

## Clean energy technologies in sustainable development of energy, agriculture, food security and environment

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| <p><b>Research Article</b><br/>Received on February 16, 2023<br/>Revised on March 10, 2023<br/>Accepted on April 18, 2023<br/>Published on April 30, 2023</p> <p><b>Article Authors</b><br/>Vinod Kumar Sharma,<br/>Joginder Singh</p> <p><b>Corresponding Author Email</b><br/><a href="mailto:vinodkumar.sharma@enea.it">vinodkumar.sharma@enea.it</a></p> | <p>It is now a well-established fact that the rapid industrialization, economic growth, human civilization and its progress, restrain inadequate availability of energy demand to meet basic needs of the society such as communications, health, shelter, transportation, etc. The implementation of the transition towards a low carbon economy requires measures transforming the energy and transport system. In addition to the climate challenges, we are now facing challenges related to high energy prices and the high risk of supply shortages. Renewable resources prove to be of strategic importance to achieve a sustainable energetic supplying. So far environmental pollution is concerned, energy efficiency and utilization of renewable energies, seems to be a better route to follow. As renewable energies are becoming a growing part of the energy portfolio, focus is being put on increased performance of a sustainable renewable energy sources World-wide and more so in the context of the developing countries. The present paper will focus its attention predominantly on comprehensive review of most appropriate and advanced environmental friendly renewable technologies best suited to reduce huge amount of carbon emission into the atmosphere, global temperature rise, threats of climatic changes, etc.</p> |
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### HOW TO CITE THIS ARTICLE

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One of the biggest challenges facing humanity today is climate change. Since both final energy consumption and world carbon dioxide (CO<sub>2</sub>) emissions have doubled in the last 35 years. Science is a powerful driving force in the success of any nation, contributing to its economic well-being and the individual fulfilment of its people. Applied sciences help to identify mechanisms to adequately use knowledge and transfer technology. Applied/basic research is fundamental not only for technological advancement, but also for global sustainable development. Technology has profoundly shaped society, the economy and the environment.

Technology has caused many environmental and social problems, but it is also key to addressing environmental degradation, climate change, food scarcity, waste management and other pressing global challenges. Enhanced global awareness and increased education in the applied/ basic sciences is vital to attain sustainable development to improve the quality of life. Basic sciences for sustainable development is linked directly to the main objectives to enhance inclusive participation in science regardless of geography or gender; strengthen education and scientific training.

In order to thrive moving forward to design, commercialization and use of processes and products, it is of utmost necessity to reinvent our efforts and actions that needs to be taken to prepare well-trained force of engineers of the future, able to protect natural resources, decrease the amount of energy used, work with renewable sources, consider, curtail polluted output and waste in manufacturing. It is true that AI, robotics and additive manufacturing will likely be the primary technologies driving all fields of engineering for the next decade but the fact remains that software and electrical engineers without support from mechanical engineers, usually cannot actualize their designs. The implementation of the transition towards a low carbon economy requires measures transforming the energy and transport system. Renewable energies are critical for achieving the climate goals, complemented by a rapid phasing out of fossil fuels. In addition to the climate challenges, we are facing now challenges related to high energy prices and the high risk of supply shortages.

It has been estimated that every billion kilowatt-hour of renewable electricity would reduce carbon emissions by over 200,000 tonnes, sulphur emissions by 10,000 tonnes and particulate by 2000 tonnes. Variety of scenarios can be cited where sustainable development brings about good to the common man. Using recycled materials or renewable resources is an example of sustainable development.

### **Energy Security**

After the oil supply disruptions of the early 1970s, almost all the nations have increased their dependence on foreign oil supplies. This increased dependence impacts more than just their national energy policy. Burning of vast quantities of fossil fuels, such as coal and oil, has already caused a great deal of harm to the environment. Use of fossil fuels has contributed significantly to global warming. The primary goal of developing green sources of energy is to generate power while minimizing both waste and pollution, to thereby reduce the impact of energy production on the environment. Scientists who advocate the use of green energy say that using such sources will reduce the rate at which climate change occurs, although it cannot stop or reverse the temperature increase.

Another important objective is creating energy sources that are renewable.

### **New Energies: Which Ones?**

Only the natural resources have the capability of a long term energetic survival of mankind: Nuclear energy (via both fission and fusion nuclear reactions) renewable energy, solar energy from the sun, geothermal energy from heat inside the earth, wind energy, biomass from plants and hydropower from flowing water. Renewable energy should be looked as the most important instrument for the socio-economic development, eradication of poverty and unemployment and an instrument of rural development. World is certainly moving in this direction and let us commit ourselves to the development of pollution-free renewable energy technologies, as well. So far solar energy is concerned, it is worth to note that The World's primary energy consumption is only 1/10000 (one ten-thousandth) of the one available on the surface of earth in sunny countries.

### **What is Green Energy?**

Green energy is energy that is produced in such a way as to minimize its negative impact on the environment. Traditional energy sources, most notably fossil fuels, produce greenhouse gases that are believed to be the primary cause of an effect known as global warming or climate change. Sources of green energy, such as solar, wind, geothermal, and hydro energy are developed and promoted as alternative sources that make little or no contribution to climate change. Even nuclear energy is sometimes considered a green energy source, because some types of nuclear technology produce much less waste than oil and coal.

### **Why Green Energy is Important?**

Renewable energy is important because of the benefits it provides. Key benefits *are*:

### **Environmental Benefits**

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies.

