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Fast Growing Energy Forest - Is "The Fifth Element" That Humanity Lacks for a 100% Changing to Clean Renewable Energy

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Abstract: Renewable and clean energy sources are the only way for humanity to live harmoniously on planet Earth. How to achieve this goal? Solar and wind energy are produced only when the sun and wind are present. The percentage of hydropower is quite small. Therefore, compensating sources of energy are needed at night and in winter. Today, these are coal and gas-fired power plants. The goal of the Fast grow Energy Forest project is to grow and harvest wood (biomass) as a source of replacing fossil coal and gas for power plants and boilers. Ten-year research by scientists together with producers demonstrates the effectiveness of growing fast-growing trees, which are technologically cut with harvesters for biomass every 3 years. This project has great economic, environmental and energy prospects and needs immediate support from financial institutions, scientists and the government. This is a real ecologically clean bioaccumulator of solar energy. After the complete cutting of plants, willow plantations, the shoots grow again and after three years the upper part of the tree is completely restored. That is, when cutting Fast grow Energy Forest for wood, we do not destroy it, but restore it. Is this project environmentally friendly? After all, we burn sawn wood and pollute the air with CO_2? Yes, this project is ecological and works with "zero" use of CO_2 and even additionally cleans the air. In Figure 1 of CO_2 absorption, we see the complete cycle of carbon movement. Every three years, the plantation absorbs about 200 tons of CO_2 from the air. During combustion, 70% of CO_2, 140 tons, is released into the air, and 60 tons, which is 30%, remains in the roots. This process is repeated every 3 years and involves 8 or more biomass harvests. Europe's potential of 117 million hectares of marginal land (land unsuitable for agriculture) and 5.5 million kilometers of roads is also the potential for FgEF creation. In conversion, this amounts to 82.6 billion m^3 of gas equivalent. We are also reducing CO_2 emissions by 3.17 billion tons.

Keywords: Solar Energy, Wind Energy, Hydrogen, Fast Growing Energy Forest, Biomass, Carbon Emissions, Green Certificates

1. Introduction

Humanity is on the threshold of transition to 100% use of renewable energy sources. What needs to be done to accelerate the achievement of this goal? Is everything so simple and straightforward? We propose to consider the pros and cons of all of the 5 main elements of renewable energy for obtaining heat and electricity from sources that are also called clean energy or inexhaustible or energy with zero CO_2 emissions. Today, solar energy is the cheapest form of energy. Investments in it pay off in 2-4 years. However, at night in the winter period, which lasts about 4-6 months a year, the efficiency of these stations ranges from 2 to 30%. Wind power plants are also a fairly cheap form of energy that does not depend on the sun and the time of year. However, the presence and strength of the wind is difficult to predict. Hydroelectric power plants are clean energy that does not depend on the sun or wind. But climate change and increasingly frequent droughts in Europe lead to a decrease in the share of this energy source. Green hydrogen, which is planned to be produced from the excess energy of solar and wind stations, has a great future as a means of accumulating green energy from renewable energy sources. But the implementation of this technology as a replacement for

natural gas or automobile internal combustion engines requires a lot of time and serious tests to talk about mass use. Biomass energy is energy produced in the process of converting bio-derived sources into fuel through combustion, biodigestion, fermentation or pyrolysis. Fast growing Energy Forests are an attractive option for renewable energy because they can be planted quickly, provide a constant supply of fuel, and require minimal maintenance compared to other energy sources. However, this energy source also has some problems, as it requires large volumes of land. But marginal, nutrient-poor, unused land is being used.

2. Solar Power

Indeed, to date, mankind has not invented another source of energy as budget friendly as the energy of the sun. Many industries are ready to invest money in this direction. In fact, these are good investments, which today pay off in 2-4 years.

So why are the countries of the world not ready to make 100% bets on this type of energy?

Countries such as Canada, U.S.A., Australia, Nigeria, Portugal, Italy, Spain and many other countries with 250-300 sunny days per year or more see their future in the direction of renewable energy using solar panels as the main source of energy. For example, the Portuguese energy company EDP combined energy sources such as hydro-61.8%, wind-24.2%, solar and other renewable sources-14% into a single energy network, and for peak loads built a powerful energy storage system in batteries and as a result, she received 100% renewable, clean energy [1].

