Chapter 6

Solar Energy and its Multiple Applications

David A. Wood^{1*}, Mohammad Reza Rahimpour²

¹DWA Energy Limited, Bassingham, Lincoln, LN5 9JP, United Kingdom

²Department of Chemical Engineering, Shiraz University, Shiraz, 71345, Iran

* dw@dwasolutions.com

Abstract

Solar energy is commercially exploited to provide benefits in the form of various products and capabilities applying a range of technologies. Electricity generation is achieved either directly from photovoltaic cells made of various materials or indirectly through the steam production from concentrating solar thermal systems. Whereas solar thermal power generation requires large scale plants, photovoltaic systems can be large or small in scale and building integrated, if required. Both types of generation can be standalone or connected to power grids. Solar energy is also extensively used for water and space heating, cooling and drying purposes. It can also be stored and/or transformed into a range of clean fuels and contributes energy to the manufacture of various energy-intensive products. The research into the artificial photosynthetic synthesis of biofuels although encouraging is, however, yet to be achieved commercially exploited on a large scale. Much scope remains for innovative technology breakthroughs to further improve the efficiency and uptake of all the solar energy technologies currently exploited or under investigation. Policy frameworks, renewable portfolio standards, feed-in tariffs and net-metering play an important and ongoing role in promoting the uptake of photovoltaics in particular.

Keywords

Solar Energy, Photovoltaic, Concentrating Solar Thermal, Thermochemical Transformations, Evaporative Cooling, Net Metering

Contents

Solar Energy and its Multiple Applications134

1. Introduction.....	135
2. Insight to solar energy in terms of its potential and challenges	136
3 Advance utilization of solar energy.....	137
3.1 Photovoltaics configured to generate electricity on a large scale	137
3.2 Photovoltaics for the purpose of small-scale supply to residential consumers.....	139
3.3 Solar thermal electricity generation.....	139
3.4 Exploiting solar power to conduct thermochemical transformations	140
3.5 Heating water and space with solar energy	141
3.6 The expectation of artificial photosynthesis to produce useful fuels.....	142
3.7 Evaporative cooling	142
3.8 Policy and regulatory efforts to promote solar energy uptake.....	143
Conclusions	145
References	146

1. Introduction

To date, humanity has experienced miscellaneous improvements to its quality of life and gained access to resources that have expanded its capabilities. Many of these benefits have resulted from developments and refinement associated with innovative technologies. The primary aim of seeking and exploiting new technologies is to enhance prosperity while improving the quality of human life. For instance, new technologies that enhance energy resource recovery [1-6] and /or improve efficiency in a sustainable manner constitute beneficial advances for human existence. The diverse and rapid development of innovative technologies associated with the exploitation of solar energy has the potential to provide a significant environmentally friendly and sustainable portion of future energy supply.

The sun provides about 99.9% of the world's total energy [7,8]. Nuclear fusion reactions occurring within the sun are responsible for the generation of energy within the sun. These reactions have been operating for billions of years and will likely persist for billions of years into the future. The sun releases its energy at a mass-energy conversion

rate of 4.26 million metric tons per second, which equates to 3.846×10^{26} watts. However, the earth receives just 0.000000045% of this power [9]. This is because the energy emitted by the sun is spread over the area of a sphere with a radius of about 93,000,000 miles as it impacts the earth.

2. Insight to solar energy in terms of its potential and challenges

Solar energy possesses a wide range of benefits compared with other energy sources. It is incident and available at some point each day across the entire earth's surface but with different intensity at each location. This means that solar energy as a resource is in plentiful supply, readily available to exploit and sustainable for the foreseeable future. Solar energy has the potential to be transformed into several different and exploitable forms of energy. This means that it can be flexibly configured for beneficial uses in a wide range of applications at many locations around the globe. These transformations are environmentally friendly as they do not involve the formation of pollutants such as greenhouse gases. Conversion of solar radiation at low concentrations can be usefully employed in photovoltaic or solar thermal receivers that are suitable to install on the rooves of urban buildings.