## Energy for Our Children's Children

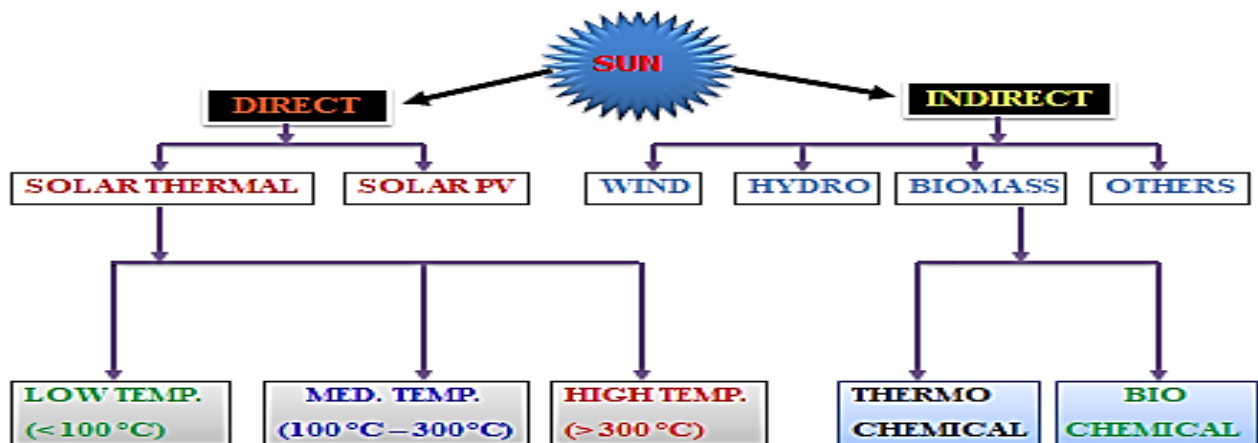
Renewable energy will not run out ever while other sources of energy are finite and will someday be depleted.

## Jobs and the Economy

Most renewable energy investments are spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within the country that means energy dollars stay home to create jobs and fuel local economies rather than going overseas. Meanwhile, renewable energy technologies developed and built in the country are being sold overseas, providing a boost to the country trade deficit. The sun's heat also drives the winds, whose energy, is captured with wind turbines. Then, the winds and the sun's heat cause water to evaporate. When this water vapour turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydroelectric power. Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass.

Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called bioenergy. Hydrogen also can be found in many organic compounds, as well as water. It's the most abundant element on the Earth. But it doesn't occur naturally as a gas. It's always combined with other elements, such as with oxygen to make water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity. Not all renewable energy resources come from the sun. Geothermal energy taps the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings. And the energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the Earth. In fact, ocean energy comes from a number of sources. In addition to tidal energy, there's the energy of the ocean's waves, which are driven by both the tides and the winds. The sun also warms the surface of the ocean more than the ocean depths, creating a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity.

## TRADITIONAL CLASSIFICATION OF RENEWABLES



Solar thermal energy is a technology for harnessing solar energy for thermal energy (heat). Solar thermal collectors are defined as low-, medium-, or high-temperature collectors.

- Low temperature collectors are flat plates generally used for domestic water heating and swimming pools.

- Medium-temperature collectors are also usually flat plates and vacuum tube collectors used for creating hot water for residential and industrial use.
- High temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.

It is important to involve the policymakers, representatives of the solar thermal sector, and other industrial sectors and highlight them the contributions, the solar heating & cooling sector can bring to a decarbonised and decentralised energy sector.

### **India and Potential of Solar Energy**

Use of Innovative technologies for exploitation and widespread diffusion of renewable energy at large scale is the only option that offers India the theoretical potential to service all its long-term power requirements. The Indian subcontinent is blessed with abundant renewable energy resources. Solar energy could certainly be a game-changer for India: It has the potential to re-energize India's economy by creating millions of new jobs, achieve energy independence, reduce the trade deficit and propel India forward as a green nation. While coal-fired power plants meet 70% of India's power needs, progress is being made towards transitioning away from dependence on fossil fuels. It is worth to mention that the world is not going to achieve its targets of halting global warming unless India can reduce its carbon emissions and India changes its trajectory right now. Solar energy offers too many benefits for India to ignore or delay its development. For instance, taking advantage of 300 to 330 sunny days a year, India could easily generate 5000 trillion kWh of solar which is higher than India's total yearly energy consumption. The confidence that India will successfully transition from coal dependence to an increased reliance on renewable energy comes from nationwide progress in generating wind and solar.

As per Information available from MNRE, the alliance aims to install 1000 GW of solar electricity in its member states by the year 2030. Currently, 18% of India's electricity needs can be met by renewable energies. Solar is cheaper than fossil fuels, but there are still questions about consistency and battery storage which remains expensive. Electricity sector reforms will be essential not only to reducing India's carbon footprint but enabling the country to meet its goals. Green electricity will be a crucial step towards improving the quality of life in India while taking us toward being a net-zero economy.

### **Research and Development Topics of Interest in Solar Thermal**

Though technologies for converting sunlight energy to power have made a lot of progress, high capital price and low conversion proficiency are the main obstacles to the common use of these technologies. Solar energy is a crucial energy source that requires solar capture, conversion and storage. Topics of interest for this research topic include but are not limited to:

- Thermal energy grid storage for further applications via the CSP/ multi-junction photovoltaics system, solar fuels through thermochemical redox cycles, photochemical and high-temperature electrolysis systems with better economic performance due to the dramatic drop in the cost of solar energy.
- Thermal energy storage materials and techniques (phase change material, thermochemical materials, metal hydrates thermal energy storage materials, sensible heat storage, latent heat storage, thermochemical heat storage, or a combination of these), thermal energy storage materials development and characterization.
- Solar thermal systems with thermal energy storage (concentrating solar thermal system, solar water heating systems, solar cookers, solar desalination, solar dryer, solar greenhouse, thermal processing of food in agriculture, photovoltaic thermal system, hybrid solar thermal system, thermal energy storage in the building).

In brief, research and development topics of interest in solar thermal at low-medium temperature applications are:

### **Research and Development of Energy Storage for Solar Energy Application at Medium Temperature**

- Research and development of hybrid system using solar, wind and biomass
- Develop a toolbox including the basic components for the construction of small/ medium size CS multi-generative power plants to be integrated in the buildings. The goal should be to combine and optimize innovative subsystems for the efficient capture of solar energy to generate electricity, produce heat and cold, drive thermal processes such as desalination or sterilization, alone or in combination with backups (*e.g.* gas or biomass).

- To deploy technologies through technology optimization, integration and validation, case studies analysis and impact assessment, through small scale demonstrative units of poligenerative concentrating solar (CS) technologies.

### Generation of Electric Power using Solar Energy

Concentrating solar power plants produce electric power by converting the sun's energy into high temperature heat using various mirror configurations. The heat is then channeled through a conventional generator. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts heat energy to electricity. Concentrating solar power systems can be sized for village power (10 kilowatts) or grid-connected applications (up to 100 megawatts).