And here are the countries of the northern part of Europe, such as:

Germany, Belgium, the Netherlands, Great Britain, Austria, Hungary, Romania, Poland, Ukraine, Sweden, Finland, Norway, and many others cannot count on a large percentage of solar energy because there are not many sunny days in these countries.

And even if batteries are installed to store energy at night, according to the calculations carried out in the winter period, which lasts about 4-6 months a year, the efficiency of these stations is from 2 to 30% of the rated power of the station, that is, if we have solar station with a capacity of 10 kW, then in the winter months we will receive from 0.2 to 3 kW of energy per hour. After all, this is catastrophically insufficient even to charge the batteries for nighttime work. In this regard, it is necessary and significant to develop a high-efficiency energy storage system with high safety, low cost, environment compatibility and large-scale processability [2].

3. Wind Energy

Wind power stations are also a rapidly developing business segment - these stations do not depend on solar radiation and can work around the clock! According to GreenMatch, wind energy is one of the fastest growing business segments in the world.

According to Conserve Energy Future, despite a 25 percent increase in the use of wind turbines over the past decade, wind energy provides only a small fraction of the energy used worldwide. These numbers are likely to increase if we consider that most of the disadvantages of using wind energy have been overcome, especially in terms of cost and siting difficulties - we can see more offshore wind farms being built and wind turbines attached to buildings. Floating offshore wind technology looks set to become the new "variable" with significant capacity potential in regions with good wind resources. And these are the countries of Europe, the Asia-Pacific region and the United States. In 2021, the world's largest project with a capacity of 50 MW, Kincardine off the coast of Scotland, is commissioned.

Each method or energy source has its pros and cons. Indeed, cost and environmental impact are deterrents to the use of clean wind energy.

The most prominent and widely used are probabilistic mathematical functions such as Weibull and Rayleigh; wind atlas data; and indirect methods such as atmospheric boundary layer wind tunnel testing and numerical simulation with Computational Fluid Dynamics (CFD).

A large variety of wind turbine types and designs is available at present. Typically, efficient designs with high performance are influenced by several design criteria related mainly to the application to serve and the location where the turbine is to be installed. In fact, knowing the application and the location of the turbine to be installed is a key guidance for choosing the size of the turbine and its generator type, the method of control, and how it is to be constructed and operated [3].

Disadvantages of wind farms are the complexity of the location, the large areas of land occupied, and the impact on living organisms is not the most beneficial.

And the main factor why wind does not occupy a leading position in the field of renewable energy - wind is not always difficult to predict, and the main thing is to guarantee the presence of wind and as a result of electricity, from wind stations at night, when solar stations cannot help us.

4. Hydroelectric Power Stations

A good source of renewable energy. This is clean energy that does not depend on the sun or the wind, has no ecological footprint, but as one of the leading magazines in Portugal wrote about hydroelectric plants, "unfortunately, the drought does not allow the continuous use of hydroelectric plants".

Portugal is restricting the use of some reservoirs for hydroelectric power and irrigation amid an unusual winter drought. Five hydroelectric dams in central Portugal will be almost totally shut down and another in the southern Algarve region will halt irrigation [4].

And this leads to a decrease in the percentage of use of this type of energy.

Also, not many countries of the world have this really clean and cheap source of energy.

5. Green Hydrogen

Green hydrogen has a great future as a means of storing green energy from renewable energy sources such as solar and wind. However, in the technology of hydrogen production - the process of its storage and transportation requires significant scientific know-how for its further safe mass use.

Biomass gasification is an emerging technology with the potential to replace fossil fuels and fulfilling the energy needs of the future sustainably. However, with the present form of the gasification process, there are a few obstacles in terms of technical, economic barriers, and some other external factors related to the gasification for the commercialization/ industrialization of this technology at its full capacity. [5].

"Pink" hydrogen is obtained from nuclear energy. By using nuclear energy as a source to power the electrolysis process, splitting water into hydrogen and oxygen. It can be stored as an alternative electricity storage system or converted directly into energy to support the grid during peak night loads and in winter. Some specialists in the field of atomic energy determine the stability of "pink" hydrogen.

