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Safety of Alternative Energy Sources: a Review

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The article summarizes a short review of the literature focused on safety in the field of alternative energy sources. With an increasing orientation towards sustainable and renewable energy sources, new technologies will come to the fore. These facts must be demonstrated in occupational health and safety. Several studies focused on alternative energy sources are mentioned and show the trends for the future. Especially in the area of hydrogen and battery technologies, systems should pay attention to acquisitions as a normal part of our lives. Safety research is essential for the acceptance of cleaner, efficient, and sustainable future.

1. Introduction

Currently, society is more interested in alternative fuels or alternative energy sources. If these topics are mentioned many people imagine alternative fuels for cars as LPG, CNG, or electricity. These types could be an alternative to petrol and diesel. But with the connection to alternative energy sources, there are other factors that will be important in the near future not only in transport, but also in energy and heavy industry. Currently, the generation is trying to focus on renewable energy sources, especially inexhaustible sources such as hydropower, wind, and solar. Except these main sources, combustion of biomass, biogas or waste energy should be mentioned. With the idea of a clean future and production, decarbonization and reduction of greenhouse gases (GHG), hydrogen is the most mentioned alternative energy source. Hydrogen is connected with energy policy, transportation, and also with heavy industry. They can be proved by hydrogen strategies which were accepted not only in Europe. But, as was mentioned by Rivas et al. (2021), Europe built on a strong effort to mitigate and adapt to climate change. Instead of reducing GHG emissions and increasing resilience, which is led by European Commission (2016), the first priority for the next few years is the Green Deal (European Commission, 2019). The main goal is to make Europe climate neutral by 2050 and transform it into a modern, resource-efficient, and competitive economy. These facts could lead to changes in industry, householders, or in transport and other specifications.
In this article, alternative energy sources are mentioned further. For each of them, the safety for handling, transport and using is discussed in the context of the future changes in society, industry and the emerging risks. In the end, the evaluation and comparison of the current knowledge and possibilities are determined.

2. Alternative energy sources

Today society is aiming for a better future in the sense of clean and safe production. The aim is to reach a complex process in which renewable energy sources have minimal impact on the environment. Stančin et al. (2020) use the term alternative fuels that could be used for the development of energy or energy storage. The authors describe selected alternative fuels with their advantages and disadvantages. The purpose of using alternative fuels is clear: sustainable and clean production without other emissions of CO_2. Several countries have adopted decarbonization goals with changes in the next few decades.
The explanation is given by Boyle et al. (2021), three policies in the field of future and their climate situation. The aim of the Green Deal is to use renewable energy sources and establish a zero-emission energy system. Based on this, the differences between three distinct climate policy paths to 2050 are shown. The main goal for

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the next generation is to use a renewable, zero-emission energy system which will lead to improved equity, health through environmental and labour justice. These policies lead to minimized climate catastrophes and displacement. In the study of Boyle et al. (2021) 14 different climate policy proposals were compared. All compared policies were with characteristics of the Green Deal framework on multiple jurisdictional scales. Analysis shows current areas that are included in the Green Deal and also differences in the level of detail of specific plans. As mentioned above, society is focused more and more on hydrogen as the future of energy storage. With connection to energy input such as solar energy or wind generators, this combination is green, meaning zero carbon emission. Zohuri (2018) gives an elementary account of hybrid renewable energy systems. This system combines two or more forms of energy generation, storage or end-use technologies and other benefits compared to single-source systems. Renewable energy sources for power generation are solar energy, offshore and onshore wind and hydropower. Stančin et al (2020) mentioned various alternative fuels such as electro fuels, hydrogen, ammonia, biodiesel/biomass, alcohol derived fuels and non-recyclable waste. The combination of renewable energy sources and alternative fuels must be able to substitute non-renewable energy sources in the future. Non-renewable energy sources are represented by coal, petroleum, natural gas or nuclear fuel as rich energy sources but exhaustible. These sources make up about 85 % of overall energy consumption worldwide, and resources are finite and reserves are depleting (Abdalla, et al. 2018). Research and exploitation of renewable sources takes place depending on it. For the purposes of this article, the energy sources that could be named alternative fuels or alternative energy sources were chosen. These are, solid fuels, such as biomass or waste-derived fuels, hydrogen and batteries. For these alternative energy sources, potential risks and dangers are described. Especially with respect to future changes in the industry and the focus on renewable and zero-emission production.