Some systems use thermal storage during cloudy periods or at night. Others can be combined with natural gas and the resulting hybrid power plants provide high value, dispatchable power. CSP has been theorized and contemplated by inventors for thousands of years. Seventeenth century, is considered to be the beginning of modern solar concentration. The early twentieth century brought many new concentrating projects varying from solar pumps to steam power generators to water distillation. Both these applications were of priority strategic interest, in terms of their impact on the national energy and environmental sectors, as well as in terms of technological innovation aimed at increasing the competitive edge of the Italian companies.

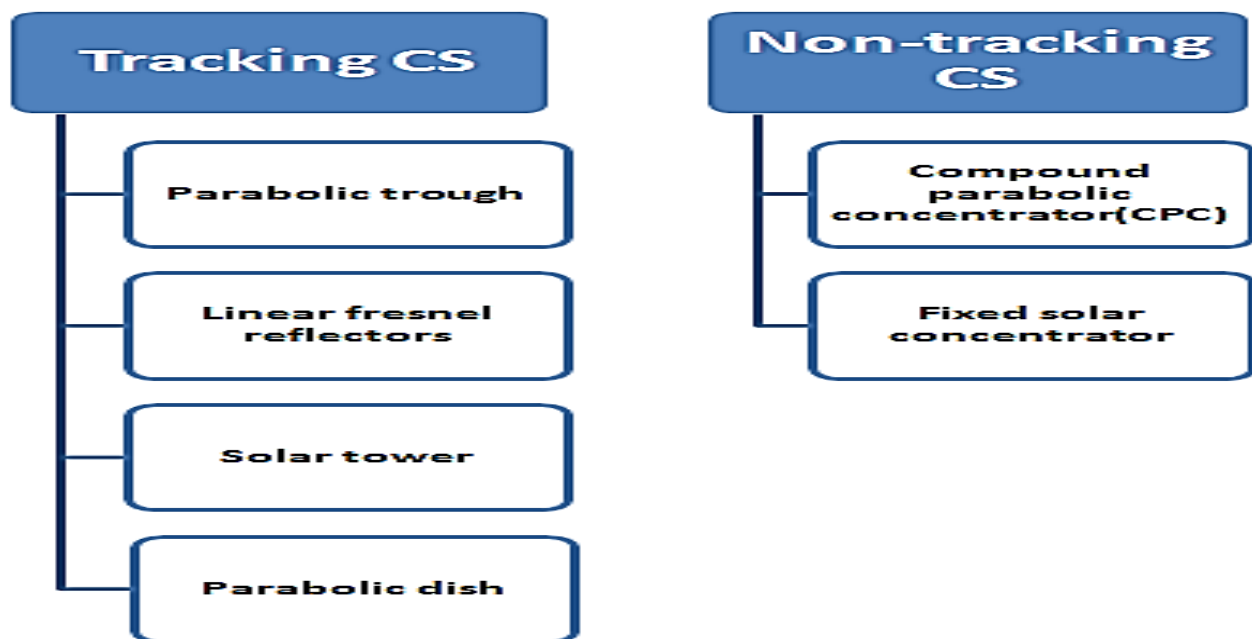


Fig 2. New Concentrating Projects varying from solar pumps to steam power generators to water distillation

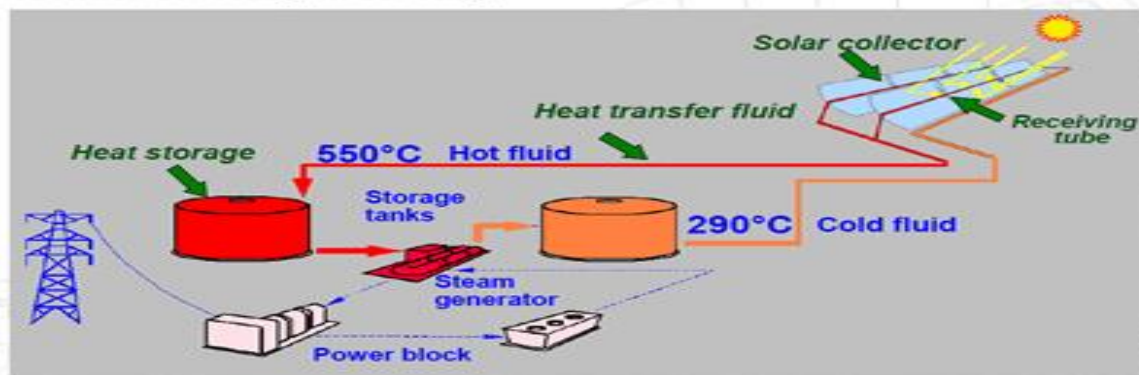
### ENEA Concentrating Solar Energy Program Main Objectives

Since 2001, a vigorous ENEA programme has been launched on two main subjects. Both activities are suitably funded and organised as large projects:

- ◆ Medium temperature (about 550°C) heat collection and storage, primarily intended for **electricity production**.
- ◆ High temperature (greater than 850°C) heat collection for direct **hydrogen production**.

ENEA design introduces relevant improvements to the current technology

- The introduction of an adequate energy storage
- The use of an alternative transfer fluid
- A new solar collector design
- An innovative receiving tube design



### World's First Solar Power Plant Installed in Italy

The archimedes project combining the best technology of today with that of tomorrow consists of a solar field, a storage system and a steam generator, first of its kind in the world is operating in Italy since 2010. Here, the solar energy is collected in the modular solar field comprising of 360 linear parabolic collectors. The movable collectors are arranged in parallel rows each forming a single string.

### Innovations Introduced by ENEA

ENEA introduced a new fluid heat carrier (molten salt a mixture of 60%  $\text{NaNO}_3$  and 40%  $\text{KNO}_3$ ) in order to increase the operating temperature and the possibility of storing heat. Another innovation of ENEA is the design of a new type of concentrator based on thinner mirrors that saves construction and installation costs. The use of large scale heat storage (another innovation in the Archimedes project) enable the plant to provides heat to the steam generator at a constant rate 24 hours a day, regardless of variations in solar energy availability. The steam generator consists of 'tube and shell' heat exchangers in which heat is transferred to water to produce super-heated steam for use in a conventional thermoelectric plant. 5 megawatt capacity solar plant costing nearly 60 million of Euro, has a unique characteristic to collect and conserve thermal energy of the sun for many hours thus enabling the plant to generate electricity both during off sunshine hours and the overcast sky.