Solar energy does have some disadvantages as well, as being intermittent and not immediately available during night-time, it is more dispersed as an energy source than most other sources, such as fossil fuels. Consequently, solar power facilities require wide surface areas to gather large amounts of solar energy when it is available. The spectrum and severity of sunlight are different at each point on the earth's surface which substantially affects solar energy availability. These characteristics of sunlight are themselves functions of the dimensions of gaseous material that light from the sun must penetrate as it traverses the atmosphere to reach the earth's surface. Additionally, aerosols, clouds, dust, and smoke can play a negative role by diminishing the intensity of light energy arriving at the planet's surface. This means that some geographic locations, i.e., those with a high number of hours with clear skies, low atmospheric pollution levels and relatively low latitudes, can generate more solar power per unit surface area.

Another application of solar energy includes utilizing solar energy as a complementary source of energy to assist fossil fuels to provide more energy in hybrid power generation systems [10]. In terms of economic benefits, hybrid solar power facilities can be adapted to exploit some of the available sites and infrastructure associated fossil-fuel plants to provide incremental power at relatively low cost of supply. Optimal land allocation needs to be carefully planned for large non-urban solar power stations such that they are integrated, accessible and adequately backed-up by more continuously available power supply and adequately synchronized for smooth entry to the power transmission /

distribution grid. Various, commercially viable solar energy conversion technologies are now readily available and selection among them requires careful consideration.

Most solar energy transformation technologies currently involve higher levelized cost of supply than most fossil fuels, although the cost-of supply trend for non-concentrating photovoltaics has reduced rapidly in recent years [11]. That trend is attracting more capital globally into solar energy projects [12]. Large-scale solar energy systems do require substantial capital investments and require careful quality control, project budgeting, planning and management in order to deliver cost-competitive facilities.

3 Advance utilization of solar energy

Procedures employed to gather solar energy radiation and transform it into readily useable forms of energy have been developed over many decades and innovations continue to improve efficiency. The products of these procedures include low-grade heat, high temperature steam, synthesis gas, hydrogen, ammonia, metals, and power. The technologies involved to produce such wide range of products are at varying levels of development and sophistication.

3.1 Photovoltaics configured to generate electricity on a large scale

Photovoltaic (PV) technology originated in the 1950s, was developed commercially during the 1990s and PV panels were first mass produced in 2000 [13]. Since the early 2000 global installed PVs capacity has grown almost exponentially and the technologies involved continue to be improved. Crystalline and amorphous silicon and cadmium telluride photovoltaics have become economically viable competitors to fossil fuels over the past decade. Many governments have welcomed and incentivized the developing photovoltaic integration into electricity networks. Indeed, subsidies and/or mandates that insist upon power system operators facilitating the preferential entry of solar, and other renewable power generated into power grids.

Thin-film photovoltaic cells offer an option to crystalline silicon cells. These are made of either amorphous silicon or metallic compounds able to convert light into electrical energy. Many wafer-based (polysilicon) photovoltaic cells are more expensive to manufacture, and because they are heavier than thin films can be more expensive to transport and set-up. Those cells made of thin-film materials involve a small fraction of the volume of components compared to rigid silicon photovoltaic set-ups. An added attraction is that thin film is able to contribute to roofing material, building cladding, transparent materials for window use and a wide range of applications requiring light flexible materials (e.g. foldable energy blankets, drones, road vehicles etc.). Photovoltaic

cells exploiting thin-film materials are typically constructed by building up thin (semiconductor) layers on to a solid (glass /stainless-steel) substrate. This process requires carefully controlled conditions and is typically performed in vacuum chambers. Laser scribing is required to isolate and electrically connect each electrical cell making up the thin-film photovoltaic module. The semiconductors used are often metallic, especially combinations of copper, indium, gallium, and selenium (CIGS) have received much investment, research and development over recent years. The four distinct semiconducting metals of a copper, indium, gallium, and selenium (CIGS) cell require careful deposition onto the substrate in order to function efficiently. This adds cost to the manufacturing process.