It costs roughly $3.0/kg to manufacture hydrogen by electrolysis utilizing renewable energy sources, compared to $5.4/kg when using grid electricity. However, depletion of such resources as well as its negative environmental impact are some of the reasons that puts hydrogen production using nuclear energy on edge [6]. On the one hand, the environmental advantage of nuclear energy is the absence of CO_2 emissions. In the process of obtaining electricity, no greenhouse gases are created. Nuclear energy is a cheap source of energy if you do not take into account the ways of waste disposal. Producers who obtain hydrogen from nuclear sources are creating a cost-competitive energy source. Energy companies Uniper and Fortum are developing nuclear power by repurposing old reactors for hydrogen. But on the other hand, is nuclear energy really "clean" and safe? After all, the waste of nuclear plants needs to be stored somewhere for centuries and will this waste accumulate? And the issue of security is no less important, because there are not so many states that possess nuclear technologies. Will the more widespread use of nuclear power plants lead to an increase in the number of states possessing nuclear technologies? As Russia's military aggression against Ukraine shows, the possession of nuclear technologies can lead to the threat of using these technologies not only for peaceful purposes.

6. Biomass Energy

Now let's talk about the "5th Element" in the chain of sources of renewable energy. So, what is biomass energy? This is the energy produced in the process of converting bio-derived sources into fuel by combustion, biodigestion, fermentation or pyrolysis. As a result of these processes, we get either diesel fuel or electrical or thermal energy and natural fertilizers.

Biomass energy is energy obtained from:

1) Wood. The source of which is forest residues or specially created Fast growing Energy Forest (FgEF) from Energy plants such as willow, poplar, paulownia, millet, sorghum, miscanthus and other specially cultivated plants that have accelerated growth.
2) Household waste (these are all organic wastes of human life).
3) Agriculture and animal husbandry waste and other organic masses.
4) Industrial organic waste.

The process of growing special fast-growing trees and bushes is reliable, stable and environmentally friendly. This is how artificial intelligence formulated the answer to the question: What is a Fast growing Energy Forest?

A Fast growing Energy Forest is a type of forest that is planted specifically to produce energy. These forests are usually composed of fast-growing trees and shrubs that are harvested for fuel. The harvested wood is then used to generate electricity or heat through a variety of methods such as burning, gasification, and pyrolysis. Fast growing Energy Forests are an attractive option for renewable energy because they can be planted quickly, provide a steady supply of fuel, and require minimal maintenance compared to other energy sources. Additionally, these forests can help to reduce carbon dioxide emissions and help to preserve natural forests.

Bioenergetics allows you to get a number of preferences, which are also called 5E+1A:

1E. Economy - replacing coal with biomass.
2E. Environmental- combating climate change.
3E. Efficiency- using marginal land.
4E. Ecology – using only clean renewable energy sources.
5E. Energy- no dependence on external energy sources.
1A. Aesthetics – around cities and along highways young green trees, which do not cause an allergic reaction during flowering.

Also, energy willow plantations are a convenient place for animal life and nesting birds. Therefore, expanding the area of green spaces helps to preserve local biodiversity - another target «European Green Deal». Biodiversity strategy for 2030 is a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030, and contains specific actions and commitments [7].

You are probably wondering why such a rudimentary process is considered one of the main energy conversations for years to come.

At first glance, it may seem that biomass energy pollutes the environment. After all, we burn biomass (wood) and create additional CO_2 emissions? And it's true. But if we carry out measurements and calculations, we will see that, for example, 1 ha of the plantation of Energy Willow absorbs 200 tons of carbon dioxide from the air during the three years of its existence. Every three years, we receive a harvest of raw materials (biomass, wood) and burn it in the furnaces of boiler houses and power plants operating on biomass. And as

a result, we pollute the air again. However, we cut only the upper part of the plants and during burning release 140 tons of CO_2 into the air. And 60 tons remain in the roots of the plants, which grow back from the roots the next year. So, unlike burning coal or gas, we get zero CO_2 emissions for the first time, because the willow plantations again absorb the CO_2 from the air that we got from burning biomass. On the other hand, fields of energy willow or poplar additionally purify the air by 60 tons of CO_2 in three years of active growth.