It is true that cost for kWh produced is nearly five or six times more compared to cost of energy generated using conventional fuels but with 2.100 tons of oil saved and 3.250 tons of carbon dioxide emission reduced in a year, the present achievement is certainly an important milestone.

### Why Molten Salt

Given its chemical properties use of thermal oil as HTF, is environmentally dangerous, inflammable and it is not able to operate at temperatures above  $400^\circ\text{C}$ : at higher temperatures, the components are subjected to a degradation process and they cannot be used anymore; therefore, the efficiency of the overall steam is reduced. Moreover, due to the aging process, diathermic oil must be replaced every year (even if in small amount) and this leads to a further cost implementation. Also, CSP plant based on the use of thermal oil as HTF, can only operate at daytime, with the availability of direct sunlight. In order to manage above-cited issues and to mitigate the intermittency of the solar source, ENEA under the able guidance of Prof: Carlo Rubbia, introduced a heat storage system based on a mixture of molten salts (60% of sodium nitrate and 40% of potassium.

Technically speaking, the molten salts mixture, already widely used as fertilizer and available in large quantities at a lower cost, is able to provide the following advantages:

- It is not inflammable
- It solidifies in contact with ground
- It cannot be dispersed when collected
- It is environmentally safe nitrate

Molten salts can be used either as heat storage or as HTF able to reach temperatures up to 550 °C. Since molten salts are able to operate at higher temperature, the volume needed for the storage system could be reduced by 2/3 leading to as a result, a size reduction of the storage tanks with an impact of 30% in cost reduction. These savings represent around a 20% plant cost decreasing compared with usual oil plants with storage. Higher operating temperature could increase the plant efficiency up to 6%. Finally, unlike oil, molten salts are environmentally friendly, non-flammable, stable fluid and they not cause the degradation of receiving tubes

### **ENEA Presents the World's First Solar Disk Powered by Air Microturbines**

ENEA presents innovative design of world's first solar disk (consisting of solar mirrors capable to focus up to 2,000 times the solar radiation on a small focal area) where mainly because of its integration with an innovative microturbine, nearly 70 kW of radiant power captured can virtually be converted to electric power up to 15 kW. The novelty of this system consisting of the solar disk (dish power system) is the use of air microturbine engine (tried for the very first time) compared to sterling, commonly used in this type of application, the ease of operational management and the modularity enabling its use for small shopping malls and businesses, supermarkets and schools both connected and detached from the power grid.

### **Solar Energy**

When it comes to energy production, photovoltaic (PV) technology has a major advantage compared to other renewable energy sources; it can be easily integrated in buildings, infrastructures, electric vehicles and in agriculture, resulting in multifunctional applications. This is what we call integrated PV (IPV), where photovoltaic is embedded into components fulfilling other functions, exploiting modularity and synergies of use. However, the main disadvantage of PV technology is that solar panels and energy storage devices use a significant amount of land. Although the technology has improved, still installation of PV plants can be expensive to install.



**Fig 3. Connected and detached from the power grid**

### **Wind Energy**

Some people complain that they are eyesores that distract from the beauty of the environment. There is also some concern that they could harm local bird and bat populations.

### **Hydro Energy**

Damming a river and creating an artificial lake can cause damage to the environment. People are forced to relocate to create the reservoir.

### **Geothermal Energy**

The potential of geothermal energy to supply a significant portion of the world is limited by the expense of the technology it requires.

### **What are the Cleaner Fossil Fuels**

Beside from developing new energy sources, another goal of the green energy movement is to refine existing fossil fuel technology to make it more environmentally-friendly. An example of this is so-called clean coal technology, which attempts to reduce gas emissions from burning coal.

One means by which this can be accomplished is to convert coal into a gas, and then generate energy by burning the gas. While this type of energy production is cleaner than traditional methods of burning fossil fuels but the fact remains that the environmental cost is still too high. Another issue is that even though the technology is less harmful, coal is still a finite resource

### **Role of Multinational Oil and Gas Companies in Green Energy**

Business of multinational oil and gas companies operating in different countries includes three main areas:

- Upstream: finding, producing and transporting oil and gas.
- Refining and marketing of gas, oil, petroleum products.
- Renewable energy, including bio-fuels, wind, solar and carbon capture and storage.

In the environmental-related issues and the implementation of green energies multinational oil and gas companies could have positive outcomes from the regulation promoted by the respective countries in developing a green strategy and proposing to the world the image of an environment-focused company. For Example, ENI, Italian multinational energy company, launched a new strategy for renewable energy. With a focus on alternative methods for accelerating clean energy policy adoption, ENI introduced an innovative financing scheme for renewable and energy efficiency deployment. Important initiatives in the research and innovation field promoting research projects focusing on the entire energy sector, from hydrocarbons to solar energy have already been undertaken. More than 270 active partnerships involving one hundred universities in Italy and abroad were active during 2011-2022. It is worth to note that ENI was the first international energy company in Africa to invest in the production of electricity using previously flared gas. For example, the construction of Central Electricque du Congo and the renewal of Central Electricque de Djeno, led to the development of 350 MW of installed capacity, in the Republic of Congo. Also, ENI created a new electricity grid that covers about 40% of the city of Pointe-Noire, which reaches 350,000 inhabitants who until now had no access to energy, if not in small part through private generators.

In Nigeria, ENI provide electricity and natural gas by power plants (Okpai 480MW power plant, Rivers State Government 150 MW power plant), developed networks connected to industrial plants, and support the supply of electricity through off-grid systems. Today, Congo and Nigeria power plants produce nearly 60% and the 20% of national electricity production, respectively, with a significant reduction of gas flaring in both countries. In Mozambique, ENI has recently announced the construction of a 75 MW power plant in the province of Cabo Delgado in the north of the country. Among the main structured partnerships for research:

- Renewed Strategic Partnership ENI-MIT for duration of four years focused on different types of research in solar energy, oil and gas business sector, environment and green chemistry.
- Strategic Alliance Research with the University of Stanford for four years duration focused on the development of thematic research and innovation in the oil & gas upstream technologies field, and in the monitoring and environmental restoration.
- Nationally, the most important collaborations and significant in terms of quantity/quality of research and development, are with the Polytechnic of Milan, National Research Council of Italy (CNR), ENEA and the Polytechnic of Turin.

