Hybrid Renewable energy systems for rural areas

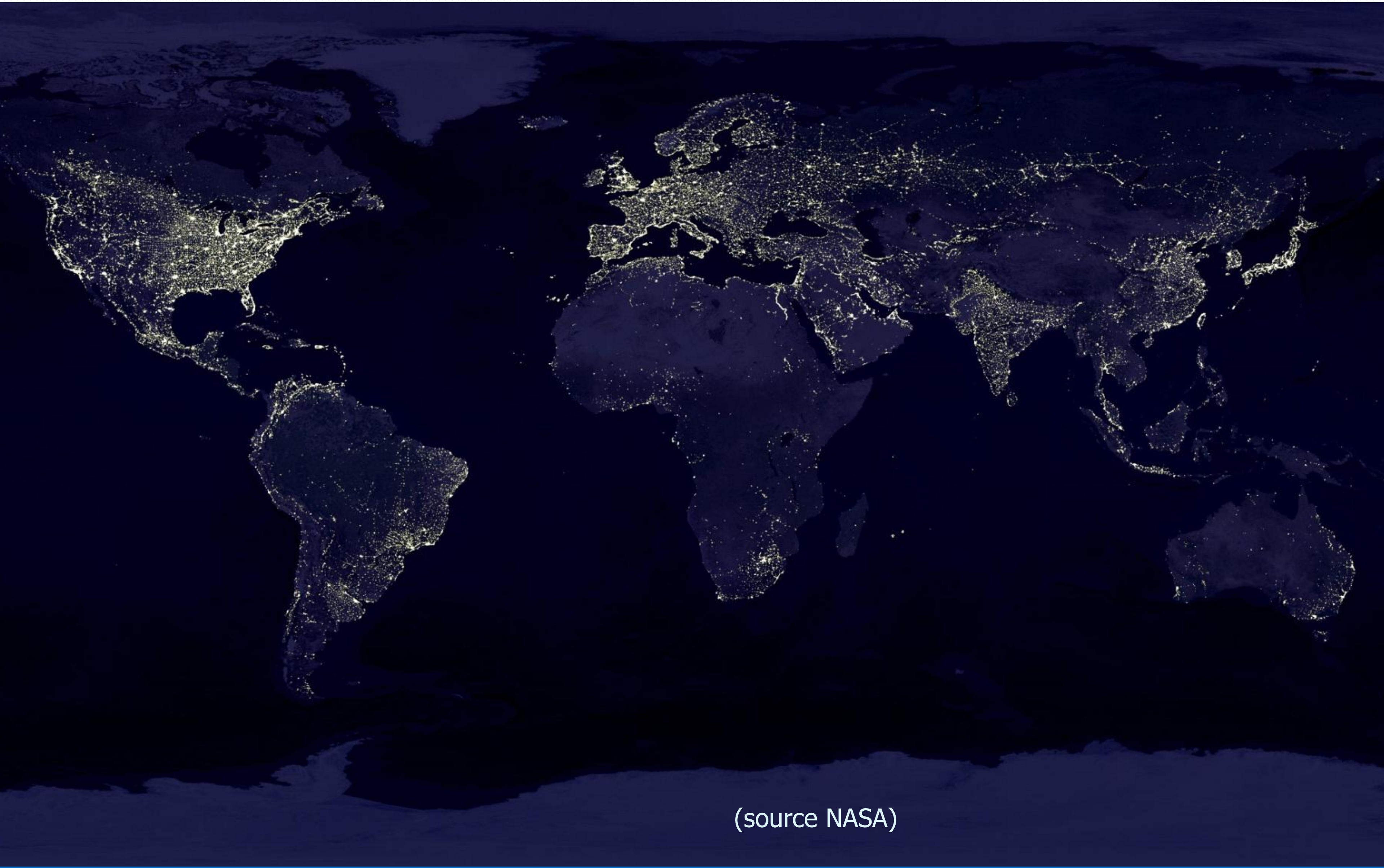
 

Abdelkader OUTZOURHIT
Centre de Développement de la Région de Tensift (CDRT)
&
Cadi Ayyad University,
Marrakech-Morocco
Contact: aoutzour@uca.ma

Outline

- Introduction
- RE Sources
- Hybrid Systems: definitions
- Why Hybrid systems?
- Topology of Hybrid systems
- The PV-Wind hybrid power plant of Elkaria
  - Description
  - Monitoring
  - Results and performance parameters
- Coupling Biomass with solar energy
- Outlook

Earth at Night



Introduction

- More than 1.5 billion people worldwide do not have access to electricity.
- About 80% of these people live in rural areas

Source (IEA, 2010)

- Rural electrification rates:
  - North Africa: 98%, Sub-saharian Africa, 22%

- Rural areas are characterized by small communities, dispersed villages, low consumption, long distances from the grid..

- Prospects of gaining access to the grid in the near future are low.

- By 2030, these numbers will not drop due to population growth!!

Alternative Solution: Renewable energy sources (RES)

- Rapidly deployable
- System size usually up to 100 kW

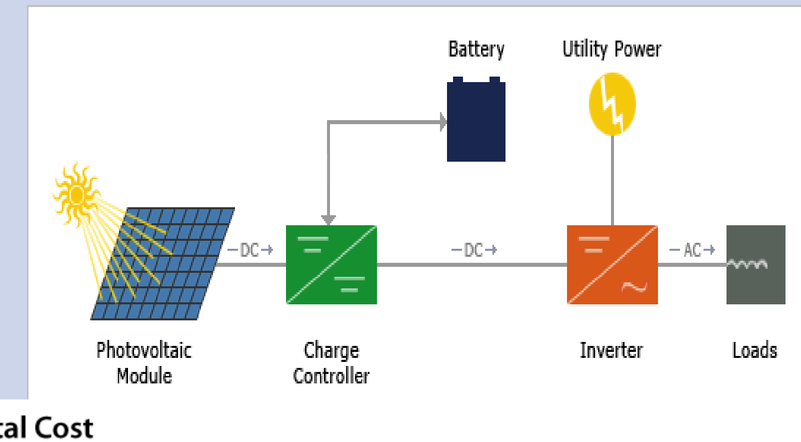
Renewable Energy Sources

Solar Photovoltaic energy (PV) ➔ DC electrical energy

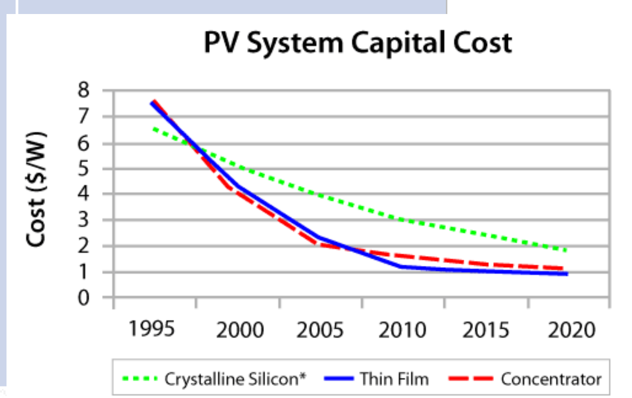
-Monocristalin Si
-Polycristalline Si
-Mono-like Si
-Thin films (a-Si, CdTe, CIGS)
Concentrated PV (site specific)



- Suitable for almost any location,
- easy to install, maintain and scale up.
- **Investment cost dropped significantly**



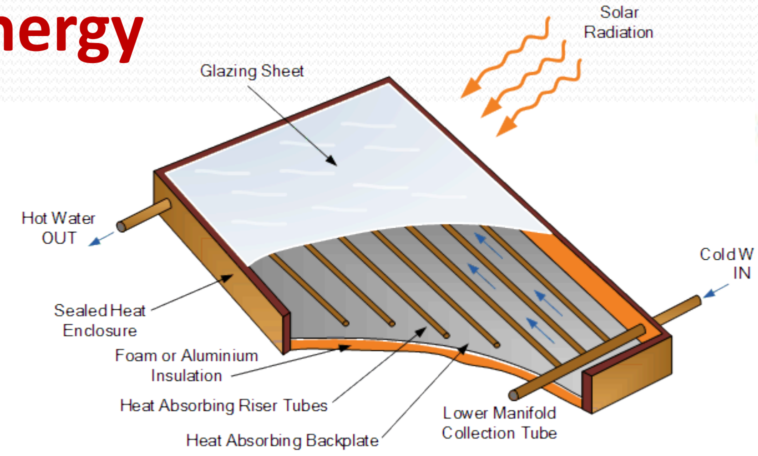
Types of PV systems
-Autonomous
-Grid connected

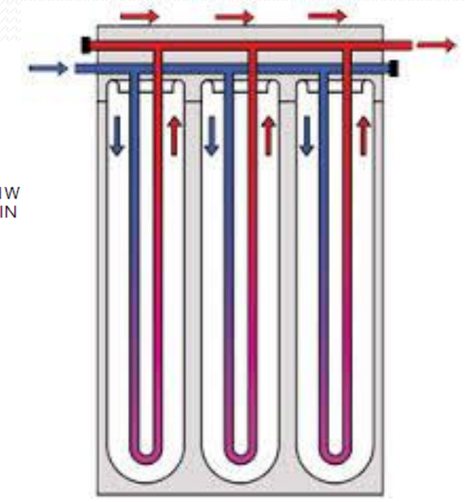


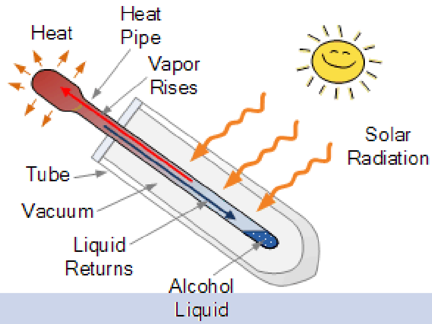
Solar Thermal Energy

- Flat –plate Panels:
- Evacuated tubes
- Direct flow
- U-pipe collectors)

Low temperatures: below 95°C (usually water heating, desalination…







Concentrated Solar Power
Higher T are attainable up to 520 °C

-Parabolic troughs
-Fresnel mirrors
-Central receivers (Solar tower)
-Solar Dishes
Possibility of providing electrical and thermal energies

Site specific technology, high DNI?