Moderately efficient CIGS cells involve a very small mass fraction of the silicon required for wafer-based cells but they remain more expensive to manufacture because of process complexity and materials costs. Technology breakthroughs are required to improve their energy conversion efficiency, which is typically between 10 to 15%, and reduce their manufacturing costs. Such improvements could expand the photovoltaic market share of thin film technologies from their current position of less than 20%. That market is currently dominated by silicon technologies with their higher energy conversion efficiency, typically from 15 to greater than 20%.

Large-scale commercial uptake of solar photovoltaics began in Japan, followed by Germany. Significant demand in those countries initiated mass production of photovoltaic cells which rapidly expanded to manufacturing centers in China and the United States as well, as the development of photovoltaic cell technologies to safely connect and integrate photovoltaic generation systems into formerly closed grids was also resolved. This has enabled very large-scale photovoltaic facilities (solar parks and farms) to be embedded in existing grids and deliver electricity at operational costs comparable to traditional electricity generation technologies. The generated electricity from such large-scale photovoltaic systems can now be for general grid supply and does not need to be dedicated to specific users [14]. The International Energy Agency's [IEA] Photovoltaic Power Systems Program [PVPS] [13] now follows miscellaneous set-up classifications in a wide range of countries. These systems are predominantly terrestrial [15]. Uptake of these systems has been extensive in Asia, Europe and North America. The main consumer markets for these large-scale photovoltaic developments have grown rapidly over the past decade in Asia and Africa. Scale and intermittency are the key hurdles that need to be overcome by photovoltaics to sustain continued growth in the global market share of power supply. In recent years for larger-scale photovoltaic generation plants it has become more common for the orientation of the solar cells to be continuously

adjusted to face the sun across the course of daylight hours. Such tracking systems substantially increase the amount of power that can be generated.

3.2 Photovoltaics for the purpose of small-scale supply to residential consumers

Many electricity utilities still express some resistance to integrating photovoltaic solar power generation systems into their networks. This is not the case for small-scale, off-grid utilization of photovoltaics dedicated to individual residential and commercial buildings, and on the scale of small communities. Such systems, usually located on the building roofs, are able to conjoin to consumption meters and eliminate or significantly reduce consumption from the utility-controlled power networks. In some cases, such small-scale photovoltaic systems can be connected to the main power grids and export some of the power they generate to the grid and be paid a specified feed-in tariff for that supply. In terms of unit capital and operating costs, small-scale systems are substantially more expensive than utility-scale systems due to the economies of scale exploited by the latter. Nevertheless, these systems can be competitive in terms of cost of supply in the retail power sector. They can also improve security of supply to locations not well connected to the power networks and/or subject to frequent grid interruption. Where such systems are installed on a standalone basis, not connected to the grid systems, their setup costs are lower than those designed to benefit from feed-in tariffs. Small-scale solar facilities typically do not incorporate solar tracking capabilities due to cost issues but this may change as such systems evolve.

3.3 Solar thermal electricity generation

As the concentration of solar flux is a function of the surface area and geographic location, constructing large-scale concentrating solar thermal (CST) plants, as with photovoltaic technologies, requires large sites. They cannot therefore, be easily embedded within urban areas or other densely populated locations. For CST plants efficiency always requires mechanical tracking for the solar collectors continuously orienting them towards the sun.

Many installations utilizing CST technologies have been employed in USA and Spain. Indeed, the early history of CST technologies led to greater uptake for large-scale power generation than photovoltaics [16]. However, the pace of growth of CST for large-scale plants has slowed relative to photovoltaics in recent years. However, several commercial-scale CST plants have also been built in Chile, Egypt, Morocco and the United Arab Emirates. China, India, and Australia have also developed mainly experimental and pilot CST plants. However, globally there is about 3.8 GW of CST capacity constructed with almost double that capacity under evaluation, planning and/or construction. The mining

industry, particularly in Chile and in planning in Australia, are particularly attracted to CST power supplies in remote off-grid areas.

