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WHAT HYDROGEN CAN BRING TO RURAL DEVELOPMENT: REVIEW AND RESULTS OF ENTREPRENEURS SURVEY IN LATVIA

***Janis Kleperis[1], Ilze Dimanta[1], Biruta Sloka[1], Laila Zemite[2]**
[1]University of Latvia, Latvia
[2]Riga Technical University, Latvia
*Corresponding author's email: janis.kleperis@cfi.lu.lv

Abstract
Biogas is an energy carrier (methane, hydrogen) produced by the fermentation of organic waste in an anaerobic digestion process and can be burned in a cogeneration plant to produce heat and electricity. Price of electricity from the grid, as well as price of fossil natural gas have been increasing recently, and farms are considering new scenarios for the economic use of produced biogas. As a possible scenario, it is desirable to consider incorporation of hydrogen that can be used for energy storage; fuel for farm electric transport and as renewable resource for the decarbonisation of agricultural processes. Researchers worldwide are working on the development of efficient microbial technologies to upgrade biogas by removing CO_2 with *hydrogenotrophic methanogens* and using external green hydrogen as electron donor. Selected case situations are analysed – renewable energy and hydrogen in the winery, hydrogen fuelled farm in future. The purpose of this article is to inform farmers through a survey about hydrogen as a local resource for energy management in farm. The article continues analyses of survey results, collected in 2021 with the aim to gather information and opinions from biogas producers in Latvia. Majority of producers is considering technology upgrades and confirm interest to follow achievements from scientific findings, but not so many cooperate with local scientists. Therefore, more proactive communication from research institutions and information availability is highly recommended by authors.
Key words: biogas, biohydrogen, bio-upgrading, hydrogen, survey.

Introduction

The World Climate Conference was held in Glasgow, Scotland, from 31 October to 12 November 2021, when 197 countries agreed to step up their efforts to curb global warming (Documents and decisions, 2021). The conference pledged to halt uncontrolled deforestation by 2030, which has suffered from severe fires around the world as the climate has changed in recent years. At the suggestion of the USA President Biden, an agreement has been reached to reduce methane emissions by at least 30% by 2030, as methane is 84 times more active in contributing to global warming than carbon dioxide. At least 90 countries have supported the phasing out of coal for energy, which not only pollutes the planet's atmosphere but also harms human health. Methane emissions are the same for natural gas and biogas and can only be reduced in the long term by replacing them with green hydrogen in all applications.

On 15 December 2021, the European Commission adopted a series of legislative proposals (European Parliament, 2021a, 2021b) to decarbonise the EU gas market by facilitating the use of renewable and low-carbon gases, including hydrogen, and ensuring security of energy supply for all European citizens.

Global climate goals may seem far away, but in this area Latvia, as a small country, has an advantage, because it is easier to operate a small farm, and we already have a very good base on which to build. For example, the agricultural sector has a great potential for biomethane production. There is already a great number of biogas plants in Latvia – 59 (Dubrovskis, 2018); therefore, raw materials and an existing production base that can be relatively easily adapted for biomethane production. Biomethane can then be used both as a transport fuel and sold on the gas network. Tandem of natural gas and biomethane could be named as one of the most promising for short and mid-term transport decarbonisation solutions both in the EU and Latvia (Savickis *et al*., 2020). In both cases, emissions from agriculture are being addressed and a renewable resource has been developed to replace fossil energy. The transition to a low-carbon economy requires the use of energy produced from renewable resources. Fraction of this green energy increases in the mix of grid electricity, but some of renewable resources, such as solar irradiation, is available in any location of our globe, and can be used without the grid – so-called distributed energy generation. The standalone solar photovoltaic, wind power as well as small hydroelectric power generation are particularly suitable for large rural areas where the cost and environmental impact of installing grid power lines are higher. It should be emphasized that hydrogen is used to reduce emissions from energy supply that contribute to climate change. Hydrogen has been shown to be a suitable substitute for fossil fuels and an excellent carrier of green energy. The production of electricity takes place by reacting hydrogen in the fuel cell with oxygen, and the end products of the reaction are electricity and pure water, that is, they do not cause local pollution. The high specific energy density is also another advantage of hydrogen, as hydrogen has the lowest weight of any fuel (Kleperis *et al*., 2021a).