Wind and Hydro

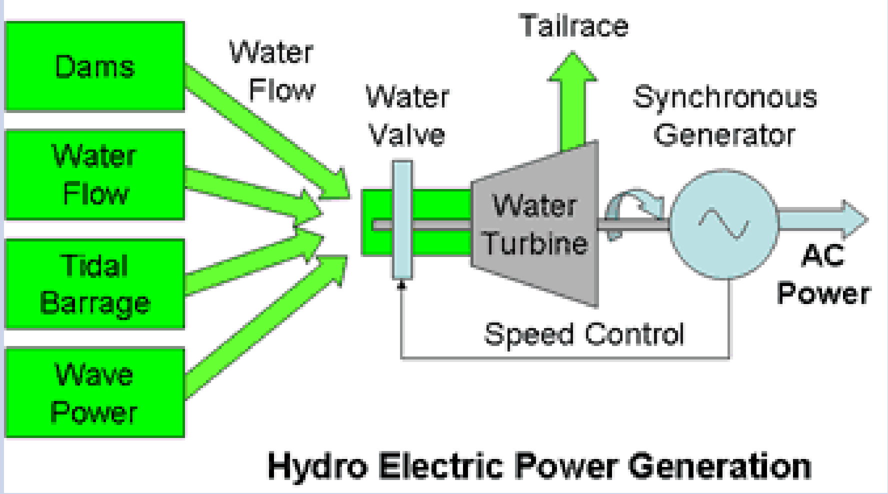
Wind energy
- Horizontal axis
-Vertical axis

Electrical energy

Strongly site specific technology

Hydroelectric power

- Mature, cheapest technology
- Small hydro (or microhydro) for isolated sites



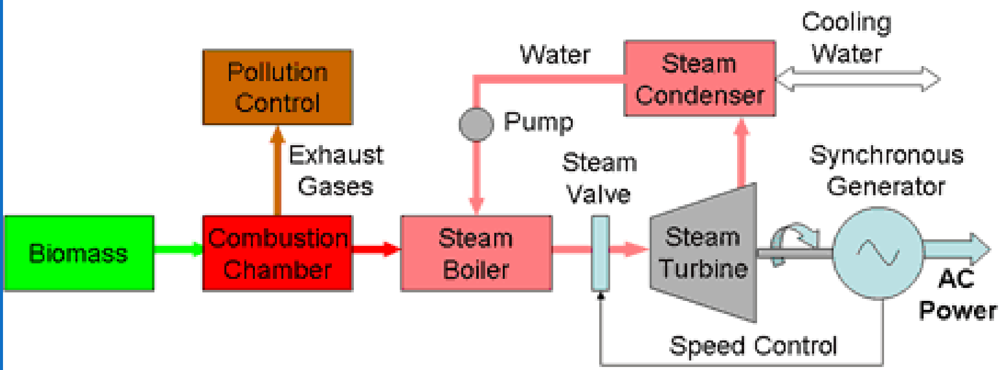
Site dependent (dams, rivers, flowing water..)

RE energy sources

Bio-energy

- Biomass
- Direct combustion
- Gasification
- Bio-Fuels

+ feed for high value-added products



Electricity Generation Powered by Biomass

- Can directly provide all three types of energy carriers: electricity, heat, and fuel (liquids, solids, and gas).
- Easily **storable and dispatchable**;

IEA World Energy Outlook 2011, "biomass and waste" accounts for 10% of global energy demand over the past decade

Strict management to be sustainable (resource depletion, monoculture and biodiversity, food security,..).

Intermittance of RE sources

Renewable **sources , especially solar (PV and thermal) and Wind are** Intermittent

→ **non-dispatchable (in the absence of storage)**
→ one RE source is unreliable

→ Use multiple RE sources and storage (Hybrid systems)

→ Use energy storage

→ Use bio-energy (Biomass, biofuels,..) as a back-up

Classification:

- Autonomous systems (remote sites)
  Used for the supply of electricity in isolated sites, or where grid extension is not economically viable.

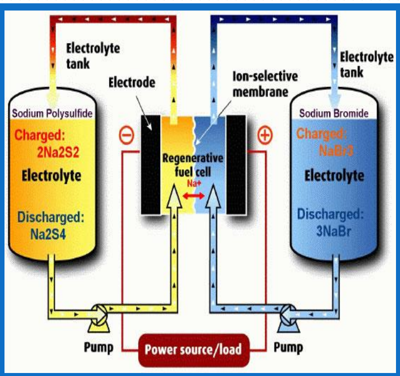
- Grid-connected systems

Energy storage

Electricity Storage

Electro-Chemical Storage (DC in-DC out)
–Lead acid batteries
- Li-ion..
– Flow batteries
Appropriate energy management to maximize the lifetime

Pb-acide or Li-ion



Flow batteries

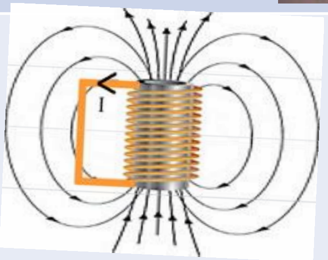
Mechanical storage (AC in AC out)
-Hydro (large scale): $W_v = \rho g h$
– flywheel: $E_c = I\omega^2/2$
– compressed air

Not yet commercially deployed

Electromagnetic
-SMES (DC-in DC out)
Superconducting inductors

$$W = \frac{1}{2} L I^2$$

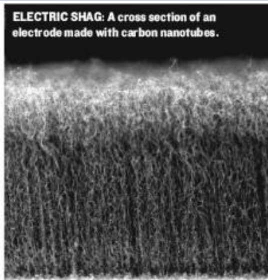
Not yet commercially Deployed (need helium or LN2 for cooling)



Electrostatic
-Super (Ultra)capacitors, DC in DC out

$$W = \frac{1}{2} C V^2 = \frac{1}{2} Q V = \frac{1}{2} \frac{Q^2}{C}$$

$$C = \frac{\varepsilon A}{d}$$



Hydrogen

Production of hydrogen

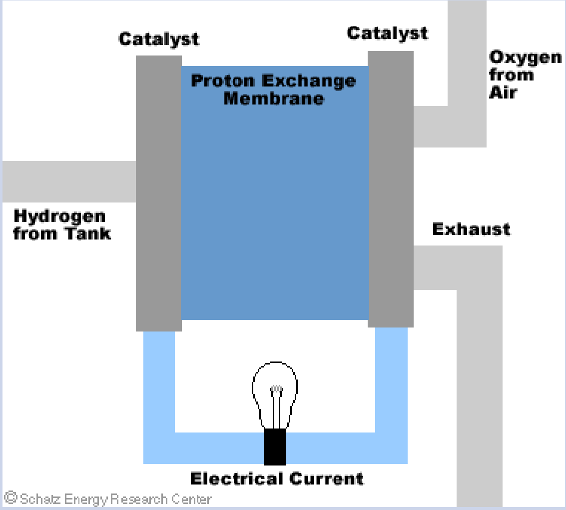
Water dissociation powered by RE (eg. Electrolysis)
➔ Hydrogen Storage problem

$H_2O(l) + energy \rightarrow H_2(g) + O_2(g)$

Fuel Cells

– PEM(proton exchange membrane)
- Alkaline
- Direct Methanol
- Solid Oxide
– Phosphoric Acid (PA)
– Molten Carbonate (MC)

Life-time, cost, security



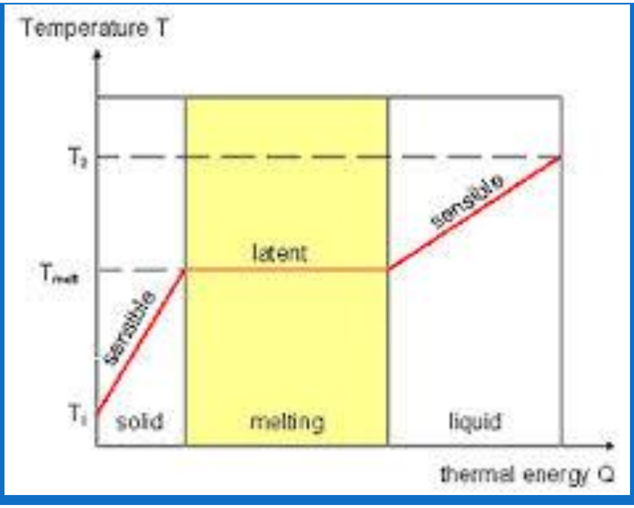
$H_2(g) + O_2(g) \rightarrow H_2O(l) + energy$