In terms of cost, CST possesses the advantage that it can be more easily connected to large-scale thermal energy storage systems than photovoltaics. Such thermal storage systems typically exploit latent heat or thermochemical conversion reactions to store energy for up to 12 hours or more smoothing the power generation outputs of CST systems across typical 24-hour periods involving day and night cycles. Integrated storage allows providing movable energy depending on demand. Large CST systems typically generate high temperatures used to raise steam and power steam turbines for electricity generation. It is also possible to develop hybrid systems that combine CST with combined cycle gas turbines, as has been done in Egypt and Morocco for example.

Concentration of solar energy is essential for CST systems to achieve high temperatures and more desirable electricity conversion efficiencies. There are various CST technologies developed and applied, including linear parabolic trough reflectors, power towers, Fresnel lenses, and concentrating dishes [17]. Linear focusing parabolic collectors are the most common among the earlier plants constructed. These tend to be associated with one-axis solar tracking and are capable of providing moderate temperatures up to about 400°C. Besides, paraboloidal dishes and centralized power towers which are associated with two-axis tracking provide greater solar energy concentration ratios and, consequently, resulting in greater temperatures. In a solar thermal power plant constructed using a central power tower, the light is reflected from an array of heliostats (moveable mirrors) towards the top of a tower. This involves a large number of heliostats arranged in concentric circles around the power tower each driven by a two-axis tracking system. The Ivanpah CST plant in the Mojave Desert California (377MW), commissioned in 2014, uses such a power tower system. That plant includes 300,000 mirrors and three 459-foot-tall towers. It provides enough electricity to power about 140,000 houses.

Currently, solar thermal generation of electricity remains much less economically beneficial in comparison with fossil-fueled power plants and photovoltaic plants in most locations. Consequently, it tends to be utilized in a location with clear-sky conditions and relatively high solar intensities and in more remote off-grid locations (e.g., to power remote mines in Chile). Technology breakthroughs and economies of scale have the potential to change this, particularly in the Middle East and parts of China.

3.4 Exploiting solar power to conduct thermochemical transformations

There are various energy storage technologies with the potential to decrease the intermittency constraints related to large-scale solar thermal plants. They include

exploiting actual and latent heat to drive endothermic thermochemical processes [18]. Some of the energy storage technologies integrated with CST plants exploit phase changes in mineral salts at high temperatures. In other cases, the generated chemicals associated with thermochemical reactions can be transported, stored and/or directly introduced to reformer reactors where heat is ultimately released in a controlled manner from associated exothermic reactions.

It is also possible to utilize solar-generated heat to conduct endothermic industrial chemical conversion processes. For instance, reactions that alter the chemical content and or molecular structure of a petroleum product to enhance its calorific value and/or increase its hydrogen content. Also, reforming processes that generate hydrogen or synthesis gas from hydrocarbon feedstocks are endothermic and could use solar power as their energy source. To be effective such reactions need to be of large-scale capacity. Some pilot plants have so far been developed [19]. This choice of energy storage and/or chemical transformation differs from latent and actual heat storage processes because the energy can essentially be retained at ambient temperatures. Solar-produced fuels have the potential to provide considerable energy transformation capacity with relatively small investments required in infrastructure to produce them [19]. Other potential product manufacturing product transformation reactions that could be driven by solar energy are the production of lime, cement, ammonia and the smelting of metals. However, those products cannot be utilized for energy storage purposes. Utilizing solar energy to power these varied production processes reduces greenhouse gas emissions and, in the case of petroleum product production, limits the environmental footprint of certain refining and petrochemical processes. Involving solar power in selected refining and petrochemical processes could be a way of extending the life of petroleum resources by reducing their carbon footprints.

3.5 Heating water and space with solar energy

One relatively easier exploitation of solar energy is to generate hot water at various scales. Today, solar water heating systems are widely utilized around the world at small, residential scales up to large industrial scales. It represents a substantially exploited renewable energy technology [20].

