Aree Produttive, Aree Pro-Adattive

ENER | Efficientamento energetico sostenibile e comunità energetiche per le aree industriali

Sustainability and efficiency criteria for territorial energy systems

a cura di
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Aims of the lesson

a. provide the main references to begin to understand the criteria of environmental sustainability and efficiency in territorial energy systems and facilitate (for the students who are interested) the autonomous study of the topics considered

Sustainable energy efficiency is the main factor for a technician/professional/planner to contribute to a sustainable development

b. some exemplary energy systems are described both to better understand the concepts exposed, and to have some indications on possible solutions

(In the nature) There is no such thing as a free lunch

Barry Commoner

But we can decide how much to use them and how to distribute them

Sustainable territorial energy systems
Renewable and non-renewable energy and waste absorption

What I mean by territorial energy system

- set of elements interrelated by processes of energy production and consumption
  - ✓ electrical network + boiler + hot water users (artificial system)
  - ✓ mining, production and supply chain of fissile material + nuclear plant + electricity (and thermal) energy users + radioactive waste treatment and disposal chain (hybrid system)
  - ✓ marine / lake basin and coastal territory (natural system)

A territorial energy system is sustainable when:

1. makes use of renewable energies (sun / wind / water / biomass) not exceeding their availability (only for biomass and soil)
2. makes use of non-renewable energies (fossil fuels and nuclear energy) not exceeding the capacity of the socio-economic and territorial systems to promptly replace them
3. makes use of renewable and non-renewable energies not exceeding the capacity of the environment to absorb their solid (radioactive waste and ashes from coal-fired power plants, accumulators for electricity, ...), liquids (waste water from thermal plants, …) and gaseous (gases harmful to health (microparticulate, ozone, ...) and climate-altering gases) wastes

Energy efficiency and first two laws of thermodynamics

- the first two laws of thermodynamics describe the relationships between thermal energy and other forms of energy and how energy affects matter
- they also help to understand many aspects of our life (see the concept of entropy)

The First Law of Thermodynamics (extended meaning)

- energy cannot be created or destroyed and the total quantity of energy in an isolated system remain the same
- as energy is transferred or transformed, more and more of it is wasted
- in an energy conversion the thermodynamic efficiency is given by the relationship between the "work / service" supplied and the energy used. Eg. Water heater
  - electric (95-100%)
  - gas plant with heat recovery (110-120%)
  - heat pump (300%)
  - solar thermal (30-90%)

Energy efficiency and first two laws of thermodynamics

The Second Law of Thermodynamics

- is about the quality of energy
- the quality of energy is given by its capacity to be reversible and to perform work and its use depends on the technological possibilities
    1. electric energy
    2. potential (gravity) and kinetic (mechanical) energy
    3. high temperature thermal energy
    4. radiant and biochemical energy
    5. low temperature thermal energy (and cooling energy)

Now we can start to enter in the “world” of sustainable energy efficiency

Energy efficiency and relationship between energy production and use

Exergy (anergy) of a territorial energy system

- is the maximum fraction of primary energy (fissile, coal, solar, chemical, ...) that can be converted into mechanical work by means of a reversible machine
- it is conserved in reversible processes and decreases in irreversible processes
- anergy is the part of energy that in an irreversible transformation is transformed into heat

It is necessary to use the type of energy that has the level of quality closest to the needs of use

- **if energy is not needed, do not use it** (it is a “waste reduction”)

- electrical, chemical and mechanical energy for mechanical works
- biochemical energy (man and animals) for easy works
- high temperature thermal energy for high temperature heat needs
- low temperature thermal energy for low temperature heat needs

Energy efficiency and life cycle of materials, structures and plants

- environmental sustainability also refers to the materials used for the construction of energy plants, systems and infrastructures: silicon, rare materials, special steels, concrete, ...
- to measure and evaluate environmental sustainability it is necessary to consider the environmental impacts of all the stages of the life cycle of such plants, systems and infrastructures
- from raw material extraction and processing (**from cradle**), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (**to grave**)
- for assessing environmental impacts associated with all the stages of the life cycle the method called **Life cycle assessment (LCA)** is used