This article is a continuation of the analysis of the results of the survey conducted in early 2021, and the first part was reported at the ERDEV conference in 2021 (Kleperis *et al*., 2021b). This article contains an original summary of information on description of different case of hydrogen use from demonstration projects in agriculture and the readiness of Latvian entrepreneurs to reflect on them. Of course, with appropriate state support, both by streamlining legislation and by offering support for European funds for the production, storage, use and decarbonisation of 'green' hydrogen in the agricultural sector.

Materials and Methods

Classical research methods, such as analysis of research findings, as well as specific policy documents and existing standards are used in the analysis of scientific articles (focused on the use of specific technologies in pilot projects). Review of publications with analysis of the results of expert surveys in a specific sector are also sought and analysed, from which the questions in the questionnaire arose of hydrogen technologies, and respondents were asked about their future plans by sending e-mails. Survey was conducted during the period January – March, 2021. From all active biogas producers in Latvia (48 in 2020) the 35 were approached also by phone to make sure that the e-mail with the survey questions was received. During the survey, 10 useful responses on the survey questions were received. The part of results was presented in 20th International Scientific Conference 'Engineering for Rural Development', 26-28 May, 2021, Jelgava, LATVIA (Kleperis *et al*., 2021b). Descriptive statistical analysis methods were used for the statistical analysis of the expert survey presented in the work: central tendencies or location indicators and variability indicators, as well as cross-tabulations were assessed.

Results and Discussion

Status quo and literature analysis. There are currently 50 million micro-digesters in the world, sufficient for family needs, and around 132,000 of engineering biogas projects in the world, of which 17,783 are located in Europe with an installed capacity of 10.5 GW (Zupančič *et al*., 2022). There are 700 plants for upgrading biogas to biomethane worldwide, 540 of which are in Europe and 1 in Latvia. The price of electricity from the grid, as well as the price of fossil natural gas, has been rising sharply recently, and farms are considering new scenarios for the economic use of their own biogas. Owners of small hydro-electro-power stations in Latvia can learn from the first model of case study about hydrogen production from local electric power (Kobzars *et al*., 2022). In these scenarios, hydrogen can serve in a variety of ways, both as stored energy and as a fuel for farm electric transport, and, of course, as a renewable resource for the decarbonisation of agriculture. The following study focuses more on the technological aspects of the introduction of hydrogen into the farm and the degree of readiness of the technology, drawing on experience from the experiments described in the literature. A more complete summary of technology information can be found in the book Lamb & Pollet, 2020.

Biogas upgrading to biohydrogen. Is the only way to convert biogas to biohydrogen by separating hydrogen from biomethane in the steam-methane reformation process? Researchers are working on development of efficient microbial technologies to upgrade biogas, removing CO_2 with *hydrogenotrophic methanogens* and using external hydrogen generated by surplus electricity from renewables as electron donor (Lai *et al*., 2021). Up to now hydrogen biogas upgrading is hindered by metabolic limitations and low H_2 transfer rate, but here design of optimal reactor configurations and genetic engineering of *hydrogenotrophic methanogens* can be helpful. Microalgal biohydrogen production has attracted researchers in recent years (Perera *et al*., 2020; Siddiki *et al*., 2020); however, it must be acknowledged that commercialization is still hampered by unresolved issues in process engineering, low microalgal productivity, oxygen sensitivity, operating costs and insufficient understanding of crop capacity. The book 'Hydrogen, Biomass and Bioenergy' (Lamb & Pollet, 2020) uses the reverse path to explore the production of hydrogen by chemical and biological means from a variety of bioresources, including solid waste, industrial wastewater, farm products, and algae.

Renewable energy and hydrogen in the winery. The results of the LIFE program`s project REWIND (Carroquino, Bernal-Agustín, & Dufo-López, 2019) has demonstrated the technical and practical feasibility of local harvesting of solar energy and energy carrier – hydrogen, to supply electricity and heat to vineyard and winery consumptions. It has been proven that it is possible to completely replace a diesel car with an electric-hydrogen car in the same area for the same work. The approach includes a standalone RES electricity supply 100%, and consumption of surplus solar energy in the form of gaseous hydrogen. Energy Management System manages the loads based on real production, consumption, and stored energy (battery charging level, hydrogen pressure) status. The hydrogen production equipment consisting from a water deionizer, an electrolysis plant, a hydrogen gas compressor, a storage cylinder and a car filling system was installed to collect surplus electrical energy from photovoltaic panels. The diesel SUV was replaced with the same electric one, and the battery pack was replaced with a PEMFC and a compressed hydrogen cylinder. This all-terrain car can be classified as zero emissions and is refuelled with hydrogen produced from surplus solar energy. The hydrogen-electric car in the vineyard and winery was able to follow the same routes and carry the same loads of crop or fertilizer as a typical diesel car.