Domestic hot water production exploiting solar thermal technologies is now commonly integrated with many buildings. It is estimated that some 18% of total energy use in the buildings in the USA, and 14% in the European Union is associated with hot water consumption [21]. Providing more of this resource from solar energy has the potential, therefore, to result in a significant reduction in urban energy emissions. About 480 Gigawatts-thermal of solar water heating capacity was installed globally by the end of

2018 [22]. Research has shown that there are a wide range of domestic hot water (DHW) consumption profiles and these impact the effectiveness of the solar thermal equipment used to produce hot water. The water volume consumed and the heating time is the key variable that impacts domestic solar thermal water heating systems [23-25]. Koroteev and Kharun [26] demonstrated how the dynamic operation of solar thermal collectors can satisfy various DHW consumption profiles. This enables the design of solar collectors to operate with just a fraction of solar coverage.

This technology does not require an urban grid connection infrastructure. It is typically installed as standalone systems using glazed evacuated tubes or flat plate collectors and unglazed systems. These systems are relatively cheap to install and maintain. There are two principal solar hot water system designs employed: open-loop and closed-loop. In open-loop or direct systems, solar radiation is used to heat water directly. In closed-loop or indirect systems, solar energy is initially used to heat transfer fluid, contained within a closed piping loop, which is then subsequently used to heat water in a tank.

3.6 The expectation of artificial photosynthesis to produce useful fuels

One way to potentially generate energy fuels in an environmentally friendly manner is to utilize solar-driven photocatalytic reactions to generate hydrogen or synthetic hydrocarbon biofuels directly by combining water and carbon dioxide feedstocks. These reactions mimic the photosynthesis reactions that sustain the green plant world and are referred to as artificial photosynthesis. Carbon dioxide fixation, in a carbon-neutral system, is conducted together with water oxidation. Consequently, artificial photosynthesis reactions have the potential to remove undesirable carbon dioxide from the atmosphere and produce useful fuel products [27].

However, as yet, there are no commercial-scale artificial photosynthesis system constructed, despite substantial research efforts conducted with a wide range of structures and materials over recent decades [27,28]. This is because the conversion efficiency of artificial photosynthesis reactions remains low. Progress in the miscellaneous fields such as catalysis [6], materials sciences and nanotechnology must be made to improve the efficiency of artificial photosynthesis reactions. Research associated with artificial photosynthesis is ongoing due to the environmental desirability to find cost-effective solutions and technology breakthroughs are likely.

3.7 Evaporative cooling

Cooling spaces in warm climates can be effectively achieved by solar-thermal energy generation, even though solar heat is primarily exploited to produce hot water and space

heating. It can also be deployed to support many industrial processes requiring moderately hot or cold conditions and also use solar for drying purposes.

Evaporative cooling is most used in countries that experience seasonal, or year-round, hot humid conditions. It is mainly exploited in the form of air conditioning. It is also exploited in many industrial systems that require cooling towers. Heat can be absorbed by warm air fan-assisted movement over water in the form of latent heat of evaporation of the water. In some systems, evaporative cooling is passive with natural wind energy moving air across open ponds. Cooling towers associated with all thermal power plants (biomass, fossil-fuel and nuclear) all rely on forced or natural evaporative cooling. It is a form of exploitation of solar energy that is usually not recorded in renewable energy statistics; yet, it represents a significant energy requirement.

3.8 Policy and regulatory efforts to promote solar energy uptake

International Energy Agency's Photovoltaic Power Systems Programme (IEA PVPS) (2019) follows and analyzes the policy of photovoltaics annually among its member nations and from time to time releases an updated report addressing the status of government policy associated with this sector (Figure 1) [29].

Figure 1 Contribution of market incentives for photovoltaics with the aim of drivers of market share (after Crawley 2013) [29].

Policies employed for photovoltaics tend to be representative of those applying to solar energy more generally [13, 30]. The most developed and utilized government-support mechanism is the feed-in tariff (FiT). The FiT mechanism enables photovoltaic systems to provide energy to a grid or network at a pre-determined price for a specified period [31]. FiTs, therefore, provide PV producers with the guarantee of profitable prices and, thereby, incentivize the construction of more PV capacity.