Thermal energy storage

Sensible Heat

Heat is stored as an elevation of the temperature
$Q = m\, c_p\, \Delta T = \rho c_p V\, \Delta T$

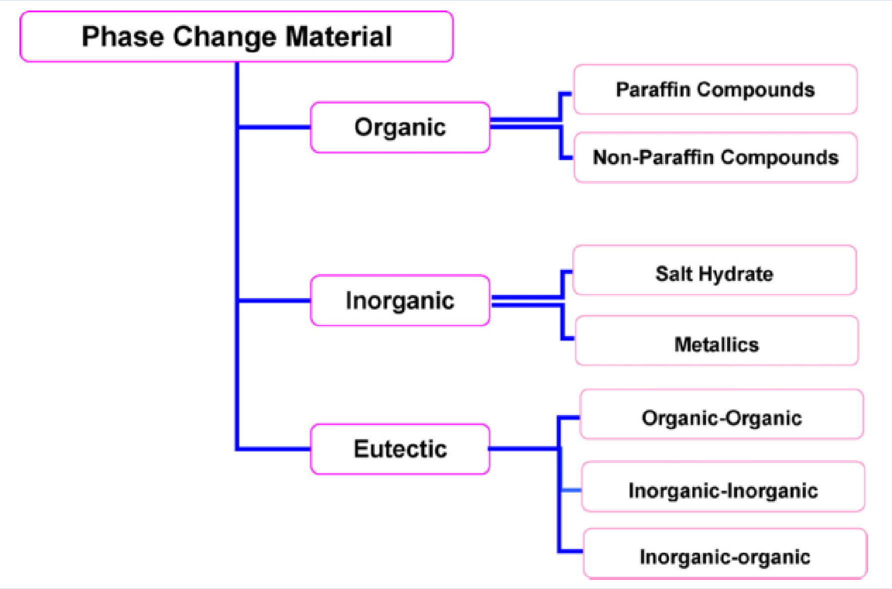
Limited by the maximum temperature supported by the material



Latent Heat

Phase change Materials (PCM)

- a suitable PCM with its melting point in the desired temperature range,
- a suitable heat exchange surface, and
- a suitable container compatible with the PCM.



Hybrid Systems

These are energy systems that combine:

- Different energy sources (renewable energy sources and conventional sources)

- Different types of loads: AC and DC

- Various energy storage elements (batteries, hydrogen, super-capacitors ..)

- Several forms of energy (electrical, thermal)
- Different types of fuels ..

Why Hybrid systems?

-Overcome the limitations associated with each source (eg intermittence of ER sources),

-Reduce the variability of a single source (i.e. wind or sun)

- Security of supply and demand satisfaction ,

- Increase in reliability: (complementary sources, multiple sources and storage systems)

- Decrease in the size of the storage system (still expensive)

- Production smoothing ,

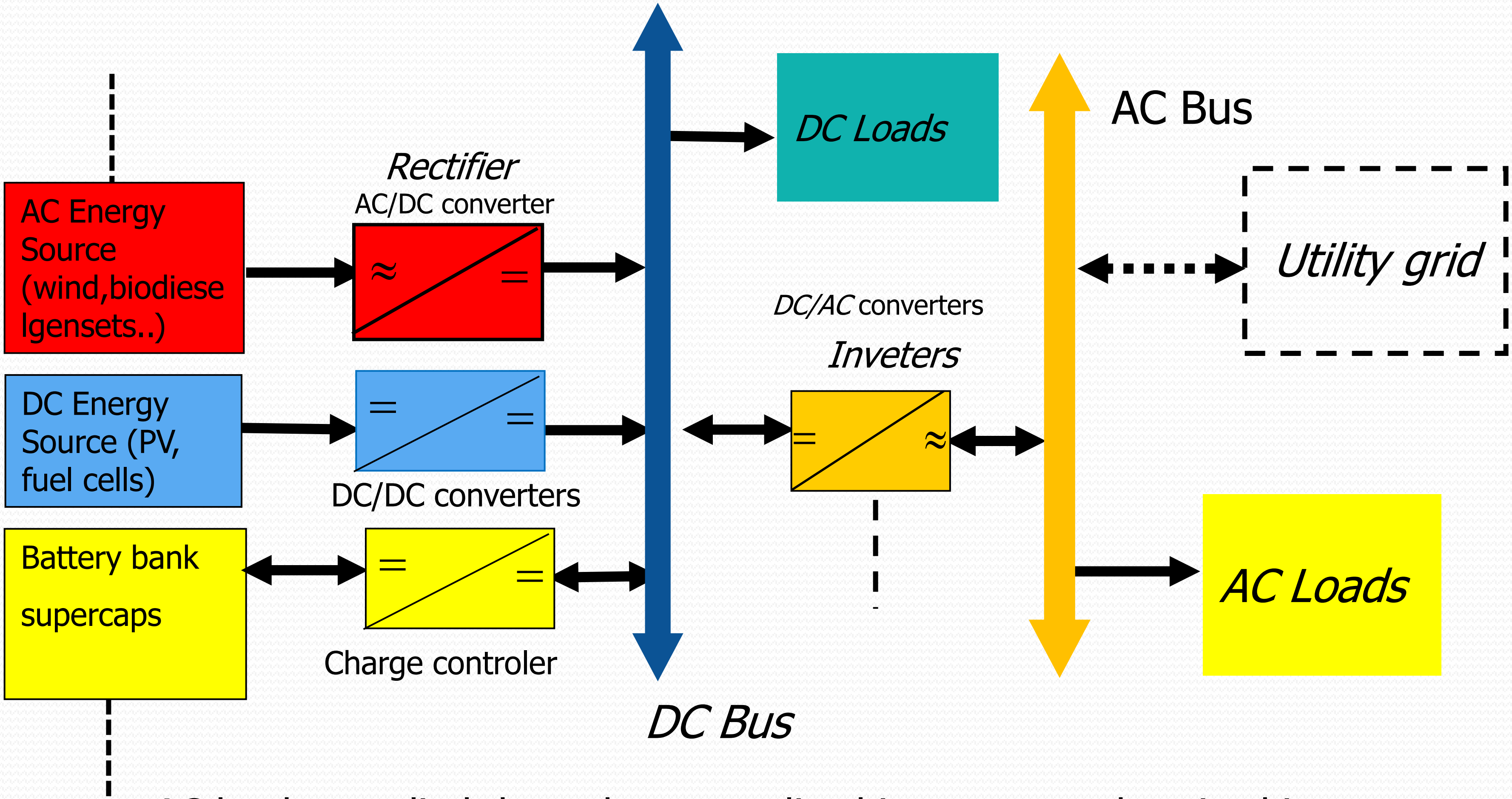
- Reduction of emissions ..

Hybrid systems Topologies

Parallel architecture

1. DC-Coupling

Sources and storage devices connected to **DC Bus** through appropriate (AC/DC, DC/DC.) converters



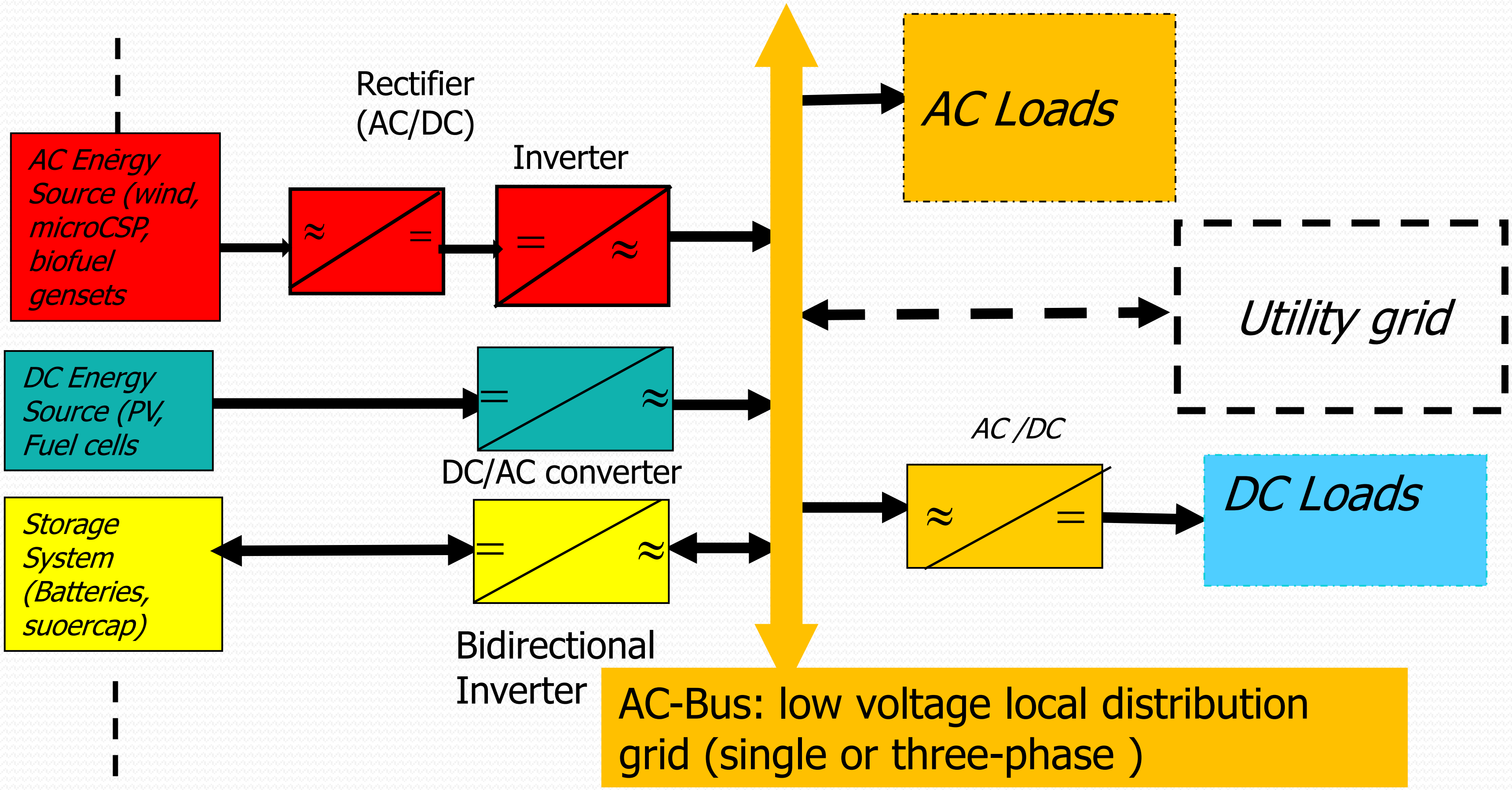
•AC loads supplied through a centralized inverter, synchronized inverter