### **Green Energy and Navy**

Renewable sources can contribute significantly to meet energy needs of the Navy. Listed below are some examples of the renewable energy technology that can certainly be considered by the Navy to meet its energy needs:

#### **Solar Photovoltaic**

The naval energy strategy requires a steep increase in the use of renewable energy at shore facilities. It could be achieved through construction of solar photovoltaic power plants at Navy and Marine Corps installations and on military land that will certainly help the department to increase its energy security and benefit the environment through clean energy generation.

#### **Wind Energy**

A number of anemometers could be installed for collecting data to verify actual wind speeds.

Needless to say that wind energy development can help to meet power requirement with green power, and serve as a symbol of the Marine Corps' commitment to reduce greenhouse gas emissions and other pollutants associated with the production of electricity and the burning of fossil fuels.

### **Ocean Energy**

Because of the Navy's association with the ocean, there exist enormous opportunities to shift away from fossil fuel to renewable energy at naval facilities. Navy can certainly help evaluating wave, tidal, ocean current and ocean thermal technologies to determine if they are technically and economically feasible.

### **Renewable Thermal Energy**

Sunlight can cost-effectively produce the hot water needed at shore facilities. Most cost-effective renewable solar technology is day-lighting - the use of the light from the sun, combined with complementary electrical lighting systems, to keep work spaces properly and efficiently lit. Solar energy can produce both renewable electricity and renewable thermal energy.

### **Nuclear Energy**

Nuclear energy is the power produced during a nuclear reaction. The energy released from a change in the nuclei of an atom produces energy known as nuclear power. This power can be produced in two different ways by nuclear fission, and by nuclear fusion. Nuclear energy that is produced naturally is the energy produced from the sun and the stars, which releases light and heat and warms the planet.

### **How Nuclear Energy is Produced**

- Nuclear power can come from the fission of uranium, plutonium or thorium or the fusion of hydrogen into helium. Today it is almost all uranium. The basic energy fact is that the fission of an atom of uranium produces 10 million times the energy produced by the combustion of an atom of carbon from coal.
- Natural uranium is almost entirely a mixture of two isotopes, U-235 and U-238. U-235 can fission in a reactor and U-238 can't to a significant extent.

- Natural uranium is 99.3 percent U-238 and 0.7 percent U-235.
- Most nuclear power plants today use enriched uranium in which the concentration of U-235 is increased from 0.7 percent U-235 to (nowadays) about 4 to 5 percent U-235. This is done in an expensive separation plant of which there are several kinds.
- The U-238 "tails" are left over for eventual use in "breeder reactors". The Canadian CANDU reactors don't require enriched fuel, but since they use expensive heavy water instead of ordinary water, their energy cost is about the same.

Nuclear fusion is the process of joining the nuclei of two atoms together. This is the method the sun uses to produce heat, as well as the method used to develop the Hydrogen Bomb. Currently, approximately 17% of electricity worldwide is produced by nuclear power plants, but in some countries, like France, over 75% of their electricity is produced by nuclear power. The United States, on the other hand, only produces about 15% of the electricity from nuclear power. Thorium or uranium is the fuel sources most often used in nuclear energy plants

### **Big Challenges: Nuclear Fusion**

ENEA is working on magnetic confinement physics by means of a nuclear fusion machine operating at the highest magnetic field called FTU (Frascati Tokamak Upgrade) plant. The Agency performs its activities within consolidated international collaborations, working together with the industry. Nowadays the Agency:

- Coordinates the National Fusion Research Programme
- At present, ENEA participates in the International Thermonuclear Experimental Reactor (ITER Project).
- 35 nations are collaborating to build the world's largest, a magnetic fusion device (tokamak) to prove the feasibility of fusion as a large-scale and carbon-free source of energy based on the same principle that powers our Sun and stars.
- The ITER Members China, the European Union, India, Japan, Korea, Russia and the United States are now engaged in a 35-year collaboration to build and operate the ITER experimental device,

and together bring fusion to the point where a demonstration fusion reactor can be designed.

- ITER is designed to produce a ten-fold return on energy ( $Q=10$ ), or 500 MW of fusion power from 50 MW of input heating power.

### **Biomass Based Power Generation**

Sustainable biofuels are currently essential for climate protection in transport: biofuels reduced CO<sub>2</sub> emissions in the transport sector by around 11.1 million tonnes in 2021. As in previous years, biofuels made by far the largest contribution to reducing greenhouse gas emissions in the transport sector. The average saving achieved by using biofuels rather than fossil fuels rose to 84% in 2021. Biodiesel, bioethanol and bio-methane made the largest contribution, reducing greenhouse gas emissions by 11.1 million tonnes of CO<sub>2</sub>. Biodiesel, bioethanol and bio-methane are sustainable and form the backbone of greenhouse gas reduction in the mobility sector, and that will remain the case in the run-up to 2030. In the light of the potential of electro mobility and fuel cells, it becomes clear that commercially available biofuels are essential in achieving the climate change mitigation goals. Sustainable biofuels also make an important contribution to energy and food security. Producing biofuels from sustainably certified oilseeds, sugar beet and feed grain generates, inter alia, high-quality protein feed and the bio-based commodity chemicals glycerol and ethanol. Processing these inputs thus benefits food security.

Biofuels had a positive economic impact. The entire production chain in the biofuel sector secures thousands of jobs, mostly in rural areas. Given the importance of sustainable biofuels in mitigating climate change and ensuring security of supply, it is a must for the government to pursue a reliable biofuel policy. This also applies to the upcoming development of a national biomass strategy. National biomass strategy must optimise utilisation of existing biomass potential. Sustainable uses of cultivated biomass can also make a valuable contribution to climate and species protection in the future, while at the same time having a positive impact on food and energy production. The rendering of bioenergy products such as heat, fuel and electricity requires the conversion of sustainably produced biomass feedstock by means of thermochemical and biological processes.