2.1 Solid alternative fuels

Solid alternative fuels are defined as solid recovered fuels in the EN ISO 21637:2020 standard. Composition of solid recovered fuels of wood, paper, board, textiles, plastics, or rubber is formed, for example, sewage sludge or end-of-life wood. Substances or objects that are discarded or intended to be discarded are waste. In connection with this, the term waste to energy is often mentioned (Puttachai et al. 2021). Waste to energy includes energy recovery from waste by direct combustion with or without heat recovery or methane combustion produced in landfill sites. Another option is organic waste which is used to produce methane for burning. Recycling of waste remains the main aim and their return to the industrial cycle. In the future, this renewable energy production might be used for hydrogen production and therefore will increase. Gil (2022) wrote about waste and by-products as sustainable, renewable and which are essential unlimited sources of biomass. Biomass is used in sustainable energy systems and generates electricity, heat and cold or bioliquids and biofuels.

In the process of use of alternative solid fuels or energy sources hazards exist which must be considered. Especially risk of self-ignition, fires, and explosion. Risk presents the possibility of loss, injury or other adverse or unwelcome circumstance or could be conceived as an insufficient potential to meet external harmful demands (Axon and Darton 2021). Due to the possible presence of dust particle size, it is necessary to consider whether biomass or other solid alternative fuels can form a flammable mixture with air (Liu et al. 2019). The study of the dust explosion parameters and combustion kinetic parameters is important for knowledge and prevention and control of dust explosion. Dust explosions are not daily incidents, but it is not advisable to underestimate this risk. The results of dust explosion could be extensive damage to technological buildings and equipment or with threat to people and employees in direct contact. The safety problems with biomass or solid fuels in its storage and transportation process become more significant.

During storage, self-heating can occur and cause a fire toxic gases or smoke. When this material is transported, friction is expected and then small dust particles develop (Liu et al. 2021). If the biomass layer represents the risk of self-heating and fire, small particles of dust are connected with a significant risk of dust explosion. A typical sample is the storage of wooden chips or biomass in the silos (Hedlund et al. 2014). Well-known is the procedure for the risks of explosion. The first is the likelihood that explosive atmospheres will occur and their persistence and also the likelihood of ignition sources. Except for this, installations which can give rise to an explosion, substances used and their possible interactions, and in the final account the scale of the anticipated effects (Molino et al. 2012). Several studies focused on biomass explosion and testing (Slatter et al. 2015) or thermal behavior of organic solid recovered fuels (Medic-Pejic et al. 2016). The determination of thermal behaviors and safety characteristics is necessary for effective protection. Medina et al. (2015) compared the explosion characteristic of the experimental measurement and the flame speeds of pulverized coals and biomass in the 1 m^3 dust explosion equipment. The results show biomass and coal with almost the same explosion characteristics and a wide range of reactivities could be found for biomass and coals. In connection with biomass, there could also be biomass gasification which presents a risk of gas explosion or liquid forms of biofuels. Dependent on the physical state safety characteristics have to be carried out similar to fossil fuels. For example, safety requirements for gas turbines, safety storage of flammable or explosive materials, or manipulation and transport of flammable liquids. Biogas consist mainly of methane and carbon dioxide. The potential hazards posed by the biogas plants of Stolecka and Rusin (2021) are listed. The most common consequences of failures in biogas plants are fires and explosions. With an increasing amount of renewable energy sources and their transformation to hydrogen in biogas or biomass plants hydrogen equipment may be present as a hybrid power plant. Explosion protection in biogas and hybrid power plants discussed by Schroeder et al. (2014) where explosion regions of mixtures of methane, hydrogen, and carbon dioxide have been experimentally determined. Gasification of waste might lead to fire, explosion and toxicity accidents. Rollinson (2018) states that the waste industry and technology have high risks associated with multiple pathways for fire, explosion and the release of environmental toxins. Experiences and lessons from past accidents must be considered for the reduction of potential future losses.