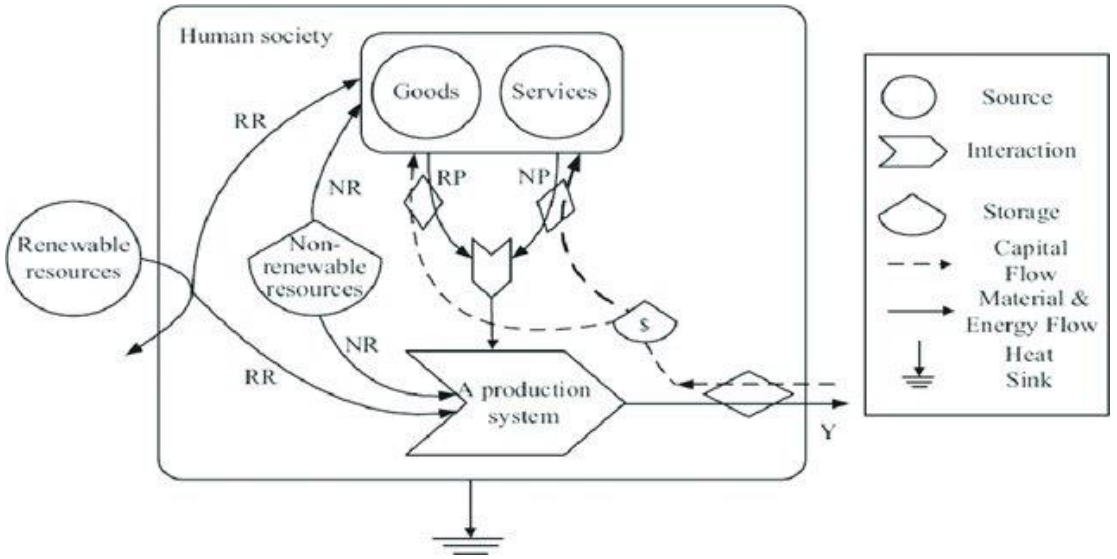
Energy efficiency and embodied energy: the Emergy concept

- in the LCA of energy plants, systems and infrastructures, "embodied" energy is considered, i.e. the energy used for their production / construction
- in calculating the Emergy, the “primary” energy incorporated is measured (it is considered the level of quality closest to the needs of use)

Emergy (memory of energy)

- is the amount of energy consumed in direct and indirect transformations to make a product or service
- It measures the quality differences between different forms of energy
- is an expression of all the primary energy used in the work processes that generate a product or service in units of one type of energy: available energy consumed in transformations (emjoules)
- accounts for different forms of energy and resources (e.g. sunlight, water, fossil fuels, minerals, etc.)

Diagram for emergy analysis of a production system



Energy efficiency and short, medium and long term energy storage

- since energy is often a flow, when it is produced it must be consumed, otherwise it is lost

- renewable energies are mostly intermittent (days and seasons), so it is necessary to accumulate them

- energy storage is one of the main problems for the spread of renewable (and non-renewable) energies
  - ✓ the accumulation of electricity is carried out through batteries
  - ✓ the accumulation of thermal energy is carried out through water or salt or stone tanks
  - ✓ the accumulation of water energy is carried out through dams

- an isolated system that has a temperature of 100 degrees does not produce energy, while it becomes an important energy tank even at lower temperatures when it interacts in a bigger energy system
  - ✓ seas and large lakes mitigate the climates of coastal territories (reduce peaks of heat and cold)
  - ✓ underground aquifers provide calories or refrigeration to air-condition buildings

Energy efficiency and territory (spatial and temporal factors)

