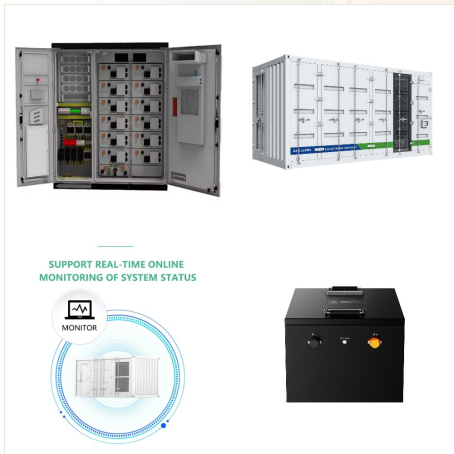


Energy Sources and Conversion Processes
 Photosynthesis Direct thermal Climate Image by
 MIT OpenCourseWare. ??? Specific Energy
 (MJ/kg) ??? Conversion Efficiency ??? Energy
 Density (MJ/L) ??? Form of energy product ???
 Phase ??? CO Conversion 16 Solar Photovoltaics
 Wind, hydro, waves tidal Ocean thermal Biomass
 fuels Chemical Nuclear



Artificial photosynthesis, which uses solar energy to
 convert CO₂ into chemicals and fuels, is a
 promising path toward carbon neutrality (1, 2). Given
 that syngas (CO + H₂) is a vital precursor for many
 valuable fuels and chemicals in various industries
 (3, 4), numerous artificial photosynthetic systems
 have been developed for solar-driven green syngas
 generation by using CO₂ and H₂ ???



The energy conversion efficiency of a fuel cell
 depends on the Gibbs free energy change rather
 than the enthalpy change, Comparing
 photosynthetic and photovoltaic efficiencies and
 recognizing the potential for improvement. Science,
 332 (2011), pp. 805-809, 10.1126/science.1200165.

ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



Main Text Introduction. As of today, solar energy remains the most abundant renewable energy resource available to us. Yet there is a huge gap between our present use of solar energy and its enormous potential (Lewis, 2007a, Lewis, 2007b). This potential is demonstrated by the sheer energy throughput of natural photosynthesis, indicating the ???



Comparing photosynthetic and photovoltaic efficiencies is not a simple issue. Although both processes harvest the energy in sunlight, they operate in distinctly different ways and produce different types of products: biomass or chemical fuels in the case of natural photosynthesis and nonstored electrical current in the case of photovoltaics.

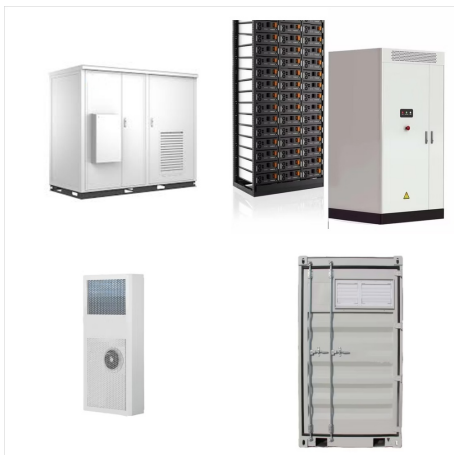


PV system efficiency. The efficiency that PV cells convert sunlight to electricity varies by the type of semiconductor material and PV cell technology. The efficiency of commercially available PV panels averaged less than 10% in the mid-1980s, increased to around 15% by 2015, and is now approaching 25% for state-of-the art modules.

ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



Solar-fuel systems use photoexcitation, chemical transformation, and transport processes to produce fuel. A typical system includes light absorbers integrated with oxidation and reduction catalysts, membrane separators, and water-based electrolytes. Three central chemical reactions are involved in the artificial photosynthesis of carbon-containing products: ???