2.2 Hydrogen energy

Prospects and challenges of renewable hydrogen were written by Abbasi and Abbasi (2011). At the time there were known hydrogen advantages, but the production of hydrogen was realized by consuming fossil fuels and CO_2 emissions were produced. The technologies are a bit further today, but still extensive research is essential to investigate and design on board. However, the cost of hydrogen production from renewable sources is expensive compared to gasoline or fossil fuels and less efficient. A large review on hydrogen production, storage, transportation and key challenges with applications was conducted by Abdalla et al. (2018). It is noted that for the near future it is necessary to develop new technologies and infrastructure for production and storage. Abdalla et al. (2018) mentioned several types of hydrogen production such as steam methane reforming, from coal, partial oxidation, etc. But for the future, a sustainable and zero emission future is necessary to ensure hydrogen production from renewable sources. Ma et al. (2021) compared hydrogen and ethanol production, storage, and transportation as representative of existing fuels produced from renewable green energy sources. Also, several options for each process were mentioned. Other comprehensively review focus on hydrogen safety (Abohamzeh et al. 2021) analyse safety challenges in hydrogen storage, transmission and application processes. Attention is aimed at CFD modelling of safety aspects of hydrogen handling. Good tools for predicting hazardous scenarios in hydrogen applications. For example, Kim et al. (2017) presented simulations of blast wave and fireball occurring due to rupture of a high-pressure hydrogen tank. Hussein et al. (2020) simulated dispersion of hydrogen release in a naturally ventilated covered car park, which confirms trends with hydrogen in cars. The use of hydrogen in internal combustion engines from the point of view of combustion performance was studied by Akal et al. (2020). Hydrogen influenced engine performance and exhaust emission. Notwithstanding these facts, it is mentioned developing suitable lubricant oils and oil materials for internal engine parts because of longtime use of hydrogen inside the engines. For combustion engines, synthetic fuels could be prepared. This type of fuels could be the real future of sustainable mobility and safe not only for classical combustion engines or hybrid electric vehicles, but could also be used for heating or for the production of plastics and other materials. Synthetic fuels are produced by the chemical reaction of hydrogen and carbon dioxide. In a way, it is a storage and accumulation of energy. Depending on the input sources of energy, hydrogen, and carbon, it could be a low-carbon or carbon-neutral technology of production of synthetic fuels. Synthetic fuels might substitute fossil fuels in the sectors where it is necessary to use fossil fuels (García et al. 2022). Synthetic fuels are energy storage, but great advantage is the use of existing and available infrastructure for storage, transport, and utilization. Compared to hydrogen production, it is easier for use, but there is the same question about energy efficiency.

From a safety point of view, Yang et al. (2021) focused their study on hydrogen safety and analyzed 120 incidents related to hydrogen. The most common cause of accidents, pipeline and valve failure, or filters in the water system. Only detection and identification of gas release should be the main focus for ensuring safety. The development of hydrogen, the option for using and energy storage shoes the importance of hydrogen using. But adding it to daily life is necessary to solve a problem with transport for long distances. Natural gas transport is carried out through the pipeline system. The use of this existing infrastructure is a potential option for hydrogen transport from countries with redundancy of green hydrogen. But hydrogen can have a negative impact on material properties and therefore loss of function and safety. Based on this, the current pipeline system is not capable of transporting clean hydrogen or mixing with natural gas because a small percentage of hydrogen can influence transport safety, including reliability and durability Messaoudani et al. (2016). Hydrogen transport should be ensured at least to such an extent as in the case of hydrocarbon technologies. Najjar (2013) characterized risks in hydrogen connection as physiological (frostbite and suffocation), physical (embrittlement and component failures) and chemical (burning and explosion), where the creation of flammable or explosive mixture with air is primary danger. With hydrogen manipulation, extra care must be taken in particular to avoid easy escape of hydrogen, low ignition energy, and wide range of flammable mixtures with the air and the pressure magnitude. The ability for embrittlement of metals has to be considered for ensuring the safe operation of hydrogen systems. Loss of integrity of hydrogen systems could have serious consequences, such as fire and explosion. This topic was critically evaluated by Ustolin et al. (2020), focused on the entire life cycle of hydrogen technologies. Safety is mentioned at the end as one of the common aspects for life cycles related with distributions and development of these systems and technologies, which makes hydrogen a multidisciplinary theme.