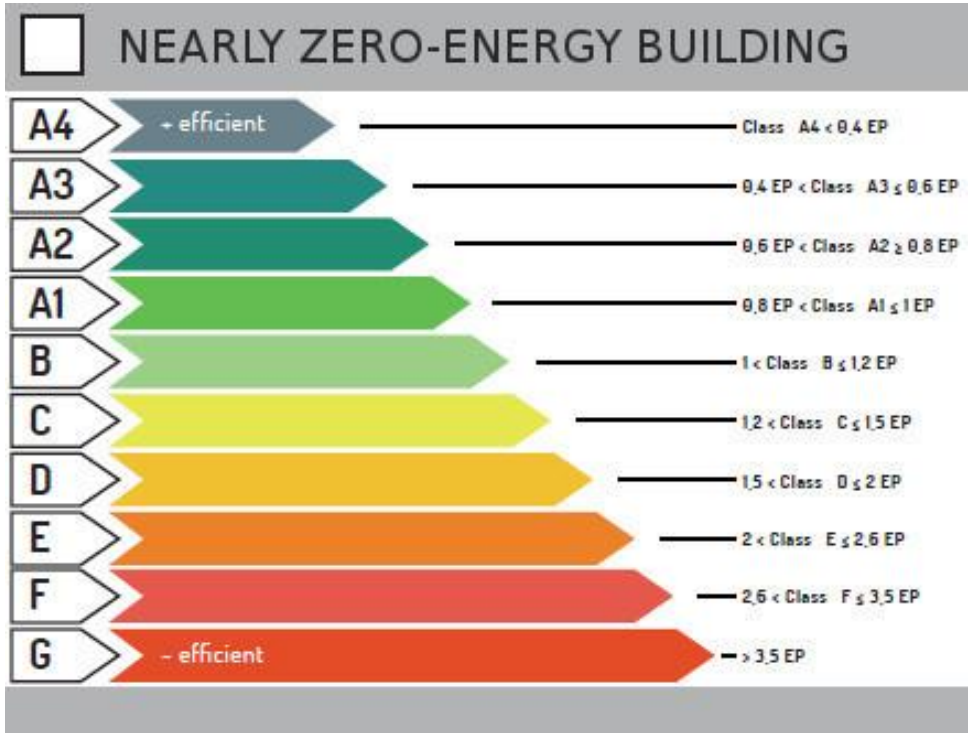
- a territory is made up of many elements (buildings, neighbourhoods, infrastructures, cities, rural areas, woods, mountains, plains, coasts, etc. and also the inhabitants) which oppose a very strong inertia to the modifications of their energy systems
- the territories are not homogeneous with each other and within them in the production and consumption of energy and in the presence of renewable and non-renewable energy sources
- there is a need for infrastructures to transport energy sources and flows from the places of presence / production to the places of use
- it takes a long time to adapt a territory to the infrastructural needs of new types of energy systems, including the more efficient and sustainable ones
- it takes time to change the behaviour of a population in the use of new types of energy systems, including the more efficient (and without energy waste) and sustainable

Nearly Zero-Energy Building (NZEB)

- a NZEB is “a building with very high energy performance”, where “the nearly zero energy required should be covered by renewable sources produced on-site or nearby” (Energy Performance of Buildings Directive, 2010)

- the energy class is given by the **global non-renewable energy performance index** (EPgl, nren) which indicates the total non-renewable energy consumed annually by a building per square meter of floor surface