The physics of photon absorption, exciton and free carrier generation, relaxation, transport, recombination, and collection is analyzed and compared, step-by-step, between photosynthetic complexes and photovoltaic cells. By unifying the physics of the biological photosynthesis process and the device physics of photovoltaic cells, it is shown that well ???



Makita, H. & Hastings, G. Inverted-region electron transfer as a mechanism for enhancing photosynthetic solar energy conversion efficiency. Proc. Natl Acad. Sci. USA 114, 9267-9272 (2017).

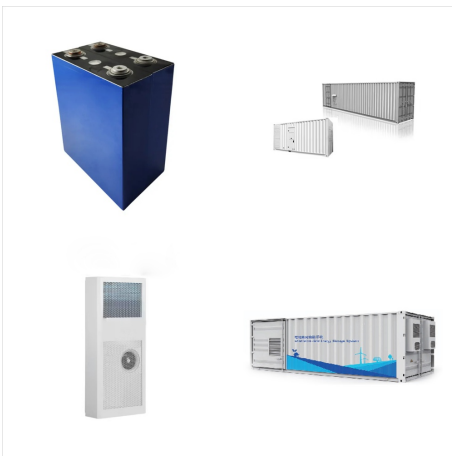
ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



The energy-conversion efficiency for a given species (solar-to-CO in this example) is defined by equation (1): Efficient photosynthesis of carbon
Gao, P., Gr?tzel, M. & Nazeeruddin, M. K



Reported timeline of research solar cell energy conversion efficiencies since 1976 (National Renewable Energy Laboratory). Solar-cell efficiency is the portion of energy in the form of sunlight that can be converted via photovoltaics into ???



The above aspects also put the term energy conversion efficiency in a relative perspective: although, nature has a relatively low overall solar water oxidation efficiency, photosynthesis still operates more stable and reliable than any artificial biomimetic system today???it operates all over the planet and under various different conditions.

ENERGY CONVERSION

EFFICIENCY PHOTOSYNTHESIS

PHOTOVOLTAIC



Solar energy conversion originated from Jan Ingenhousz's hypothesis in 1779 (Magiels, 2007). Jan based this concept on Joseph Priestley's cylinder created in 1771 which was inspired by photosynthesis, a process used to sustain life on earth for 3.5 billion years (Matthews, 2009). The first photovoltaic observation was conducted in 1839 by Becquerel through ???



Although both photosynthesis and photovoltaics harvest energy from the sun, they operate in distinctly different ways producing different fuels. It is not a simple task to find common ground between the two in order to compare energy conversion efficiency. "In order to make meaningful comparisons between photosynthesis (which provides stored



"Artificial photosynthesis"???comprising a PV cell that provides the electricity to split water into hydrogen and oxygen???turns roughly 10 percent of incoming sunlight into usable ???

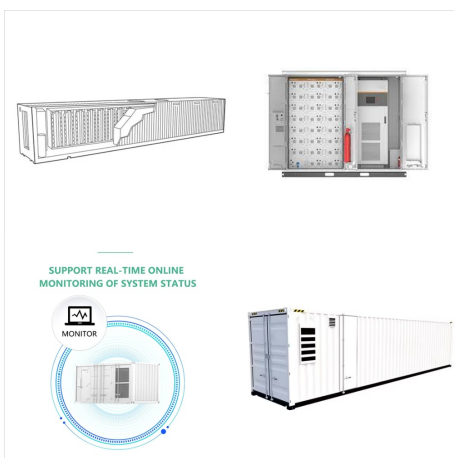
ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



Ever since solar cells appeared, experts have always wondered about which method of harvesting the Sun's energy is the most efficient. Many say that photosynthesis ??? nature's way of doing things



Both harvest the energy in sunlight, operate in distinctly different ways and produce different types of products: biomass or chemical fuels in the case of natural photosynthesis and non-stored electrical current in the case of photovoltaics. To find common ground for evaluating energy-conversion efficiency, a group of researchers lead by Robert Blankenship of Washington ???