Parallel architecture

2. AC coupling

AC, DC generators, storage media and loads are coupled on the AC-bus

➔ Needs synchronized inverters



Applications of Hybrid Systems

•**Decentralized electrification**: for remote isolated villages (off-grid mini-grids)

•**Water Resource Management** (desalination & water pumping systems..) in isolated and rural areas.

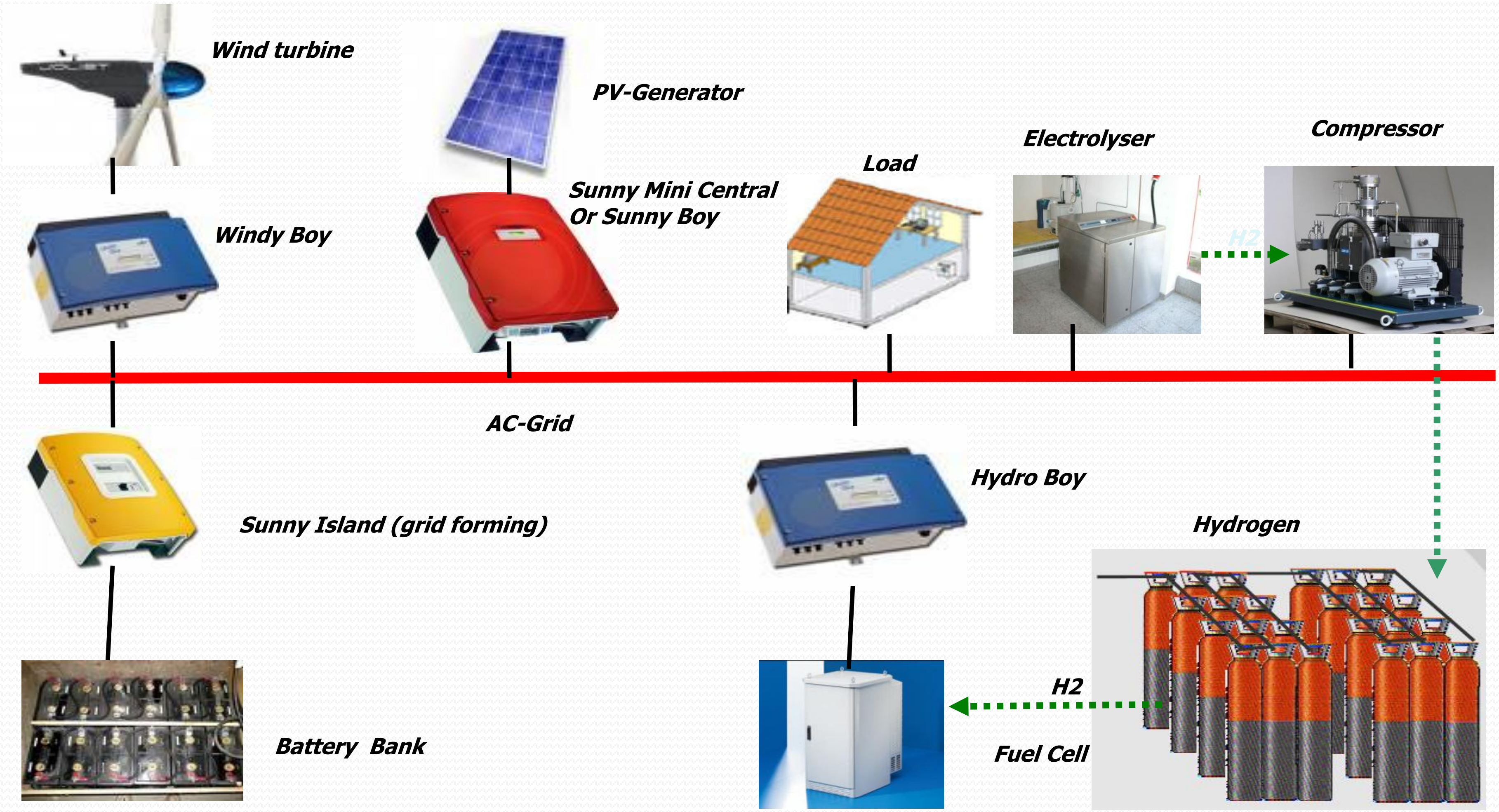
• Distributed generation in a conventional utility network

•Isolated or special purpose electrical loads (Communication relays, military installations,..)

Examples of Systems

PV-diesel-genset-battery
Wind-diesel genset-battery
PV-wind-battery
PV-wind-diesel-battery
PV-fuel cell
PV-wind fuel cell…

PV-wind-fuel cell hybrid system



Panahandeh B., Bard J., Outzourhit A., Zejli D. *Simulation of PV–Wind-hybrid systems combined with hydrogen storage for rural electrification.* International Journal of Hydrogen Energy, 2011

HYBRID PV-WIND power plant of Elkaria

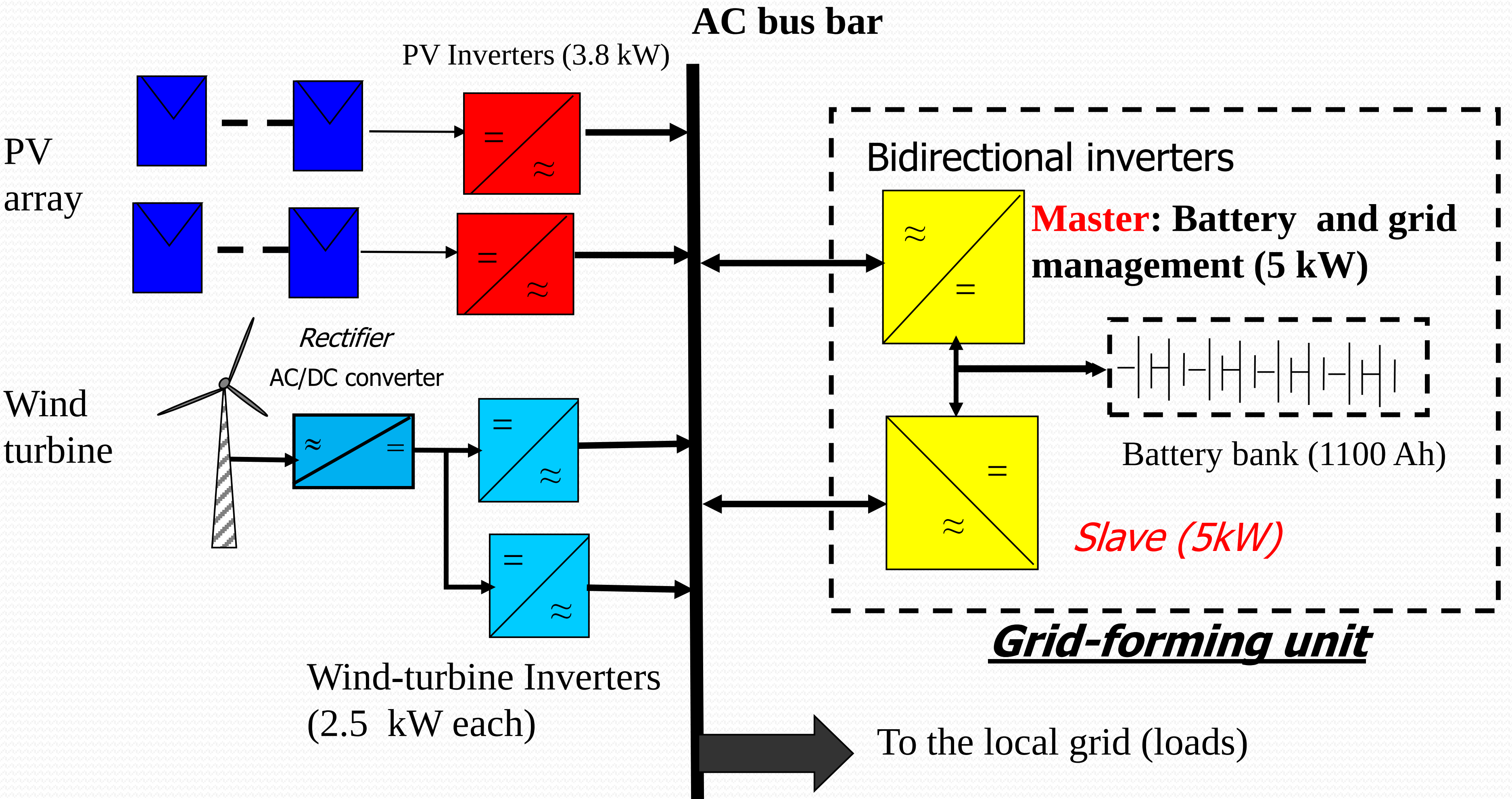
Essaouira region *(Source: Hyress project)*