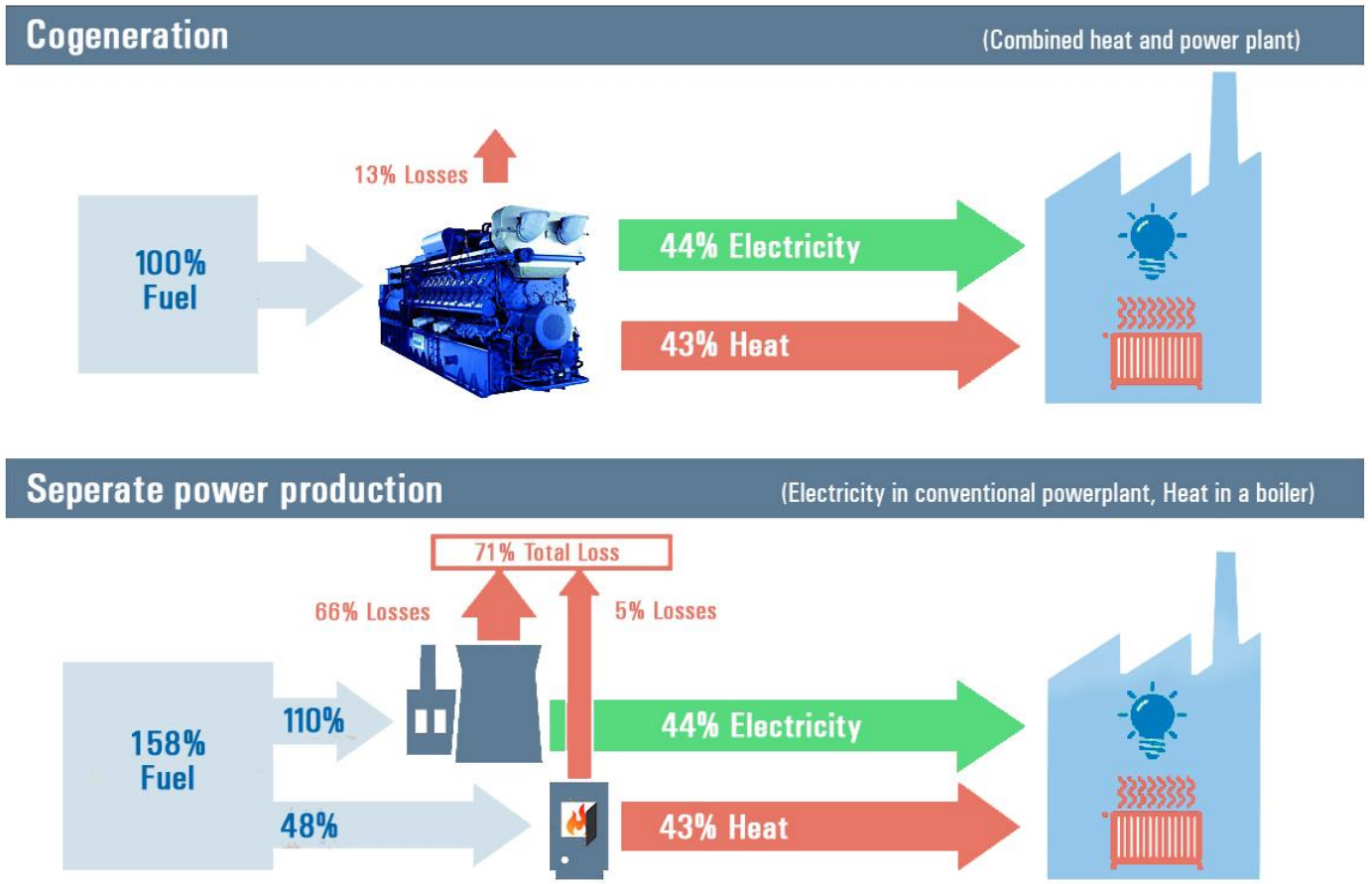
- the energy considered concerns winter heating, summer cooling, hot water production, lighting and ventilation