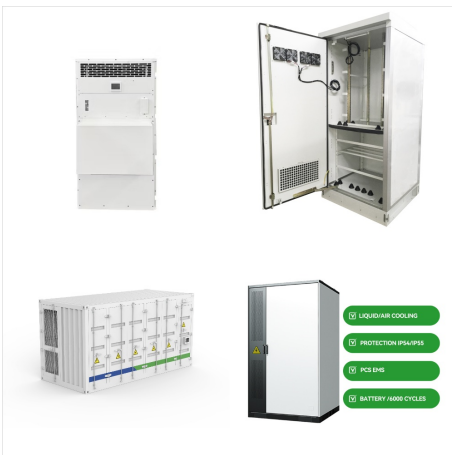


Although this efficiency value falls far below the benchmark of most opaque Si-PV modules or other hybrid systems, such as concentrating photovoltaic/thermal (CPVT) [66], which is due to the inefficiency of photosynthesis, the SCAPV represents a hybrid system with an overall solar energy conversion efficiency higher than that of any existing

ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



Recently, a review by experts in the field of artificial photosynthesis critically analyzed both the photosynthetic and photovoltaic energy conversion mechanisms and clearly emphasized that comparing the energy conversion efficiency of current photovoltaic cells vs. living photosynthetic cells is difficult because both systems work very



Photosynthetic water oxidation by Photosystem II (PSII) is a fascinating process because it sustains life on Earth and serves as a blue print for scalable synthetic catalysts required for renewable energy applications. The biophysical, computational, and structural description of this process, which started more than 50 years ago, has made tremendous ???



Comparing photosynthetic and photovoltaic efficiencies is not a simple issue. Although both processes harvest the energy in sunlight, they operate in distinctly different ways and produce different types of products: biomass or chemical fuels in the case of natural photosynthesis and nonstored electrical current in the case of photovoltaics.

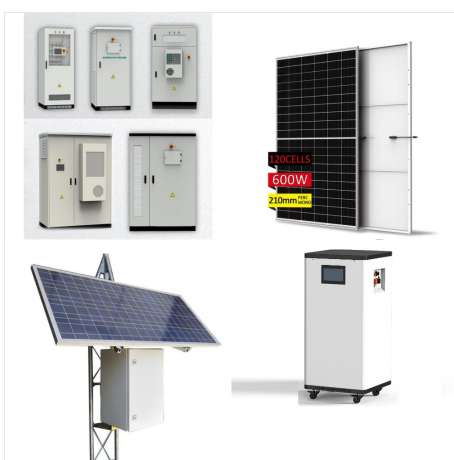
ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



Minimum energy sources associated with biomass production. Zhu et al 2010. This analysis indicates that a theoretical maximal photosynthetic energy conversion efficiency is 4.6% for C3 and 6% for



The free energy needed to split water is essentially the same as that needed for photosynthesis or a solar cell, so the comparison provided a level playing field. Using this type of calculation, the annual averaged efficiency of solar-cell-driven electrolysis is about 10 percent.



These are contrasted with actual measurements in a variety of photosynthetic organisms, including green microalgae, cyanobacteria, C4 and C3 plants. Minimizing, or truncating, the chlorophyll antenna size of the photosystems can improve photosynthetic solar energy conversion efficiency and productivity up to 3-fold.

ENERGY CONVERSION EFFICIENCY PHOTOSYNTHESIS PHOTOVOLTAIC



In this review, we focus on a comparison of the charge carrier dynamics underlying the function of photovoltaic devices with those of both natural and artificial photosynthetic systems. The solar energy conversion efficiency is determined by the product of the rate of generation of high energy species (charges for solar cells, chemical fuels



There is plenty of room for improvement, since photovoltaic conversion efficiencies for inexpensive organic and dye-sensitized solar cells are currently about 10% or less, the conversion efficiency of photosynthesis is less than 1%, and the best solar thermal efficiency is 30%. The theoretical limits suggest that we can do much better.