Such processes convert feed-stocks into higher energy value products amenable to industrial and domestic applications. The industrial scale FICFB gasifier (designed, developed and installed at ENEA Research Centre, Trisaia in Italy) used for thermo-chemical conversion of waste biomass to produce both thermal and electric power, uses steam as gasification agent. The term bioenergy refers to all types of energy derived from plant biomass such as the lignocellulose feed-stocks. Thermal energy, electrical energy, transportation fuels are bioenergy products that can be obtained by application of different transformation technologies to the woody biomass. Conversion of biomass feed-stocks is a key step in bioenergy production.

The value of bioenergy products is related to their suitability for particular energy applications, which is determined by the interaction between characteristics of the feedstock and the conversion process applied. Thermochemical conversion processes are primarily combustion, pyrolysis, gasification and direct liquefaction, while biochemical conversion of biomass involves hydrolysis to monomeric sugars and organic acids, followed by fermentation/ digestion to liquid and gaseous bio-fuels. Technology selection for biomass conversion represents a key decision in the formulation and selection of a bioenergy production process.

### **Role Biomass can play in the Technologies Mix to Decarbonize the Future?**

Decarbonisation is a key element to fight climate change and also, to a smaller extent in identifying sources of renewable and circular carbon. As part of the implementation plan, novel technologies have emerged including CO<sub>2</sub> capture and the development of a global clean-hydrogen system. Game-changing technologies are expected to play an important role in accelerating the achievement of the Paris goals and the pathway to net zero. Which will require system transition and complementarity technologies to enable the use of biomass and sustainable carbon sources? Although decarbonisation seems like the most effective solution in the battle against climate change, sustainable carbon sources are needed for the chemistry industry, as carbon is the main building block for many common chemicals.

Therefore, the chemical industry is advancing research into sustainable carbon sources, including feed-stocks and, depending on the applications, novel materials with increased biodegradability and biocompatibility that for example could assist in soil carbon restoration. Bio-refinery is a term used for many years to describe different types of bio based industries. The future implementation of this concept will imply the exploitation of local sources of sustainable biomass feed-stocks to produce a wide spectrum of bio based products along with the use of CO<sub>2</sub> and/or recycled carbon. To move bio based industries forward, the build-up of local scenarios in a global framework is required in order to promote integration of more renewable sources at a local level, which undoubtedly is a key element in stimulating local opportunities. An exchange of ideas is required to define the role of biomass in the move towards a decarbonized and sustainable circular. Bio economy and also conversations are essential in identifying the appropriate recent and future aspects that will assist in influencing and attracting public, private and novel investments. With this scope in mind, your knowledge is essential to understand the current state of research and to share your vision in drawing the future and identifying not only the opportunities, but also the gaps and the barriers in full market implementation.

### **Gasification Activities**

A number of experimental plants based upon different technologies (fixed bed, BFB, FICFB gasifier) and of different sizes (10kWth, 100kWth, 500kWth, 1MWth) are available at our centre at Trisaia. Fixed bed gasifier plants, of power capacity 25-30 and 80 kW<sub>e</sub> most appropriate for their use in the agricultural sector, especially, in the developing countries have already been designed, developed and installed at Trisaia. The plants have been investigated experimentally to test the most promising field of application (production of fuel gas for power generation) following different possible ways such as via internal combustion engine, gas turbines and high temperature fuel cell (MCFC). MCFC is a high-temperature fuel cell that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic matrix.

The use of biomass gasification for syngas production to biofuels conversion has also been considered. More recent activities are aimed at the development of gasifiers dedicated to the production of syngas (to be used in an internal combustion engine), synthetic biofuels (sun-diesel, methanol) as well as hydrogen. A number of experimental plants based upon different technologies (fixed bed, BFB, FICFB gasifier) and of different sizes (10kWth, 100kWth, 500kWth, 1MWth) are available at our centre at Trisaia. Fixed bed gasifier plants, of power capacity 25-30 and 80 kW<sub>e</sub>, most appropriate for their use in the agricultural sector, especially, in the developing countries have already been designed, developed and installed at Trisaia. The plants have been investigated experimentally to test the most promising field of application (production of fuel gas for power generation) following different possible ways such as via internal combustion engine, gas turbines and high temperature fuel cell (MCFC).

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### **Novelty of the R&D Activities on Biomass Gasification at ENEA**

The use of steam as gasification agent gives helps to obtain nearly nitrogen free product gas and that too with a high calorific value of around 12 MJ/Nm<sup>3</sup> dry gas compared to 4-5 MJ/Nm<sup>3</sup> while using air as gasifying agent. Purification of the product gas is obtained thanks to the inclusion of a high temperature ceramic filter in the cleaning section.

By using a natural catalyst as bed material and gasification temperature above 800 °C, the tar content was reduced below 5 g/Nm<sup>3</sup>. Moreover, an adequate purification of the product gas is obtained thanks to the inclusion of a high temperature ceramic filter in the cleaning section. By adding in the reactor a specific catalyst, the hydrogen content in the product gas can go over 50% and its quality can be further improved.

### **Production of Ethanol from Lignocellulosic Biomass**

The technology for bio-ethanol production from sugar and starch crops (sugar cane, sugar beet, maize, etc.) is mature enough to permit to achieve liquid fuel competitive, both for price and performances, to gasoline and diesel. With perspective of its diffusion on large scale use, but not to penalise the alimentary product market, it was necessary to find alternative raw materials. It is in this context that ENEA focused its research on the use of lignocellulosic biomass that could be specifically cultivated or easily recovered from agricultural, forests or agro-industrial wastes. In spite of quality and availability of the raw material, it is necessary to improve the technologies for pre-treatment, enzymatic hydrolysis and separation of alcohol from the broth, apart from the valorisation of the current processes that of lignin and hemicellulose.