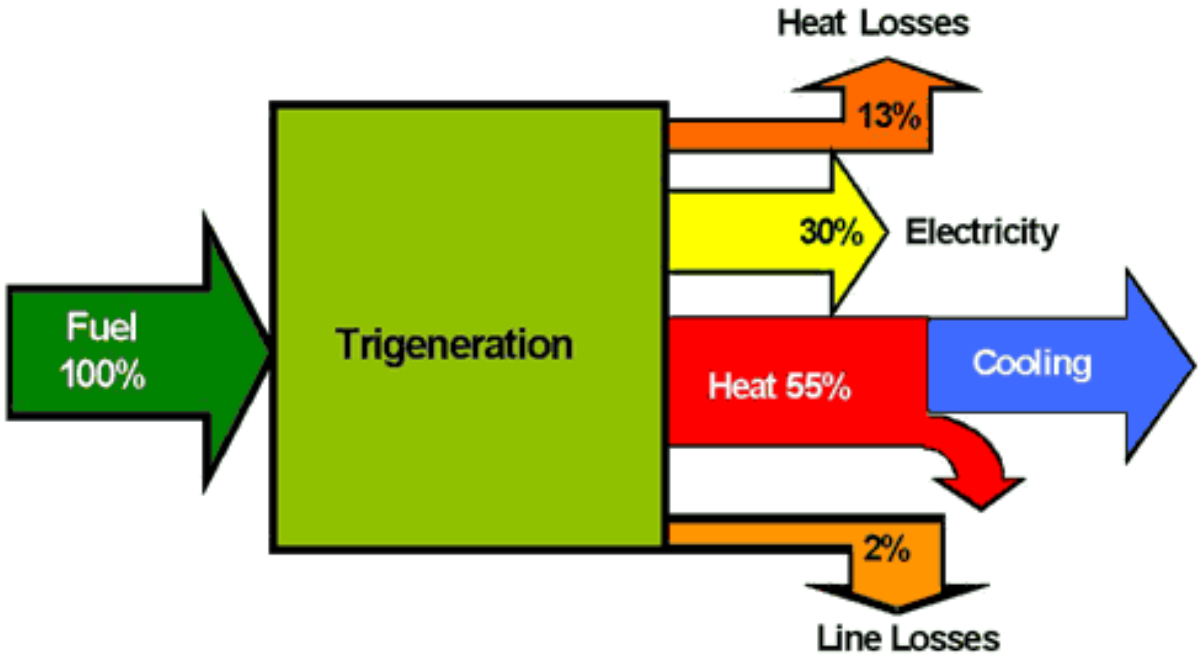
Recovery of "waste" of energy sources and flows

- a waste of energy source or flow is energy that is not used
- they could be thermal or cold (medium / low temperature fluids), kinetic (braking of cars) or combustible (gas emitted or burned by oil wells), etc.
- excesses of electrical flows are used in very distant places through electrical networks or are accumulated in hydro-electric basins (pumping)
- thermal and refrigeration flows could be recovered through cogeneration and trigeneration and district heating
- gases from oil wells start to be recovered (problem: high costs of recovery and transfer of gas)