FiTs have been employed extensively in Germany, Italy, United Kingdom, Japan and China. The cost of sustaining them is borne by the consumer, general taxpayer and/or by carbon taxes paid by fossil fuel power producers and utilities.

A renewable portfolio standard (RPS) is a policy backed up by regulation that mandates the increased production and supply of energy from renewable energy sources. When an RPS is in place utilities must honor its requirements or pay penalties for not doing so. An RPS provides a market-based remuneration for renewable electricity producers for their output to the network. Many jurisdictions have allowed projects to remunerate locally produced electricity connected to the grid to take into account local or self-consumption through some form of net-metering mechanisms. These result in a decrease in demand for imported grid electricity and, consequently, a cost-saving for the PV generator/energy consumer and a reduction in cost for the grid utility to supply that component of self-consumed power. Following the successful introduction of RPS, FiT and net-metering in Germany a decade ago, these features are now widely used in many countries around the world.

The way net-metering mechanisms are applied by many utilities often does not adequately compensate PV producers/consumers connected to the grid for the true cost savings they achieve for the grid. For instance, the utilities persist in charging small-scale PV providers high connection charges. Regulators are beginning to recognize the justification to adjust traditional energy-based and capacity-based tariffs to reflect the true value of small-scale PV producers to grids [32]. Nevertheless, the demand for grid-connected solar energy and uptake of net-metering schemes continues to increase due to the enhancement of the energy efficiency of PV cells and systems and the growth of solar energy connected to many power grids [33]. By providing more favorable tariff structures and net-metering adjustments regulators have the potential to motivate higher uptake of small-scale PV installations in many countries. Consequently, many power utilities operating system designed, built and operated to primarily use large-scale fossil-fuel generation are opposed to more favorable net-metering and connection tariff terms for small-scale embedded PV power generators.

Further reductions in the cost of supply of renewable energy generation is desirable. However, the observed continued trends of PV cost reductions are resulting in some difficult decisions for policymakers and operational challenges for system operators [34]. For instance, the enhancement of PV power production and the number of intermittent embedded generators tend to increase system management costs, decrease its stability and security of supply. This makes accurate prediction of solar power availability taking into account diurnal and seasonal fluctuations in solar intensity. Sufficient solar capacity and historical solar power generation data exist in Germany that makes it possible to use machine learning algorithms to provide accurate hourly solar power availability forecasts on a regional or country-wide basis [35]. Competition and availability between distributed and centralized power generators become less predictable. As PV costs fall it becomes more difficult for governments and regulators to justify any cost burden on the taxpayers to support new capacity and this can undermine the motivation to achieve the RPS.

Conclusions

Significant progress has been made to address most of the technical challenges facing solar energy technologies, including conversion efficiency, suitable materials and systems configurations, stability, durability and issues related to low and high temperatures. Today, solar energy is exploited in several forms using a range of technologies that continue to improve in terms of their performance due to ongoing innovation and technology refinements. This means that it can be used competitively for various applications. Power generation via photovoltaics, on small and large scales, and concentrated solar thermal for large-scale and sometimes remote applications is a primary use. It is also widely used for water and space heating and cooling on large and small scales. Although energy from the sun is intermittent, it can be successfully stored by a range of thermo-chemical reactions. It can also be usefully transformed by other reactions into valuable fuels and materials but its full potential in this regard has yet to be widely exploited at a commercial scale. Ongoing research into artificial photosynthesis reactions exploiting solar energy to generate clean fuels from a combination of reactions involving water and carbon dioxide requires further technology breakthroughs before it can be established as commercially viable. Integrated policy initiatives and regulatory mandates incorporating feed-in tariffs, net-metering and aspirational renewable portfolio standards have helped to promote and motivate photovoltaic technology uptake in many countries.