PV array	7,2 kWp
Wind turbine	5 kW
Battery bank	1100 Ah (C_{100})
Local mini-grid	Single phase(*230 V*, 50 Hz) 2 km
Number of households	16

Topology of the Hybrid Plant of ELKARIA

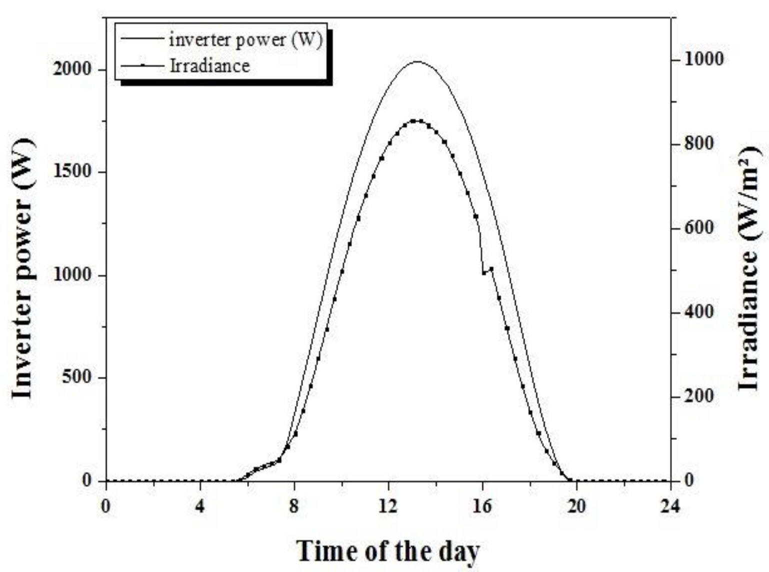
- **AC-Coupling**

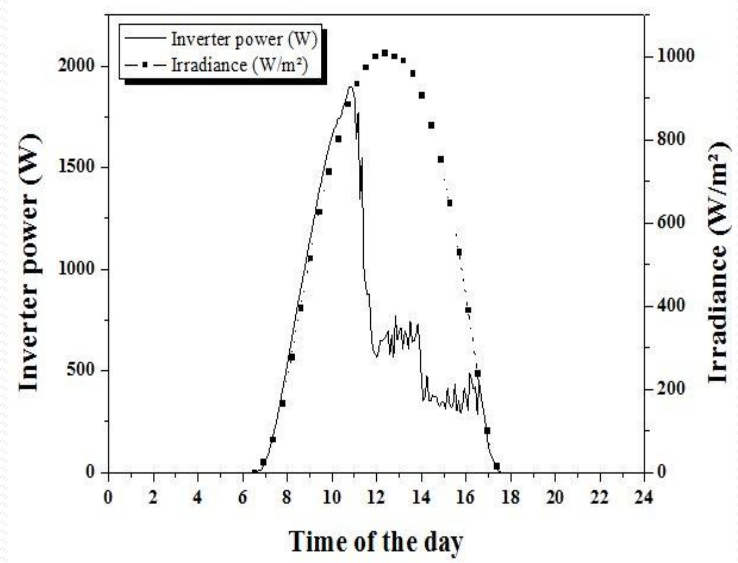
➔ All generators are coupled to the AC distribution grid via inverters

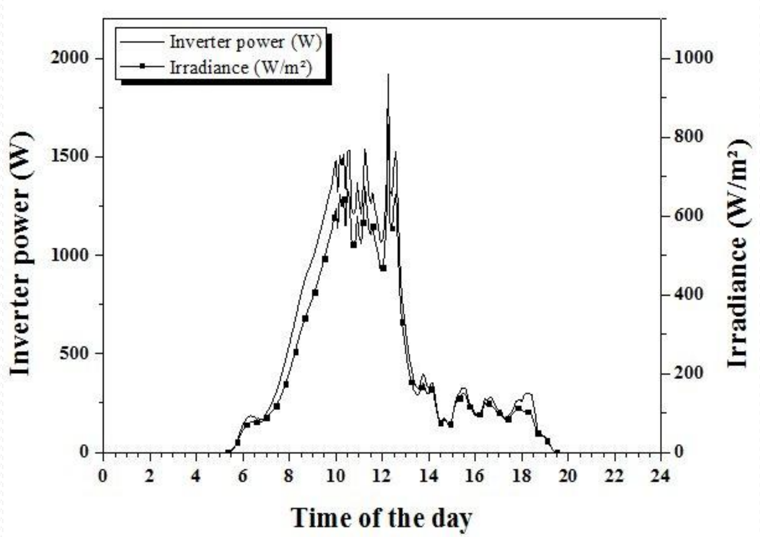


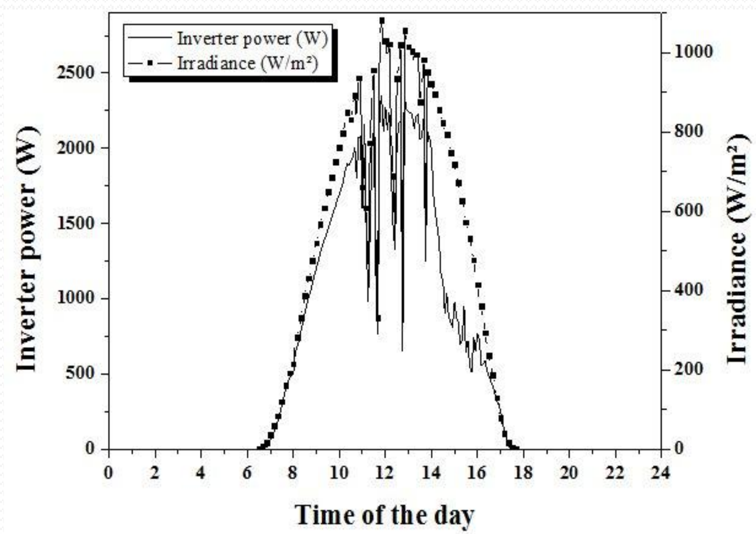
Monitoring of the Plant

Monitoring of the PV plant..

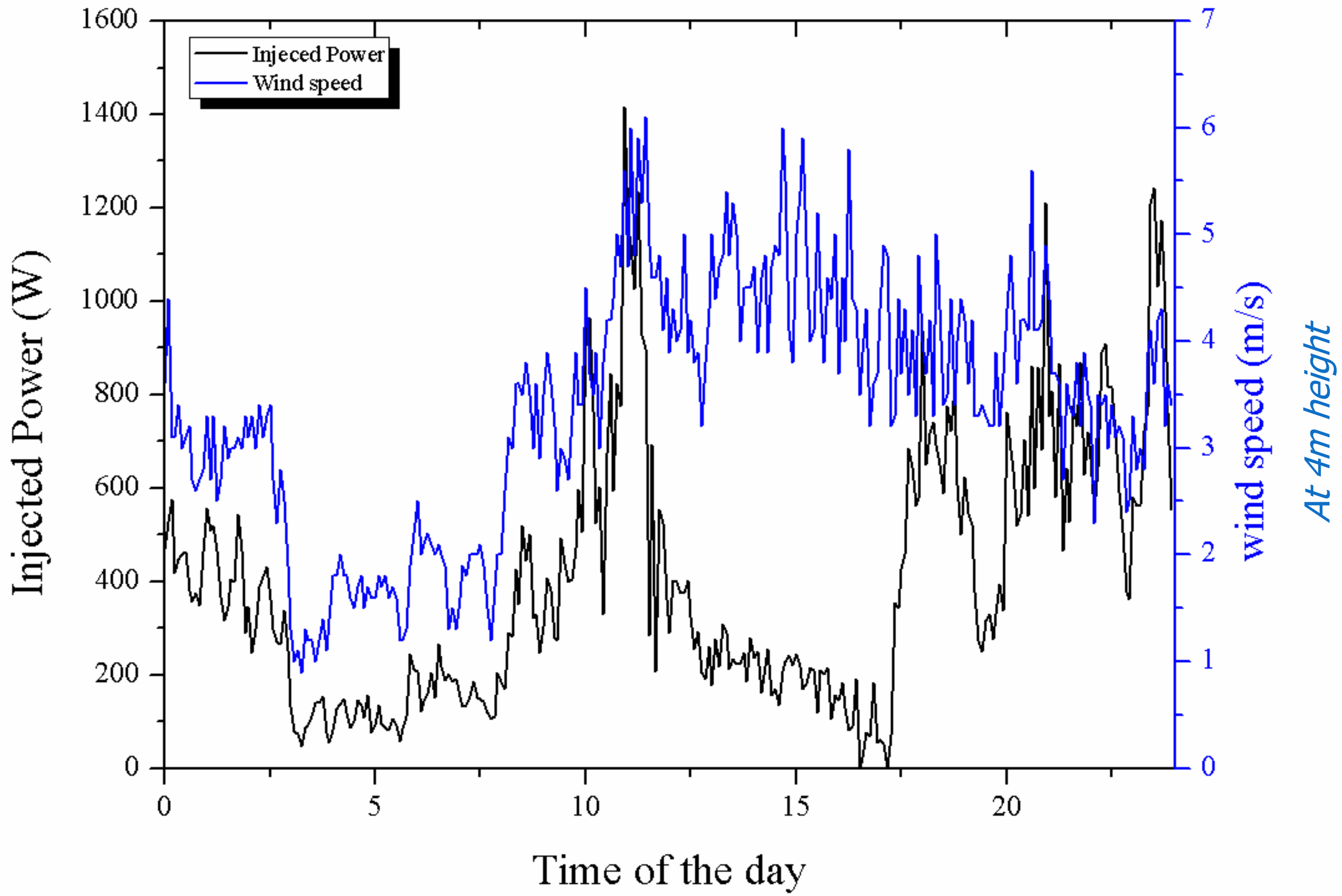








Monitoring of the wind plant..