Cogeneration plant vs separate energy plants

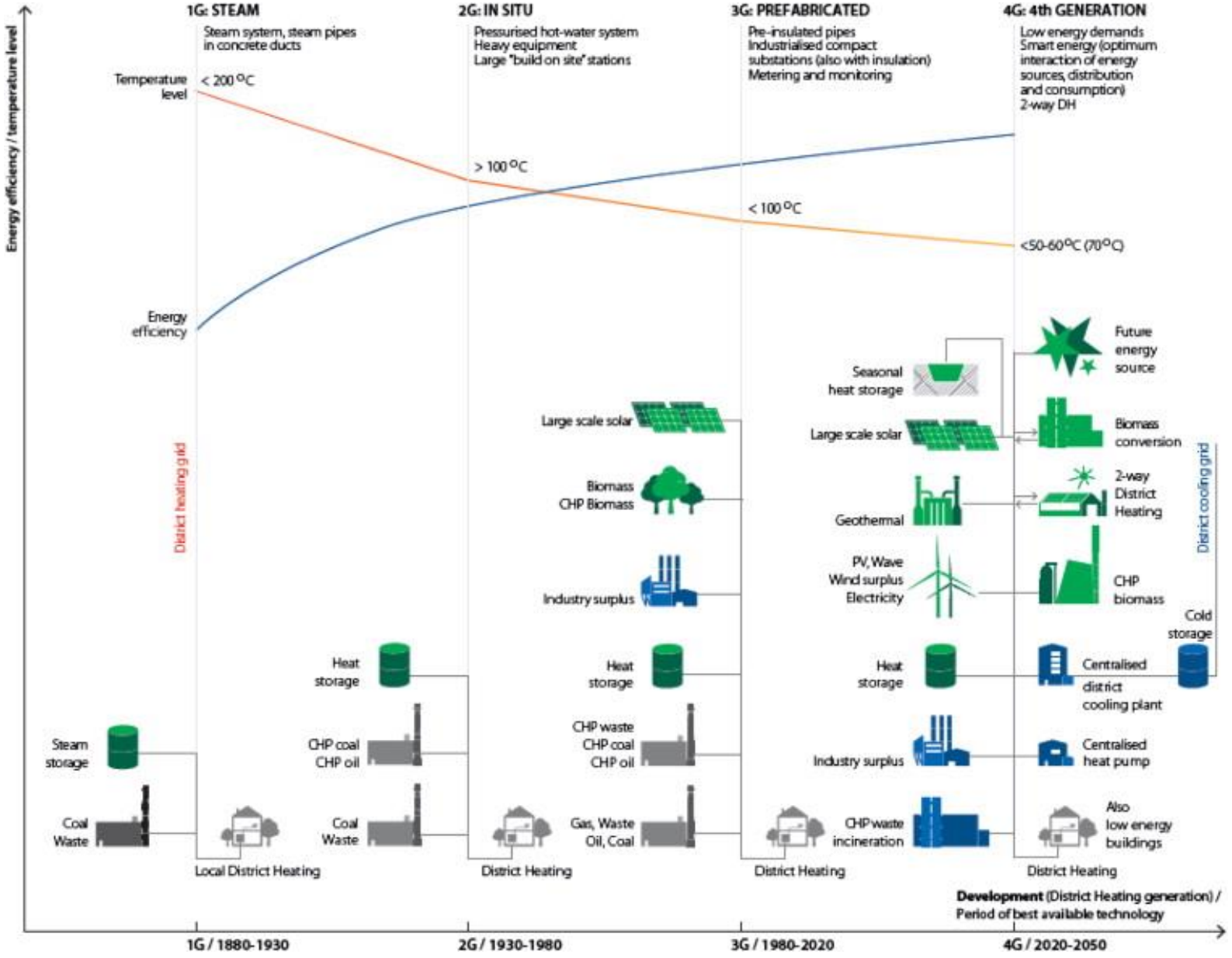


Trigeneration plant (absorption cooling)



4th Generation District Heating (4GDH)