2.3 Battery

Batteries are another way to store electrical energy. Battery systems are energy storage and it is necessary to pay due attention from the point of view of safety and to eliminate random and uncontrollable energy release. In connection with the above mentioned, this will increase not only hydrogen technologies and systems, but also batteries and their use. Batteries are used especially in electric vehicles to reduce air pollution. For batteries, self-heating and explosion caused by thermal runaway is typically (Zichen and Changqing, 2021). The main causes of heat release the heat accumulation and local overheating during charging and discharging. Lin et al. (2021) states that lithium ion batteries are preferred in new energetic vehicles due to their speed of self-discharge, long life, and high performance and energy density. But degradation and heat safety are the main challenge for research and development.

Schismenos et al. (2021) provide a review of lead acid and silver zinc batteries in the battery hazards and safety area. These battery types are the most common use with lithium-ion batteries. The article meets with safety regulations and with possibly threats which could be caused by batteries. It is necessary to know the risks associated with battery mistreatment or improper maintenance. Several studies are focused on the simulation and modeling of accidents caused by batteries. Henriksen et al. (2021) carried out a simulation of a premixed explosion of gas vented during li-ion battery failure. Catastrophic battery failure should be caused thermally, electrically, or mechanically based on historical accidents such as a battery energy storage system fire, likely from a single cell failure, leading to an explosion with the injury of several firefighters. Fires in electric or hybrid cars can cause explosion due to accumulation of flammable gases from damaged battery.

The problem occurs with batteries also during firefighting and because of that new methods of cooling or suppression and extinguishing battery fires are developed. Yuan et al. (2021) reviewed the fire-extinguishing agent to suppress lithium-ion batteries fire. In the article several extinguishing agents, including gases, dry powder or water-based extinguishing agents, and aerosols were discussed with their typical advantages or disadvantages. Zhang et al. (2022) focused their attention on the experimental investigation of intermittent spray cooling and the toxic hazards of thermal runaway from lithium-ion batteries. During experimental measurement, investigate insider temperature, battery voltage and also releasing gases during a thermal leakage. The results show the necessity of strict safety protections in the cases where intermittent spray cooling is used. Jin et al. (2021) combine the experiment with simulation and analyzed the process of explosion caused by battery failure. Battery failure leads to the release of flammable mixtures containing organic carbonates and flammable gases such as hydrogen, methane, or propane. Henriksen et al. (2019) tested the explosion characteristic in a 20-liter explosion sphere for dimethyl carbonate, diethyl carbonate, and ethyl methyl carbonate in different concentrations. The results are compared with those of hydrogen, methane, and propane experiments. Baird et al. (2020) present an overview composition of battery exhaust gases for different chemicals. Critical models for estimate lower flammability limit, laminar flame velocity, and maximum overpressure are discussed. The paper provides instructions on how to use these models for the prediction of the combustion properties of exhaust gases. Batteries are in everyday life and increasing problems occur constantly. These must be prevented or responded to quickly and effectively because they present significant risks. Christensen et al. (2021) present comprehensive knowledge in the area of risk management of all lithium ion batteries in electric cars.

3. Conclusions

In the near future, one has to expect an increase in the use of alternative sources of energy. With the coming new technologies, development and research, the society must respond and prepare to overcome the possible dangers. The most talked about for the future is hydrogen, but also batteries or solid materials. New technologies, development in the industry and hybrid systems bring to society advantages but also emerging new risks. It can be assumed, that the integration of new pressure systems may lead to a higher accident rate if not taken serious from the beginning. Although there will be a new safety assessment, it can be based on experience from scientists and experts and adapt existing legislation to new facts. It is safe to say that industry and society are undergoing some renewal, revolution and safety should pay a key role in gaining confidence in new systems. From this point of view, it is necessary not to underestimate these facts and prepare for them in the phase of learning, education, training or research. New options are generated in the area of preparedness of firefighters for new and emerging risks related to alternative energy sources. It is necessary to prepare also employees and employers or people for new technologies, new cars and infrastructure.

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