However, when assessing environmental benefits and impacts, belowground biomass is also critically important. Root systems stabilize soil, contribute to belowground net primary productivity, add organic matter into the soil, aid in biogeochemical cycling, and, importantly for perennial energy cropping systems, provide a carbon sink in the form of belowground biomass [8].

Figure 1. *CO_2 absorption.*

When it comes to sustainability, sources like solar and wind energy are still more efficient. But bioenergy, which produces biomass, can quickly replace coal in existing Power Plants and Boiler Houses. At the same time, this can be done gradually, initially mixing 2-5 percent of biomass with coal, and as the FgEF area increases, the percent of coal can be reduced to zero.

After all, coal and biomass are interchangeable, as they have the same basis of origin - the process of photosynthesis during plant growth. Only through the creation of FgEF can we obtain industrial volumes of ecological biomass without damaging the environment, unlike the polluting effect of fossil coal and gas. The replacement factor of 1 ton of coal corresponds to 1.12 tons of biomass. Biomass is a product that allows replacing fossil coal in the ratio of 1 ton of biomass (chips) = 0.8 tons of brown coal, or = 0.46 tons of anthracite, or 510 m^3 of natural gas. It is used in Power Plants and Boiler Plants for partial and in the perspective of complete replacement of fossil coal.

Outlining the pros and cons of biomass energy, Recond Oil argues that bioenergy is widely available on Earth, is both renewable and carbon neutral, and can even reduce waste.

However, this energy source still has some challenges ahead, as it requires large volumes of land. But marginal, nutrient-poor, unused land is used to create FgEF. That is, it also significantly improves the ecological condition around the newly created forests.

Marginal land is underutilized for agricultural production for a variety of reasons such as shortage or excess of rainfall, extremes of temperature or edaphic stress such as soil salinity. Despite the uncertainty in defining precisely what is marginal land, and consequently knowing how much can be used for energy crop production, there is possibly as much as 100 Mha available globally. This marginal land is not productive or cost-effective for food crops, yet it is still considered capable of producing energy crops [9].

The world's soils are the second largest sink of carbon, second only to the oceans. There is strong scientific evidence that on-farm technologies combined with the widespread adoption of regenerative and climate-smart farming practices – such as zero-tillage, cover crops and the rational use of nutrients and manure – can reduce greenhouse gas emissions through prevention while reducing the negative impact of agriculture on the climate. What is "zero tillage" - it means that significant areas will not be plowed every year. Having created FgEF once, we leave the earth alone for 24 years. The first year we plant FgEF and then for a quarter of a century we grow the forest and no longer plow the soil.

1) This thesis investigates the potential role of Danish Energy Willow in helping to reach the Danish 2050 fossil fuel free energy goals. Willow (Salix spp). production is considered a relatively sustainable source of feedstock for bioenergy e.g. compared to straw which is a commonly used biomass for bioenergy in Denmark, with willow having low carbon footprint and eutrophication potential and high energy output to input ratio [10].
2) Sweden is hoping to become one of the first nations to abandon fossil fuels entirely. More precisely, the Swedish government has set two goals: all vehicles

fossil fuel free by 2030 and no net greenhouse gas emissions by 2045. The country already uses biofuel to meet 23% of its current power demands. Short rotation plantations have been regarded as one of the main alternatives in the shift towards a more sustainable energy supply in order to substitute for fossil fuels in Sweden. In this context, fast-growing species such as poplar and willow are of high interest, mainly as producers of biomass for fuel, but also for sequestration of C. Generally, forests have a higher C density than arable land, mainly due to the presence of perennial vegetation with high biomass. [11].

3) The willow is an important crop with high biomass production potential that has been grown commercially in Sweden since the 1990s.
4) Best practices from Finland: 47% share of Renewables in Electricity generation (67 TWh), 80% share of bioenergy in renewable energy production and 73% share of wood-based energy in renewable energy production.
5) As Mr. Kilgallon on Irish lands: "The potential of willow as an energy crop is well understood. Many Irish farmers have grown willow before. The challenge has been to make it economically viable. By demonstrating that willow biomass has multiple optimum, sustainable, and higher value uses across an extended circular economy lifecycle, we could dramatically improve the viability of willow as a crop, making it more attractive for farmers to grow and reducing bioenergy costs".