Total wind energy fed to the grid: 19 kWh
(2 inverters)

Performance Parameters

1. The reference yield (Y_R)
Y_R= H_t (kWh/m²) / G_{ref}(kW/m²) (number of peak sunshine hours)
H_t Solar insolation
G_{ref} (kW/m2)= array reference irradiance = 1 kW/m².

2. The array yield Y_A
Y_A= E_{PV} (kWh)/P_{STC}(kWp) (kWh/kWp or hours),
Number of hours that the PV array would need to operate at its rated power to provide the measured (DC) energy.

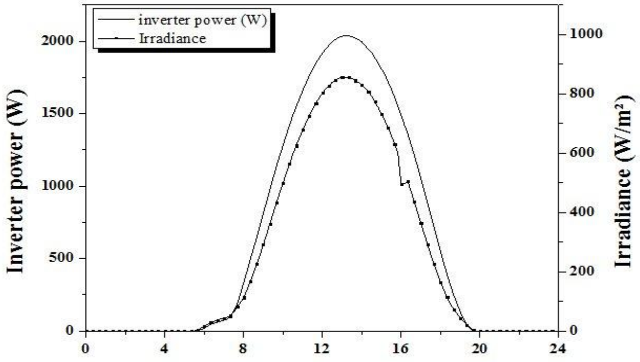
3. The final yield Y_F
Y_F= E_{sys} (kWh)/P_{STC}(kWp) (kWh/kWp or hours)
E_{sys}=total energy consumption (DC and AC loads) or in our case= Total energy fed by the inverters to the grid

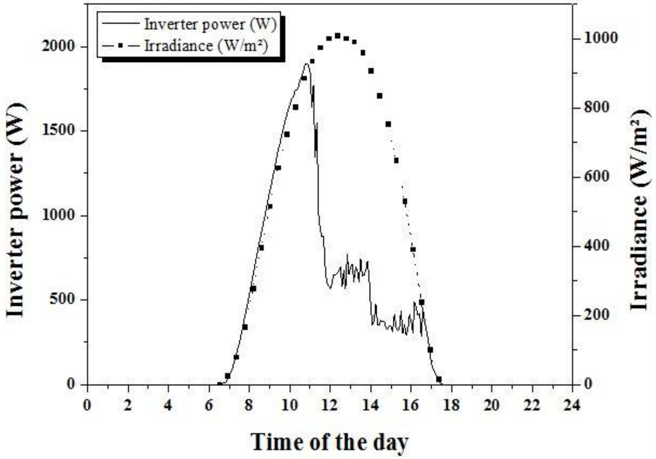
4. Performance Ratio: P_R=Y_F/Y_R
Ratio of the actual produced PV energy (fed to the local grid in our case) and the expected production over the same time period
This parameter can inform on the overall losses in the system

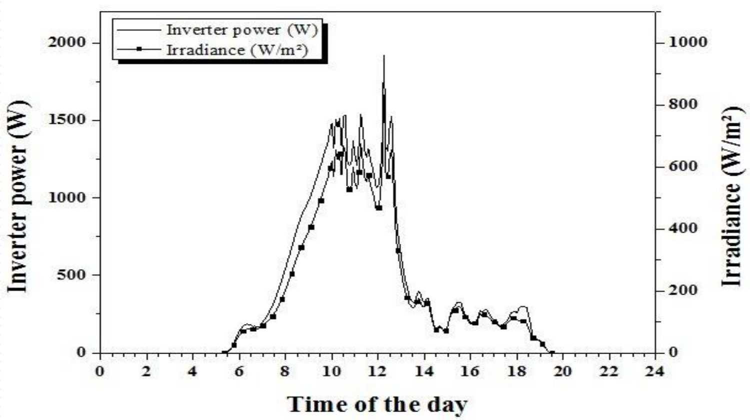
Losses
5. Array capture losses: L_C= Y_R-Y_F
6. System losses: L_S = Y_A – Y_F

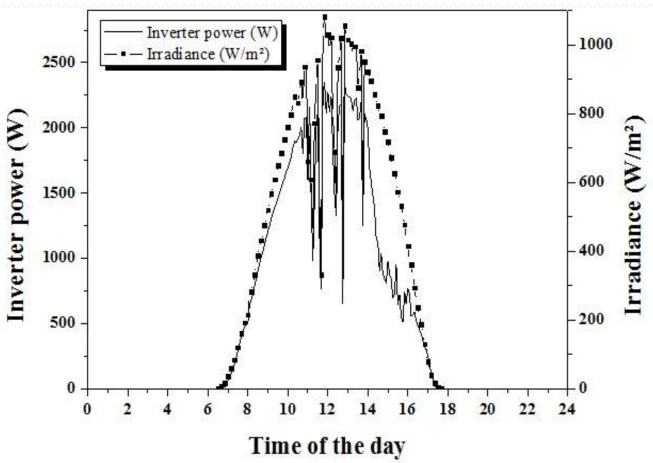
Performance Parameters for typical days

	E (kWh)	Y_R (h)	Y_A (h)	Y_F (h)	L_S (h)	L_C (h)	P_R (%)
D_1	30.3	6.0	5.0	4.2	0.8	1	70.2
D_2	16.3	3.4	5.6	2.2	3.4	1.2	66.7
D_3	15.9	6.6	11.0	2.2	8.8	4.4	33.5
D_4	24.9	6.0	10.4	3.4	6.9	2.8	55.4