### **Steam Explosion for Biomass Treatment**

In view of international fervent activities and increasing economic affair, ENEA has chosen to focus its attention predominantly on pre-treatment stages of biomass and developing technical-scientific collaborations with leading European institutions in the sector. Steam explosion with low environmental impact and producing highly biodegradable substrate, has been selected as appropriate technology for biomass pre-treatment. The process is based upon on the natural ability of the water vapour at high temperature and pressure to penetrate and breaking of chemical bonding of the polymeric, cellulose, hemicellulose and lignin in the vegetal materials. So, in brief, Steam explosion is a physicochemical pretreatment technology in which the biomass is heated to 160–260°C in a closed vessel under high pressure (7–50 bar) for a short period of time (30s–20 min) and then the pressure is

quickly released, causing an explosive effect on the cells. The final result is to make available the sugars contained in the feed material that otherwise could not be metabolised easily by the micro-organisms used in the successive stages of bio-conversion. Two experimental pilot plants both in batch and continuous version have been realised at Trisaia, to study steam explosion. The plant operating in continuous mode, called STELE, is capable to treat nearly 300 Kg/h of a wide variety of different types of biomass (wheat straw, wood chips, sorghum, kenaf, miscanthus, etc.). It is equipped with a system for the treatment of the stream of product exposed. Extraction with water, caustic solutions and filters are made on semi-industrial scale to separate cellulose and hemicellulose and lignin.

### **Innovative Concept of Agrivoltaics What is Agrivoltaics? How can Solar Energy and Agriculture Work Together?**

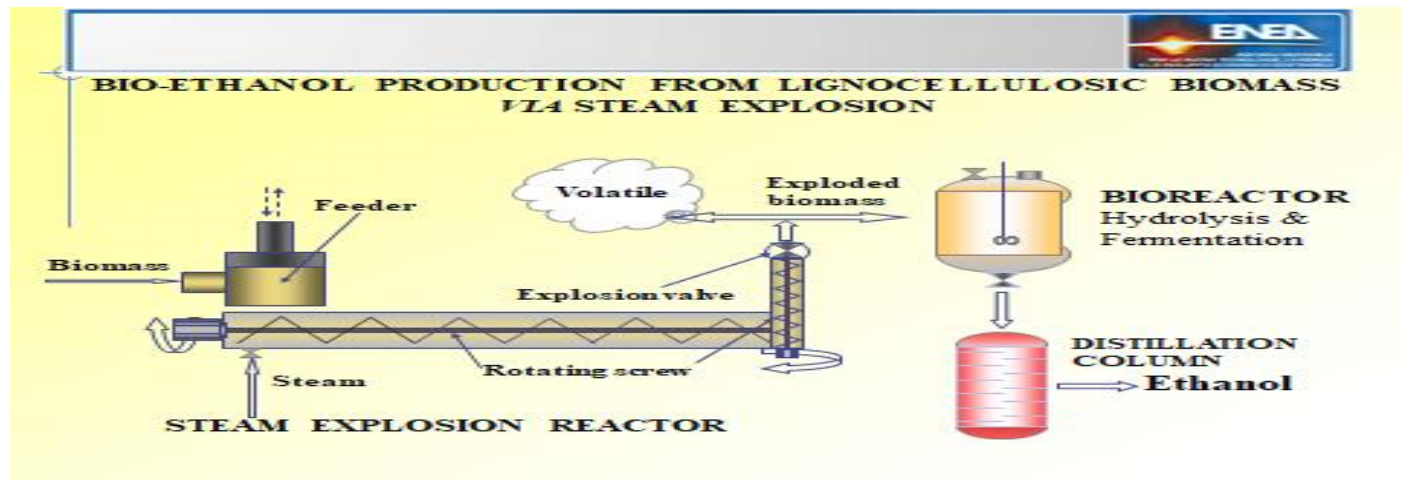
Agrophotovoltaic or agriPV is an umbrella term for open-area photovoltaics concepts that enable photovoltaics and agriculture to share use of the same space. Agri-photovoltaics (Agri-PV) combines croplands with the generation of energy produced by a photovoltaic plant. This hybrid technique helps to decarbonize the planet in addition to increasing the degree of sustainability and profitability of companies operating in the agricultural sector. AgriPV aims at sustainability, understood as a transversal factor to energy problems that include, food, environment, climate, landscape, for the improvement of biodiversity and ecosystem qualities of sites, in support of local communities. Within past recent years PV technologies has sprouted dramatically. A lot of social actors business, households, and cities acknowledged the environmental necessity and profit out of it and decided to implement it in their own fashion. It happened in farming too. Agrivoltaic can increase global land productivity by 35-73%.

### **How Solar Changes Traditional Farming**

Solar farm is a field filled with hundreds or maybe thousands of solar panels oriented into the sun. Instead of potatoes, beans or tomatoes planted in the soil, solar panels covers that land, while energy is being produced.

It's obvious that traditional farming is relatively risky business because one is very much dependent upon the weather conditions. If there is just the right amount of sun, rain and if there are no extreme storms, strong winds and etc. Thus, not to

worry about all these environmental factors and still get income is really uplifting and a bit too good to be true. Therefore, next to power generation, solar farms found another niche – agrivoltaics (or in other words APV).



**Fig 4. Bio-Ethanol Production from Lignocellulosic Biomass via Steam Explosion**

It is an amazing idea for environmentally conscious world, both agribusiness and society. The examination proved that farming and PV can be compatible. With partial light transmittance achieved by differentiating solar cell arrangement and placement, not only shading can be achieved but energy demand can be reduced drastically of such agrivoltaics greenhouses. It reduces competition for land and works efficiently too, while providing additional income for farmers. The last point is worth additional emphasis. One of the main reasons why farmers move to solar farming is a guaranteed financial gain and stress-free lifestyle. It has been discovered by researches from Fraunhofer Institute's that PV installation can work along with traditional farming and bring income even if nature's conditions are incompatible grown culture's needs. Solar farming in its true sense – has big perspectives to benefit society and business more than it has ever been before. However, it might haven't happened if traditional farming wouldn't be failing. Since 2010, when the cost of installing solar systems has dropped more than a half, solar farming started to bloom. Farmers decide to replace crops with solar because it's easier and more lucrative. With solar farming, no doubt, on one hand, we produce renewable energy but at the same time, on the other hand if a field is given to PV technology, it basically means less food is grown which can have important impact for society and nature's ecosystems.

So, is there a way out? Or is it better to stop solar farming altogether and increase regulations for this field? Neither of these options sounds as good as the idea that solar technology and traditional farming can work hand in hand.