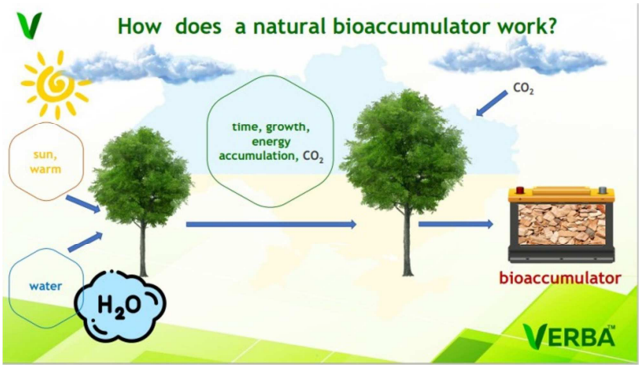

Figure 2. *Bioaccumulatoκ.*

7. Carbon Taxes

According to a Vox article, forty countries around the world are making air polluters pay for carbon pollution. By setting and constantly increasing the carbon price, states are trying to reduce global CO_2 emissions. The Kyoto Protocol to reduce CO_2 emissions was one of the first significant steps, followed by the Paris Convention, then the European Green Deal Program and Horizon-2023.

President of the USA Biden signed the law on the allocation of $ 384 billion for providing a historic amount of money for climate change mitigation that is billed as helping electric utilities deliver cleaner energy. In New York State, the NYS Connects: Climate Smart Farms and Forests Project was awarded a $60 million grant in the first round of the USDA's Climate Smart Commodity Funding Partnership [12].

The issue of decarbonization is becoming more urgent every year for all countries of the world. Industrial decarbonization was started in the EU back in 2000, and the project of the EU ETS emissions trading system was presented for the first time. And already in July 2021, representatives of the EU member states agreed to reduce greenhouse gas emissions on the territory of the Alliance by 55% by 2030, relative to the level of 1990, and to achieve the ambitious goal of complete carbon neutrality by 2050 within the framework of the European Green Deal.

There is a growing interest in using carbon taxes to reduce greenhouse gas emissions, not only in industrialized economies but also in developing economies. Many countries have considered carbon pricing, including carbon taxes, as policy instruments to meet their emission reduction targets set under the Paris Climate Agreement. However, policy makers, particularly from developing countries, are seeking clarity on several issues—particularly the impacts of carbon taxes on the economy, the distribution of these impacts across households, carbon tax design architectures, the effects of carbon taxes on the competitiveness of carbon-intensive industries, and comparison of carbon taxes with other policy instruments for climate change mitigation. [13].

To smooth the start of the carbon tax, countries like Canada are incentivizing businesses and residents with additional government rebates. Residents of Alberta and British Columbia can pay a carbon tax at the provincial level or under a federal program proposed by Prime Minister Justin Trudeau.

But the capabilities of European countries in the field of combating carbon dioxide emissions look encouraging:

1) The potential of using marginal lands of European countries (within 2% of the total area) and creating Fast grow Energy Forest (FgEF) as Industrial Plantations of Energy Willows (IPEW) to obtain a biomass harvest as a replacement for fossil coal and gas is about 211 million tons per year, or reduces natural gas consumption by 56.6 billion m^3 every year and saves 14.7 billion euros per year.
2) Reduction of CO_2 emissions by 2.3 billion tons due to the creation of Fast grow Energy Forest (FgEF) on marginal lands of European countries with an annual rainfall of more than 600 mm.
3) Creation of FgEF as a forest strip along highways (patent #139085, page #6) will replace another 26 billion m^3 of gas and save 7 billion euros every year.
4) Reduction of CO_2 emissions by another 870 million tons per year through the creation of FgEF from energy willow on the roads of European countries with an annual rainfall of more than 600 mm.

Countries such as Mexico, Australia, Chile and South Korea also have similar carbon pricing programs. Nevertheless, the vast majority of countries around the world are struggling to implement carbon taxes that meet their environmental and social needs.

As the availability of gas energy is in deep crisis and climate change is felt more and more, carbon incentives, or any other programs and directions to reduce CO_2 emissions, will be the main drivers in the coming years for federal and local governments around the world.