References

- [1] E. Sadatshojaei, M. Jamial ahmadi, F. Esmaeilzadeh, D.A. Wood, M.H. Ghazanfari, The impacts of silica nanoparticles coupled with low-salinity water on wettability and interfacial tension: Experiments on a carbonate core, *J. Disper. Sci. Technol.* (2019) 1-15. <https://doi.org/10.1080/01932691.2019.1614943>
- [2] A. Choubineh, H. Ghorbani, D.A. Wood, S.R. Moosavi, E. Khalafi, E. Sadatshojaei, Improved predictions of wellhead choke liquid critical-flow rates: modelling based on hybrid neural network training learningbased optimization, *Fuel*. 207 (2017) 547-560. <https://doi.org/10.1016/j.fuel.2017.06.131>
- [3] R. Rezaei Dehshibi, A. Sadatshojaie, A. Mohebbi, M. Riazi, A new insight into pore body filling mechanism during waterflooding in a glass micro-model, *Chem. Eng. Res. Des.* (2019) 151. <https://doi.org/10.1016/j.cherd.2019.08.019>
- [4] E. Sadatshojaei, M. Jamialahmadi, F. Esmaeilzadeh, M.H. Ghazanfari, Effects of low-salinity water coupled with silica nanoparticles on wettability alteration of dolomite at reservoir temperature, *Petrol Sci. Technol.* 34(2016) 1345-1351. <https://doi.org/10.1080/10916466.2016.1204316>
- [5] D.A. Wood, Microbial improved and enhanced oil recovery (MIEOR): Review of a set of technologies diversifying their applications, *advances in geo-energy research*. 3 (2019) 122-140. <https://doi.org/10.26804/ager.2019.02.02>
- [6] E. Sadatshojaei, F. Esmaeilzadeh, J. Fathikaljahi, S.E.H. Barzi, D.A. Wood, Regeneration of the midrex reformer catalysts using supercritical carbon dioxide, *J. Chem. Eng.* 343 (2018) 748-758. <https://doi.org/10.1016/j.ccej.2018.02.038>
- [7] M.P. Soriaga, Ultra-high vacuum techniques in the study of single-crystal electrode surfaces, *Prog. Surf. Sci.* 39 (1992) 325-443. [https://doi.org/10.1016/0079-6816\(92\)90016-B](https://doi.org/10.1016/0079-6816(92)90016-B)
- [8] Chapter 17: Solar energy. Available from: <https://personal.ems.psu.edu/~radovic/Chapter17.pdf>
- [9] J. Kennewell, A. McDonald, The solar constant, 2015, Available from: http://www.sws.bom.gov.au/Category/Educational/The%20Sun%20and%20Solar%20Activity/General%20Info/Solar_Constant.pdf
- [10] J. Mankins, Space solar power: The first international assessment of space solar power: Opportunities, issues and potential pathways forward, International Academy of Astronautics. 2011.

- [11] M.W. Parker, H. Wynne, N. Beveridge, O. Clint, B. Brackett, S. Gruber, Bernstein energy & power blast: Equal and opposite. if solar wins, who loses?, Bernstein Research. 2014.
- [12] Fund announces plans to divest from fossil fuels, Rockefeller Brothers Fund, 2014.
- [13] International energy agency-Photovoltaic power systems programme annual reports for years 2005 to 2018, Snapshot of Global PV Markets. 2019, Available from: <http://www.iea-pvps.org>
- [14] R.M. Swanson, The promise of concentrations, Prog. Photovolt. Res. Appl. 8 (2000) 93-111. [https://doi.org/10.1002/\(SICI\)1099-159X\(200001/02\)8:13.0.CO;2-S](https://doi.org/10.1002/(SICI)1099-159X(200001/02)8:13.0.CO;2-S)
- [15] R. Corkish, W. Lipiński, R. Patterson, Introduction to solar energy, in: G.M. Crawley (Eds.) Solar Energy, Marcus Enterprise LLC, USA (2016) 1-29.
- [16] J. Salvatore, World energy perspective: cost of energy technologies, World Energy Council. United Kingdom (2013) 1-48.
- [17] V.S. Reddy, S.C. Kaushik, K.R. Ranjan, S.K. Tyagi, State-of-the-art of solar thermal power plants-A review, Renew. Sust. Energ. Rev. 27 (2013) 258-273. <https://doi.org/10.1016/j.rser.2013.06.037>
- [18] P. Pardo, A. Deydier, Z. Anxionnaz-Minvielle, S. Rougé, M. Cabassud, P. Cognet, A review on high temperature thermochemical heat energy storage, Renew. Sust. Energ. Rev. 32 (2014) 591-610. <https://doi.org/10.1016/j.rser.2013.12.014>
- [19] C. Agrafiotis, H. von Storch, M. Roeb, C. Sattler, Solar thermal reforming of methane feedstocks for hydrogen and syngas production-A review. Renew. Sust. Energ. Rev. 29 (2014) 656-682. <https://doi.org/10.1016/j.rser.2013.08.050>
- [20] S. Sathishkumar, T. Balusamy, Performance improvement in solar water heating systems-A review, Renew. Sust. Energ. Rev. 37 (2014) 191-198. <https://doi.org/10.1016/j.rser.2014.04.072>
- [21] L. Pérez-Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energ. Build. 40 (2008) 394-398. <https://doi.org/10.1016/j.enbuild.2007.03.007>
- [22] REN21 Renewables 2019 global status report. REN21 Secretariat, Paris, (2019).
- [23] A. Henning, Equal couples in equal houses: Cultural perspectives on Swedish solar and bio-pellet heating design, in: S. Guy, S. Moore (Eds.), Sustainable Architectures: Cultures and Natures in Europe and North America, Spon Press, Routledge. (2005) 103-118.