#### **Agrioltaic – The Future of Farming?**

A team of French scientists lead by Christophe Dupraz were the first to use term agrivoltaic. It basically means when solar panels and food crops are combined on the same land to maximize the land use. It's an idea which could bring food producing to the next level. Their research field in Montpellier, France, indicated that agrivoltaic systems may be indeed very efficient: the increase of global land productivity can be from 35 to 73% Fraunhofer Institute's For Solar Energy Systems researchers carried out the study about the same topic. Their goal was to find out how solar radiation and food crops can be used and ended up with synergic solution. When all calculations were done, promising results appeared. Researchers discovered that land's productivity could be raised by 60%. The agrophotovoltaic system proved suitable for the practice and costs as much as a small solar roof system. The crop production is sufficiently high and can be profitably sold on the market. So we believe agrophotovoltaic is a new way of using solar technology together with traditional farming.

Of course, it still needs some discussions, testing and further development, but today it is obvious that such method – solar farming in its true sense – has big perspectives to benefit society and business more than it has ever been before. Facing the ambitious target of reaching net-zero emissions by 2050, it is of utmost necessity for the societies worldwide to focus their research efforts on innovative tools and viable solutions to increase the share of clean energy production, without causing additional environmental impact. A remarkable opportunity is offered by combining in a smart way what we already have today, agricultural activity and solar energy production from photovoltaic (PV) panels. The concept of agrivoltaics also called agri-PV or agro-PV, makes dual use of land for agriculture and solar energy generation, and it is one of the research fields that has been emerging in recent years with a large variety of novel agri-PV systems.

The SYMBIOSYST project is an Innovation Action funded by the Horizon Europe programme (Grant Agreement N. 101096352), starting in January 2023 with the aim to combine energy supply issues with the needs of the agricultural sector as well as creating a symbiosis where PV and agriculture can have a mutually beneficial relationship. The project will develop technological solutions and strategies to increase the competitiveness of agri-PV solutions across Europe minimizing the impact on landscape and surrounding environments. Another aim is to foster social acceptance and interest for agri-PV solutions and to encourage further investments. SYMBIOSYST is focused on the development of standardized cost-effective solutions in terms of PV modules, mounting structures and operation and maintenance practices to the specific needs of various crops in different climates and landscapes. The project will demonstrate the developed products and services through the set up and activation of a network of agri-PV plant demonstrators and the application, with in-field testing of the innovative solutions studied, in four agricultural scenarios differing in location, climate, size, and kind of crops. The interdisciplinary consortium in SYMBIOSYST is composed of partners across the value chain with decades of experience in agriculture, precision farming, technology, social acceptance and participatory method, PV modules

and systems, integrated PV applications such as BIPV and agri-PV. Launch of the SEAMLESS-PV project, in the framework of a new phase for Integrated Photovoltaics: the project will demonstrate the new equipment and manufacturing processes in real industrial environments. Six pilot lines hosted by industrial partners will be set-up in the project. In addition, the new manufacturing capacity will be used to build 11 different demo cases across Europe in particular:

- Five demonstrations of building integrated photovoltaics (BIPV) in Italy (Bridgwater, A. V., Toft, A. J., Bramer, J. G., 2002), France, Belgium, and Switzerland covering different building typologies.
- A new PV noise barrier, installed in the A-8/AP-8 highway at the Bizkaia Connected Corridor (BCC), a living lab infrastructure managed by TECNALIA in collaboration with the Bizkaia regional council.
- A demonstration of vehicle-integrated photovoltaics (VIPV), with the application of lightweight solar panels on three different vehicles from Sono Motors in Germany.
- Two demonstrations in the AGRI sector, addressing open agriculture and multi-span greenhouse use cases.

### **An Innovative Solution for the Decarbonisation of the Building Sector**

Biomethane can play a fundamental role to decarbonize energy consumption in the heating industry as well as the transport sector, delivering very high GHG emissions reductions and being a convenient solution for clean mobility. Biomethane is a renewable energy source derived from agricultural biomass (dedicated crops, by-products and agricultural waste and animal waste. Biomethane is a renewable and sustainable substitute for natural gas of fossil origin that can be produced locally; moreover, it favors the recycling of nutrients thanks to the production of digestate (residue from anaerobic digestion for the production of biogas) which can be used as a bio fertilizer in agriculture. These characteristics, added to its very low carbon footprint compared to fossil fuels, make it a powerful ally in the fight against climate change, as it can be complementary to intermittent energy sources, thanks to its widespread distribution network, accumulation and its versatility of use in

practically all sectors, including those difficult to decouple from fossil fuels. Biomethane is also easy to transport, since it consists of the same molecule as natural gas, and hence can be distributed through the existing gas infrastructure. European Biomet adverse project for estimated budget of 10 million of euro launched on April 2023, will focus primarily on the construction of demonstration plants for the production of biomethane. More importantly will be to diversify the technological base, increase its production efficiency and reduce costs. This gas is still expensive to produce and methanation technologies (Bridgwater, Toft and Bramer, 2002) are still not mature and widespread. In this context, ENEA will have the task of supporting developers to evaluate and optimize the technical-economic performance and the environmental and social sustainability of new technologies in view of a large-scale diffusion. In order to foster the uptake of biomethane, actions shall focus on market, society and policy frameworks. Building on these three pillars, the Green Me Up project was launched in September 2022 to enhance the deployment of biomethane at scale across the EU.

## Conclusion

Renewable resources prove to be of strategic importance to achieve a sustainable energy supply. Today, low-temperature (<100°C) thermal solar technologies are reliable and mature for market. So far generation of electric power is using solar energy, novel concept developed and experimented by ENEA, *i.e.* The Archimedes project combining the best technology of today with that of tomorrow consisting of a solar field, a storage system and a steam generator, solar disk powered by air micro turbine, etc. needs to implement on industrial scale. Due attention needs to be focused on the installation of fixed bed gasifier plants of power capacity 25-30 and 80 kW<sub>e</sub>, most appropriate for their diffusion in the agricultural sector especially in the developing countries. With respect to the energy, in order to thrive moving forward, engineers must embrace green engineering technologies. In order to thrive moving forward to design, commercialization and use of processes and products, it is of utmost necessity to reinvent our efforts and actions that needs to be taken to prepare well-trained force of mechanical engineers of the future, able to protect natural resources, decrease the amount of energy

used, work with renewable sources and consider and curtail pollutive output and waste in manufacturing. It is true that AI, robotics and additive manufacturing will likely be the primary technologies driving all fields of engineering for the next decade but the fact remains that software and electrical engineers without support from mechanical engineers, usually cannot actualize their designs.

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