TRENDS IN THE FIELD OF DECARBONIZATION. Unfortunately, carbon emissions into the atmosphere continue to grow. Private companies and governments are making new commitments to achieve ambitious zero-emission targets. These global efforts provide a number of opportunities in the accelerated growth of various environmental technologies.

For example: direct air capture (Direct Air Capture - DAC). Direct air capture (DAC) is a carbon dioxide removal technology which separates CO_2 directly from the air using an engineered system. DAC can therefore be used alongside other negative emissions technologies, in principle, to mitigate CO_2 emissions from a wide variety of sources, including those that are mobile and dispersed. The ultimate fate of the CO_2, whether it is stored, reused, or utilised, along with choices related to the energy and materials inputs for a DAC process, dictates whether or not the overall process results in negative emissions. In recent years, DAC has undergone significant technical development, with commercial entities now operating in the market and prospects for significant upscale [14]. Some companies are ready to invest and are already investing in DAC to achieve costs of 100 to 150 USD for each tonne of CO_2 absorbed from the air by 2030, which would be 60-80% less than in existing pilot projects.

Another technology is Bioenergy with carbon capture and storage (Bioenergy with carbon capture and storage - BECCS).

If we transfer the existing power plants, which currently operate on fossil fuel, the service life of which has not yet ended, to the use of biomass as a renewable fuel. This will give a number of preferences:

1) An energy source that generates clean and renewable energy.
2) A convenient and safe method of supplementing renewable energy sources.
3) The possibility of quick maneuvering during energy fluctuations at night and in winter.
4) Preservation of the value of existing assets that have not yet worked out to 100%.

BECCS technologies have yet to be deployed commercially at scale. Several large BECCS power plants are currently planned but there are none in operation or construction. The only large-scale BECCS plant in operation captures CO_2 from ethanol production (in the USA) with a capture capacity of 1 Mt per annum. Further research is needed to better understand technical and non-technical barriers and hence the potential for BECCS to deliver large scale GGR [15].

And the installation of additional CCS equipment at a power plant where the use of coal and gas has been replaced by environmentally friendly biomass allows for the production of negative CO_2 emissions: growing, biomass absorbs CO_2, and when it is burned, the CCS system prevents CO_2 from entering the atmosphere.

The next technology that also has every chance of strong growth is Biochar. Biochar is a stable carbonaceous material obtained by pyrolysis or gasification of biomass. Biochar applied in certain doses to the soil improves its composition and the productivity of growing agricultural products. And this process can gain significant momentum in industrial agriculture. The potential for reducing CO_2 emissions into the atmosphere is 2 GTons per year.

The process of binding CO_2 can also have a significant deterrent effect. So, a new method of adding CO_2 as an ingredient to concrete can reduce emissions by up to 70% and even make the cement stronger. Concrete has two main components: cement and sand or crushed stone. For the production of 1 ton of concrete, from 0.8 to 1.2 tons of CO_2 is released into the air. This is one of the most massive and polluting technologies.

The "Green" ammonia project, which is planned to be produced from "green" hydrogen, is designed to compete in price with ordinary ammonia, which has significant advantages in its use in agriculture.

8. Conclusion

No matter how many new technologies humanity invents to obtain such necessary energy for human life, in the opinion of the author, the most powerful sources of clean and renewable energy are the sun, wind and hydro. All other renewable sources, including the use of biomass and hydrogen, are derived from solar energy. After all, when we talk about creating a Fast growing Energy Forest, we are also talking about harnessing solar energy through photosynthesis and binding CO_2 molecules in the wood mass. And with further burning of wood (biomass) at the thermal power plant, we get heat, which is a derivative of solar energy. That is, the Fast growing Energy Forest is a natural battery of solar energy, it is the "fifth element" that will provide balancing power for power generation at night and in winter when there is not enough solar energy. Figure 2. And this harmonious and powerful energy can only be given by nature itself. And our task is to learn how to use these inexhaustible reserves of energy with maximum efficiency and without harming the environment, without harming the planet itself. And that we leave a beautiful and green planet Earth to our descendants.