- [24] R. Spur, D. Fiala, D. Nevrala, D. Probert, Influence of the domestic hot-water daily draw-off profile on the performance of a hot-water store, *Appl. Energ.* 83 (2006) 749-773. <https://doi.org/10.1016/j.apenergy.2005.07.001>
- [25] J. Burch, C. Christensen, Towards development of an algorithm for mains water temperature, in *Proceedings of the solar conference*. Citeseer, (2007).
- [26] D. Koroteev, M. Kharun, Influence of construction of transparent covering on efficiency of concrete heat treatment in shuttering forms with using solar energy, *Structural mechanics of engineering constructions and buildings*. 14 (2018) 64-69. <https://doi.org/10.22363/1815-5235-2018-14-1-64-69>
- [27] W. Tu, Y. Zhou, Z. Zou, An in situ simultaneous reduction-hydrolysis technique for fabrication of TiO₂-graphene 2D sandwich-like hybrid nanosheets: graphene-promoted selectivity of photocatalytic-driven hydrogenation and coupling of CO₂ into methane and ethane, *Adv. Mater.* 26 (4607) (2013). <https://doi.org/10.1002/adfm.201202349>
- [28] Z. Han, R. Eisenberg, Fuel from water: The photochemical generation of hydrogen from water. *Acc. Chem Res.* 47 (2014) 2537-2544. <https://doi.org/10.1021/ar5001605>
- [29] G.M.Crawley, *The world scientific handbook of energy*, 3, World Scientific Publishing, Hackensack (2013).
- [30] M. Miller, S. Cox, Overview of variable renewable energy regulatory issues, National Renewable Energy Laboratory (2014).
- [31] M. Mendonça, *Feed-in Tariffs, Accelerating the deployment of renewable energy*, Sterling, VA: Earthscan, (2007).
- [32] R. Passey, M. Watt, R. Brazzale, Impacts of PV, AC, Other technologies and tariffs on consumer costs, Australian PV Institute (APVI), (2013).
- [33] J.P. Marshall, Disordering fantasies of coal and technology: Carbon capture and storage in Australia, *Energ. Pol.* 99 (2016) 288-298. <https://doi.org/10.1016/j.enpol.2016.05.044>
- [34] S. Vinci, D. Nagpal, R. Ferroukhi, E. Zindler, A. Czajkowska, Adapting renewable energy policies to dynamic market conditions, International renewable energy agency (IRENA) (2014).
- [35] D.A. Wood, German solar power generation data mining and prediction with transparent open box learning network integrating weather, environmental and market variables, *Energ. Convers.Manag.* 196 (2019) 354-369. <https://doi.org/10.1016/j.enconman.2019.05.114>