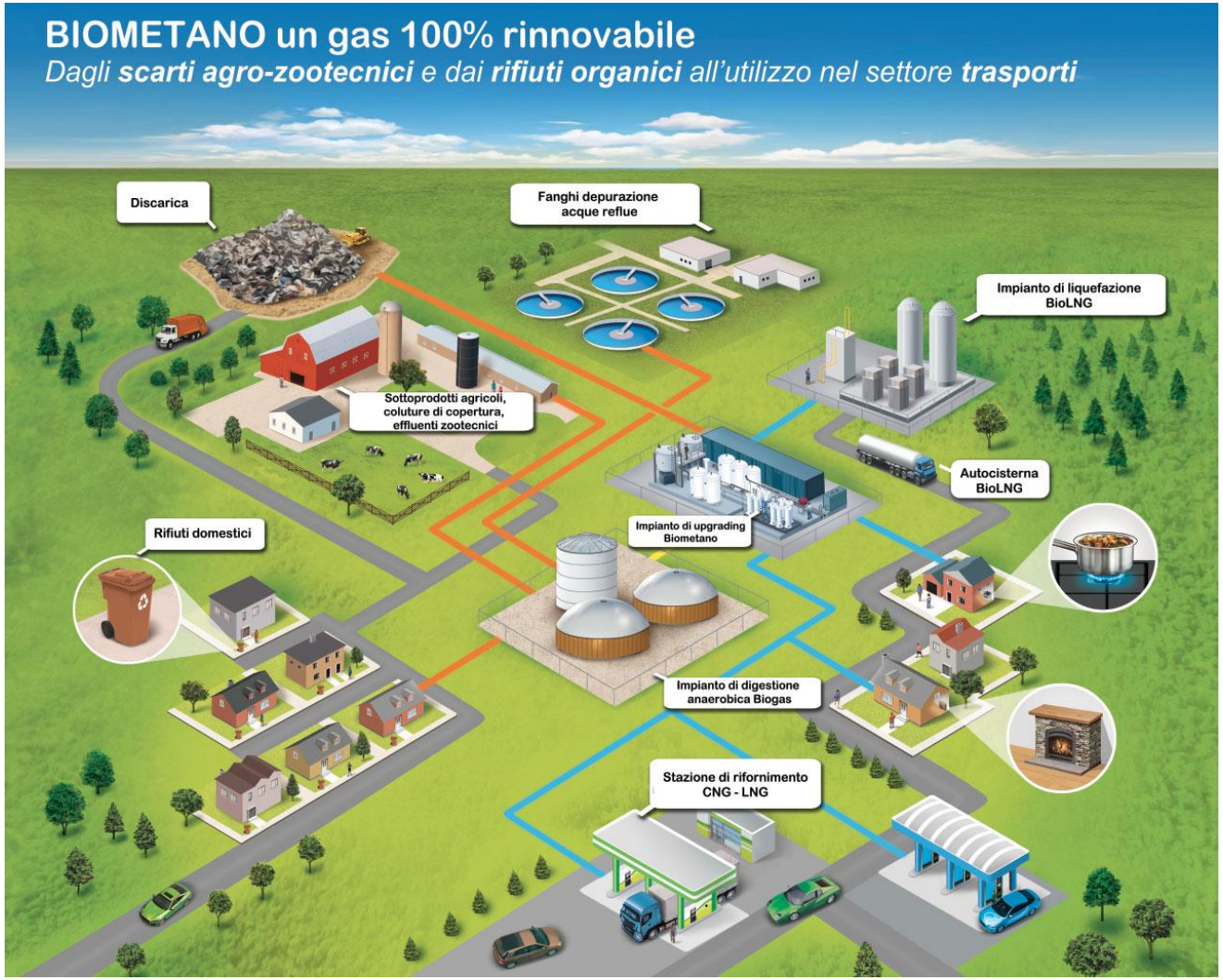
Integrating smart thermal grids into future sustainable energy systems



Biomethane produced by wastewater and solid organic waste treatment plants

- biomethane is a 100% renewable gas that is obtained from biogas coming from the anaerobic digestion of biomass such as: organic waste fraction, agricultural by-products, livestock effluents, agro-industrial waste, purification sludge

- liquefaction / storage / distribution: liquid biomethane is stored in cryogenic tanks, then distributed with cryogenic tankers (it is possible to use ordinary gas pipelines)



Main stages of Biomethane production

1. Upgrading: the biogas is purified to obtain pure biomethane gas; CO2 can be recovered in the food and industrial fields
2. liquefaction / storage / distribution

The advantages of biomethane

- programmable renewable source
- reduction of dependence on energy imports
- development of local economies
- reduction of emissions and greenhouse effect
- maximum flexibility

Energy efficiency and economic costs / benefits

What are the possible economic individual benefits (direct and indirect) by increasing energy efficiency?

1. Cost reduction due to lower energy consumption
2. Reduction of plant maintenance costs
3. Improvement of living and working conditions and the quality of products / services
4. Reduction of energy supply risks
5. Reduction of harmful and greenhouse emissions to comply with the regulations

Decision factor: pay-back of the investment with respect to the economic savings obtained

What are the benefits for the community by increasing energy efficiency?