References

[1] Dr. Ajay Mathur, Dr. Yogi Goswami. Sunny solutions: Tapping the source of unlimited opportunities. *Solar compass*. 2023. Vol. 5, P 1-2. https://doi.org/10.1016/j.solcom.2023.100038

[2] Lijun Zhou, Jinhao Xie, Diyu Xu, Yanxia Yu, Xingyuan Gao, Xihong Lu, Recent advances and challenges of anodes for aqueous alkaline batteries. *Biomass and Bioenergy*. 2023. https://doi.org/10.1016/j.enchem.2023.100102

[3] Stathopoulos T., Alrawashdeh H., Urban wind energy: Some views on potential and challenges. *Journal of Wind Engineering and Industrial Aerodynamics*. 2018. Vol. 179. P 146-157. https://doi.org/10.1016/j.jweia.2018.05.018

[4] Helena M. Ramos, New design solutions for low-power energy production in water pipe systems. *Water Science and Engineering*. 2009. Vol. 2. Iss. 4. P 69-84. https://doi.org/10.3882/j.issn.1674-2370.2009.04.007

[5] Valizadeh S, Hakimian H, Farooq A, Byong-Hun Jeon. Valorization of biomass through gasification for green hydrogen generation: A comprehensive review. *Bioresource Technology*. 2022. Vol. 365. https://doi.org/10.1016/j.biortech.2022.128143

[6] Reuben Joseph Soja, Muhammad Bello Gusau, Usman Ismaila, Nuraddeen Nasiru Garba. Comparative analysis of associated cost of nuclear hydrogen production using IAEA hydrogen cost estimation program. *International Journal of Hydrogen Energy*. 2023. https://doi.org/10.1016/j.ijhydene.2023.03.133

[7] Simon Schunz. The 'European Green Deal' – a paradigm shift? Transformations in the European Union's sustainability meta-discourse. *ECPR*. 2022. Vol. 4. 23 p. https://doi.org/10.1080/2474736X.2022.2085121

[8] Sleight, N. J., Volk, T. A., Eisenbies, M., Belowground Biomass and Root: Shoot Ratios of Three Willow Cultivars at Two Sites. *Forests*. 2023, 14 (3), art. no. 525, 18 p. https://doi.org/10.3390/f14030525

[9] Beena Patel, Akash Patel, Bakhtiyar Alam Syed, Bharat Gami, Pankaj Patel. Assessing economic feasibility of bio-energy feedstock cultivation on marginal lands. *Biomass and Bioenergy*. 2021. Vol. 154. https://doi.org/10.1016/j.biombioe.2021.106273

[10] Larsen S., Uffe Jorgensen U., Larke P., Biomass yield, nutrient concentration and nutrient uptake by SRC willow cultivars grown on different sites in Denmark. *Biomass and Bioenergy*. 2018. Vol. 116. P 161-170. https://doi.org/10.1016/j.biombioe.2018.06.011

[11] Rose-Marie Rytter. The potential of willow and poplar plantations as carbon sinks in Sweden. *Biomass and Bioenergy*. 2012. Vol. 36. P 86-95. https://doi.org/10.1016/j.biombioe.2011.10.012

[12] Hokul K., Governor Hochul Announces New York State Awarded $60 Million in Federal Funds to Advance Smart Climate Practices for New York Farms and Forests. *WE ARE NY*. 2022. 5 p.

[13] Govinda R. Timilsina, Carbon Taxes. *JOURNAL OF ECONOMIC LITERATURE*. 2022. Vol. 60. No. 4. P 1456-1502. https://doi.org/10.1016/S0961-9534(99)00085-9

[14] María Erans, Eloy S. Sanz-Pérez, Dawid P. Hanak, Zeynep Clulow, David M. Reiner, Greg A. Mutch. Direct air capture: process technology, techno-economic and socio-political challenges. *Energy & Environmental Science*. 2022. Iss. 4. P 1360-1405. DOI https://doi.org/10.1039/D1EE03523A.

[15] Garcia-Freites S., Gough C., Roder M., The greenhouse gas removal potential of bioenergy with carbon capture and storage (BECCS) to support the UK's net-zero emission target. *Biomass and Bioenergy*. 2021. Vol. 151. https://doi.org/10.1016/j.biombioe.2021.106164