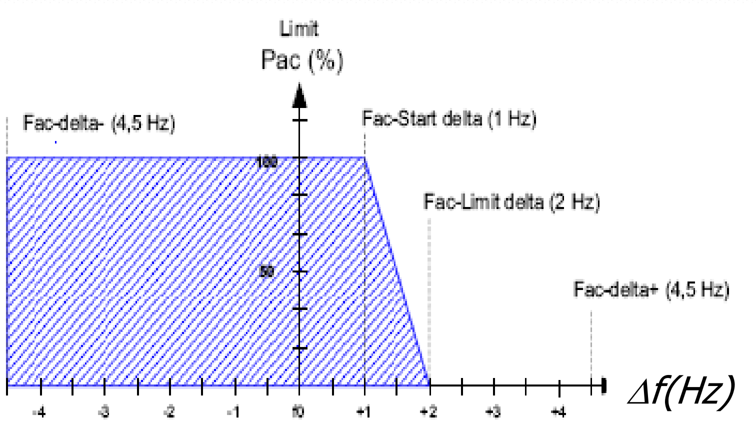




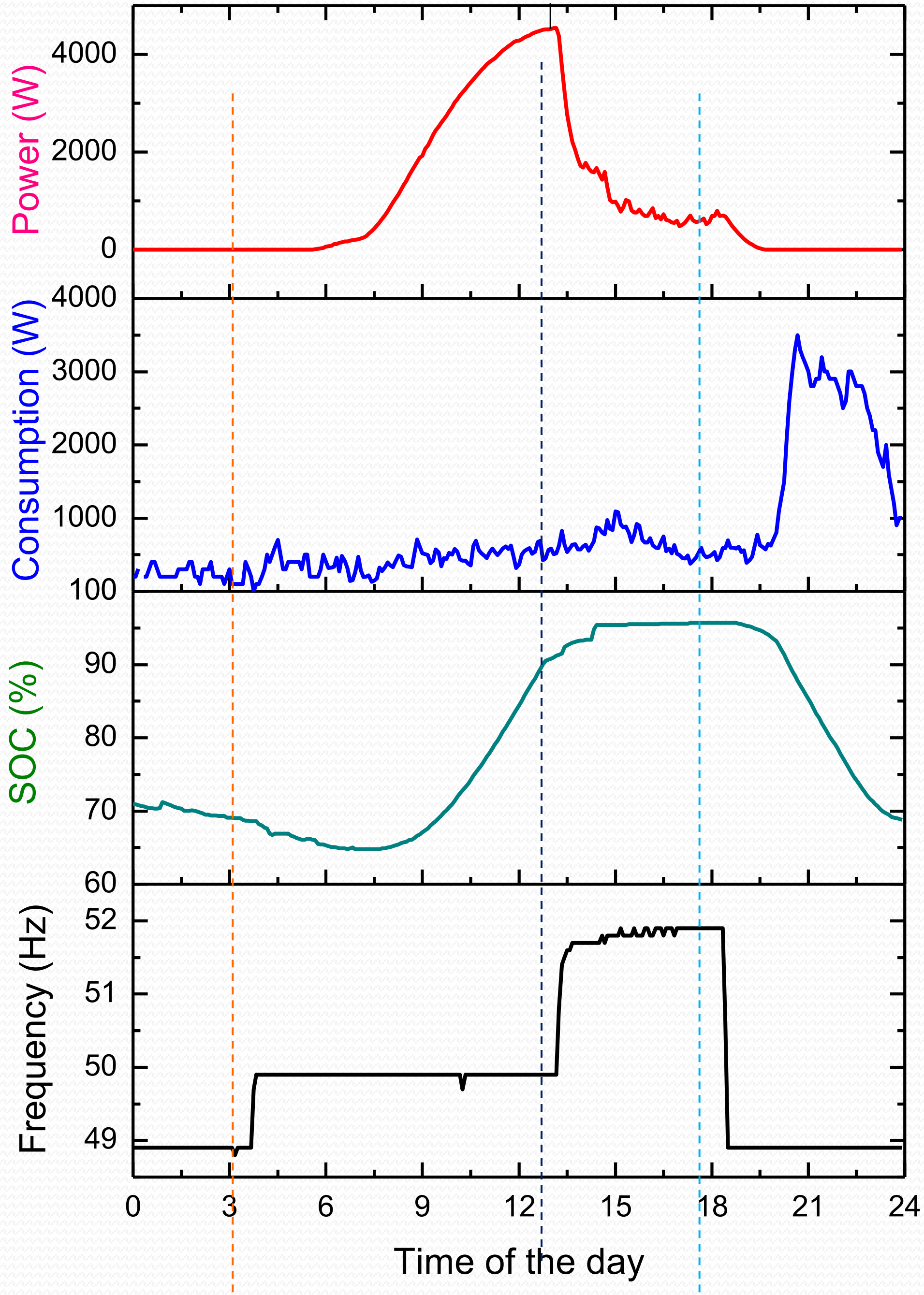
•If generated power greater than demand (Pg > Pc), the frequency is increased beyond 50 Hz

• If Pg < Pc, the frequency will drop below 50Hz

•Added control parameter: SOC

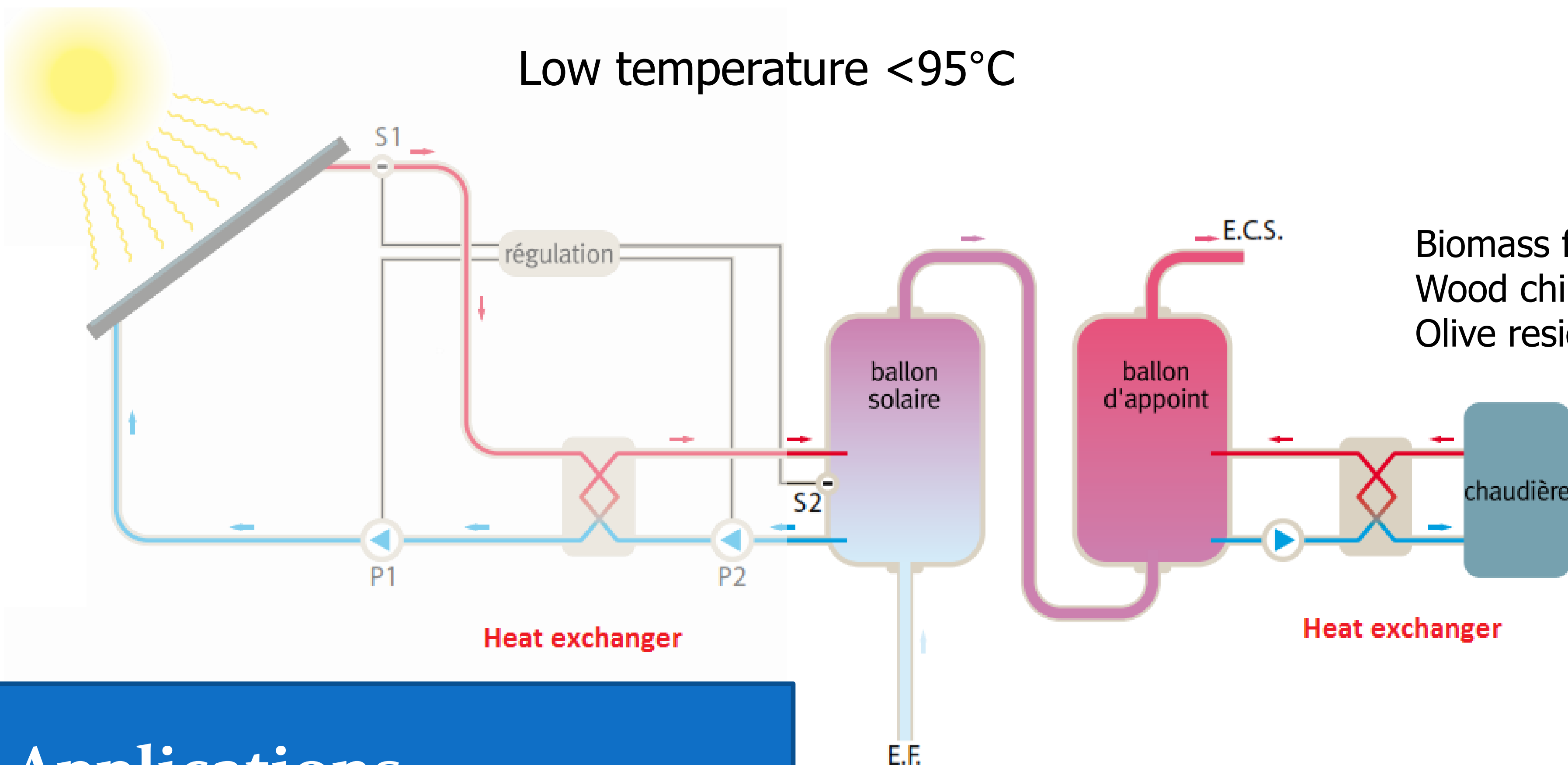


Source: SMA



Hybrid Solar thermal/biomass systems

Low temperature <95°C



Biomass feeed
Wood chips,
Olive residus,

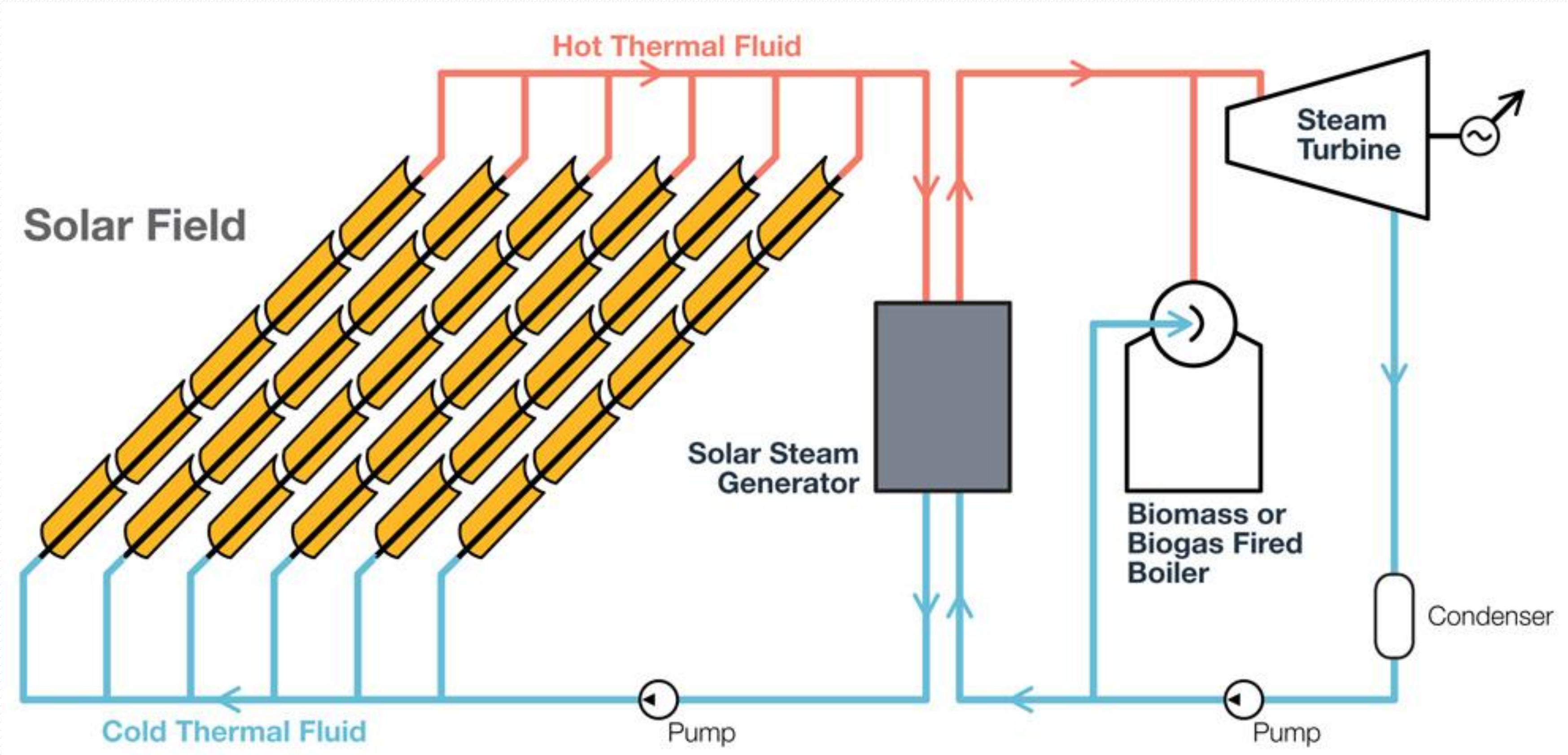
Applications

- Solar water heating/domestic/destric heating
- Production of Process heat
- Desalination