1. Extra reduction of harmful and greenhouse emissions compared to the standards
2. Reduction of the environmental impact of the energy production process and transport
3. Reduction in the import of fuels and energy

Decision factor: assumption of ethical motivations by the individuals or there is a need for public funding

Energy prosumers and communities

- the energy transition requires a fundamental contribution of energy production from energy users
- the exponential increase in distributed electricity generation, mainly due to photovoltaic systems, requires the integration of energy production and consumption within neighbourhoods or production districts to facilitate the optimal functioning of the national electricity system
- one solution is to match the local energy production with the demand for the house-condominium-neighbourhood or company-building-commercial circuits

Energy prosumers (word that comes from the union of producer and consumer)

- subjects (individuals, groups or companies) who create energy systems of medium-small power to satisfy part or all of their energy consumption and sell or buy the other part according to their needs to obtain an economic benefit and greater energy autonomy

Energy communities

- group of users who, through a contract, collaborate to produce, consume and manage the energy (generally renewable) through one or more local energy plants at affordable prices for their members
- collective self-consumption of condominiums and energy communities in Italy are legally recognized, even if the related legislation is being defined

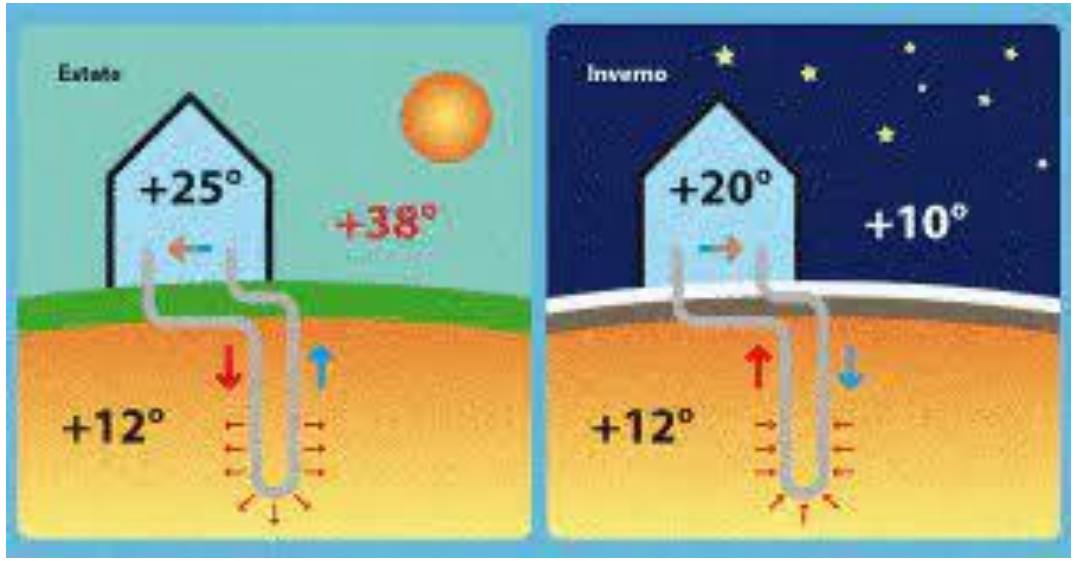
Photovoltaic with low enthalpy geothermal heat pump (also air-to-air)

(air conditioning and hot water production in civil buildings and others medium-low users)

- a single system makes the functions of heating and cooling the buildings and producing hot water
- the heat / coolness of the surface layers of the soil or aquifers is used to reduce the energy demand

This type of system consists of

- a system for capturing heat (pipes with vertical or horizontal probes)
- a heat pump
- a photovoltaic plant (possibly hybrid) to provide electricity to the heat pump
- a heat storage and distribution system
- a cold distribution system



Hybrid solar panels for the production of electricity and heat on green or cold roofs

- The hybrid solar panel produces electricity and heat
- the photovoltaic cell transforms part of the incident solar radiation, while a part of what it fails to transform is recovered as heat through a water or air heat exchanger
- reducing the panel temperature makes photovoltaic transformation more efficient (the lower the operating temperature, the higher the efficiency of the photovoltaic transformation)
- placing hybrid or photovoltaic panels on a green or cold roof increases the efficiency of the photovoltaic transformation because the operating temperature of the panel decreases

Benefits

- with a single panel it is possible to obtain the production of electricity and heat necessary to air-condition a building and have hot water
- with the same performance, the surface of the panels is smaller
- lower risk of fire due to the lower operating temperature of the panel

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