kick-off : 01/02/2021 (30 months overall)
- Total budget: 3.5M€

- Partners:
  - Poland: Electrum (leader), Wroclaw University, EU Copper Institute
  - Germany: Fraunhofer IFF, Arte Mobel, Krebs Engineering
  - Italy: University of Rome Tor Vergata (UTV), IVECO
  - Switzerland: Swiss Federal Institute of Technology in Lausanne (EPFL), GridSteer, Romande Energie

- Objective: development of a multi-energy SMART-HUB, based on multiple energy storage technologies
- The italian partnership will focus specifically on the sustainable mobility problem

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