Biomass is used to supplement the solar field at night and during cloudy days

- Series operation, solar is used to pre-heat wate

Hybrid CSP/biomass power plant

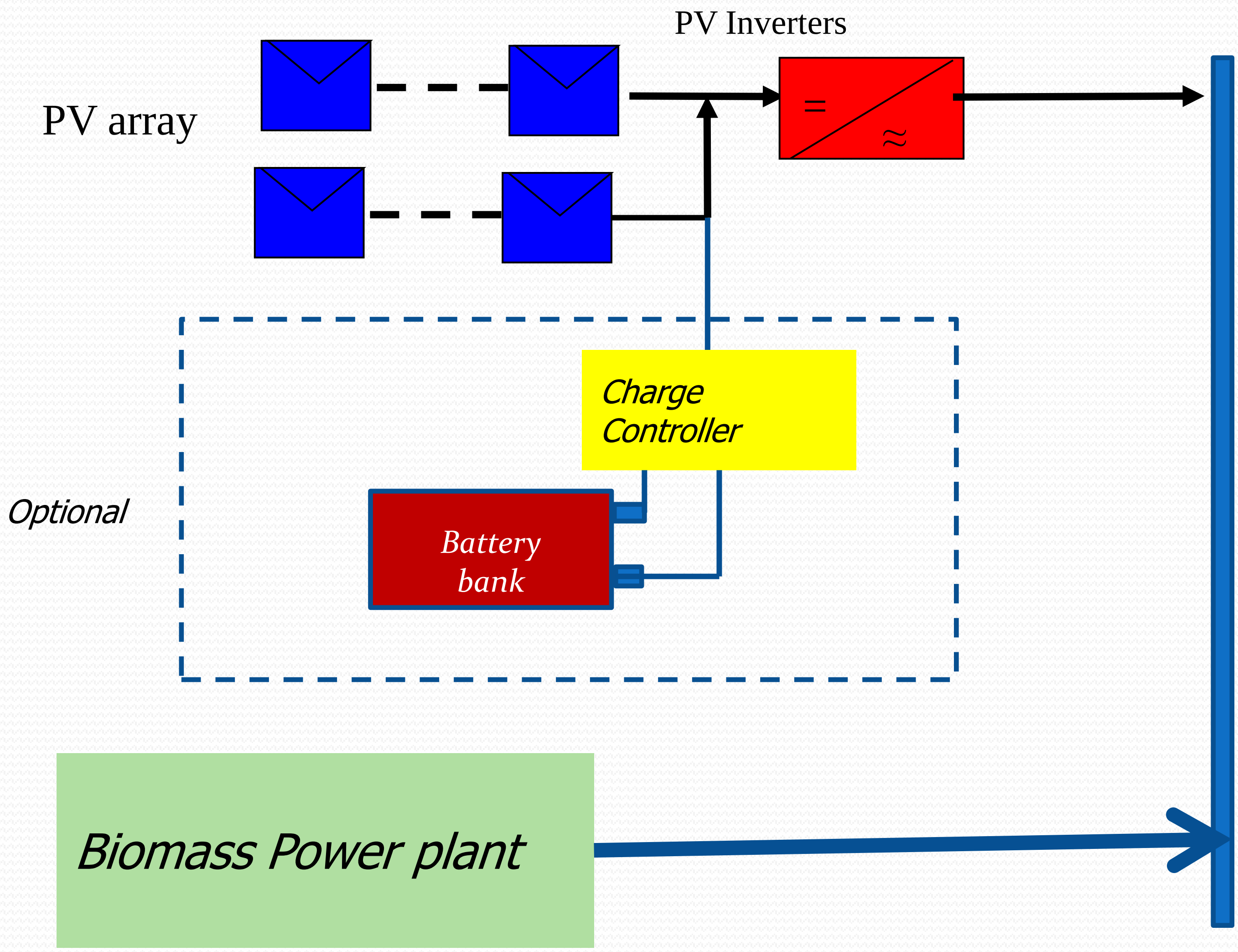


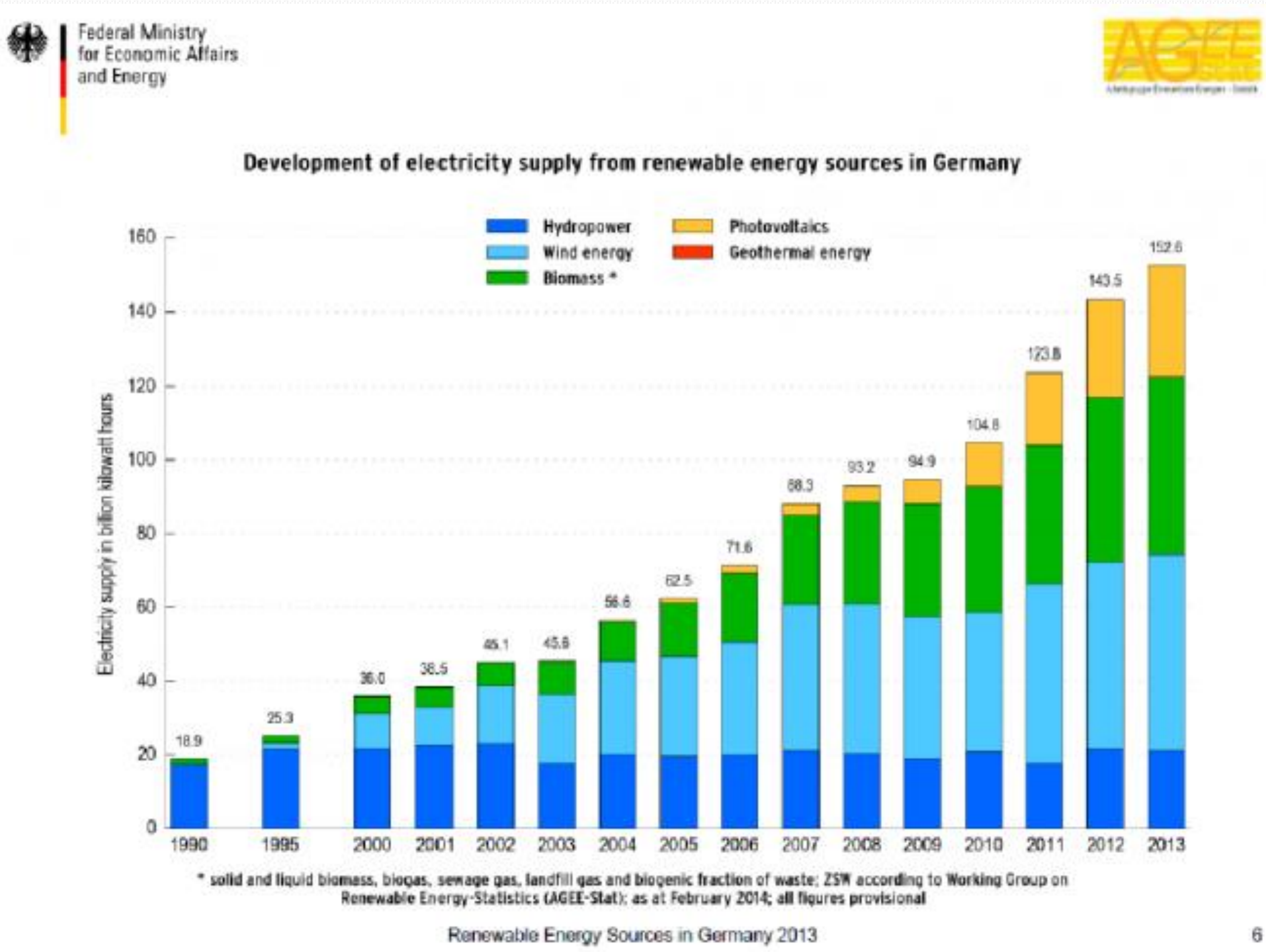
Advantages:

- Reliability,
- No need for energy storage
- Can be down-scaled for small communities or industrial uses by using MicroCSP

Recent Hybrid plant: Borges (Spain)
Biomass: 36 MW
Solar CSP: 22.5 MW

Hybrid PV/Biomass power plant





- Biomass will represent nearly 2/3 of Germany's renewable energy consumption by 2020.
- Source of energy and also provides food and high-value materials

Acknowledgements

Special Thanks to:

- EU
- CNRST (Driss Zejli)
- Cadi Ayyad University

- **PhD Student: Amine Elfathi**

  Monitoring, energy management and dynamic modeling of the Hybrid Plant of Elkaria Village