Hydrogen fuelled farm. Farms are generating electricity from renewables (Sun, Wind) to split water in electrolysis in hydrogen and oxygen. Hydrogen can be stored in high pressure cylinders and applied as fuel for electric trucks, tractors, and harvesters, as well as to make fertilizer (ammonia) (Phillips, 2021) following the Haber-Bosch process by the reaction between gaseous nitrogen from air and hydrogen. On an average farm (USA), three tractors, two harvesters, four trucks consuming about 45 460 litres of diesel per year, spending $15,000 on fuel alone are used. On such a farm almost 80 000 kg of ammonia fertilizer are also consumed (year cost $105,000); together cost of fuel and fertilizer is $120,000. To get hydrogen, the farm must have its own source of renewable electricity. Let's just look at solar photovoltaic panels and wind generators, coupled with electrolysers. To produce one kilogram of hydrogen, 55.5 kWh energy, roughly the same as 3.8 litres of diesel are needed. The conversion efficiency of hydrogen in polymer electrolyte fuel cell (PEMFC) to electricity is around 60%, and electric motors in machinery run at about 95% efficiency, while diesel engines run at 45%, what means that hydrogen powered electric engine is at least 12% more efficient in summary. Simple calculations show that 7,900 kg of hydrogen fuel is needed for transport on the farm every year. The molecular weight of hydrogen in the ammonia molecule is 17.8%, and 14,100 kg of hydrogen per year will be used to produce 80,000 kg of fertilizer. Altogether 22,0000 kg hydrogen are required per year, what is equal to 1.2 GWh power or $50,000 (at price for electricity $0.0413 per kWh). Almost every biogas farm in Latvia is producing such an amount of electricity - in 2020, there were 49 biogas cogeneration plants in Latvia with a total capacity of 63 MW, the amount of electricity produced annually reaching 345 GWh. In Palouse (USA), the sun shines 5-7 hours a day on average per year; therefore, 4300 m^2 photo-voltage (PV) panels are needed to harvest per year 0.92-1.62 GWh, saving $38,000-$67,000 each year. Another alternative is Wind energy – annual average wind speed at high 100 m is 3 m s^{-1}. To generate half of the electricity needs, 25 wind turbines with a blade diameter of 22.9 meters are needed.

The analysed foreign examples of the introduction of hydrogen in an agricultural enterprise show that biogas producers can already switch to hydrogen today, the only investments would be in hydrogen infrastructure (electrolysers, tanks for compressed hydrogen storage, electric-hydrogen agricultural machinery (combines, tractors, trucks and hydrogen filling station), ammonia fertilizer plant). All of these facilities are available and tested in more than ten pilot projects, but their cost could be very high due to low demand.

Discussion on the intentions of biogas producing farmers. On a European scale, there is a large amount of installed electrical capacity (56 MW) for fermentation biogas plants per million inhabitants in Latvia (Dubrovskis, 2018). Most of them were built during 2009-2015. Untreated biogas is currently burned in gas generators and electricity is produced, still in the hope of state support in the form of a mandatory procurement component, but after the end of the support, investment should be made in biogas upgrading to biomethane for transport (Savickis *et al*., 2020). The Central Statistical Bureau of Latvia data indicate that in 2020 the 29.4% from renewable energy sources were produced in biogas and biomass cogeneration plants. The questions in the questionnaire arose from reading scientific publications and reports on pilot projects for the introduction of hydrogen technologies, and respondents are asked to identify gaps in local legislation and planning documents. In the course of the work, the questions and answer options in the pre-survey were clarified and used for the survey in March 2021 by sending e-mails. If the respondents did not reply within the specified time, a call was made. The part of results were presented in Proceedings of 20th International Scientific Conference 'ENGINEERING FOR RURAL DEVELOPMENT' May 26-28, 2021 (Kleperis *et al*., 2021b). Survey contained several questions for expert evaluations (with several sub-questions for each item):

1) For what practical purpose was your biogas plant set up?
2) In today's situation (expiration of mandatory procurement component), do you still think about staying with cogeneration or changing the target?
3) If you change the target, which biomethane enrichment process will you choose for your plant?
4) Do you plan to use a 'hydraulic piston' or other technology to compress biomethane at the plant?
5) Are you planning to invest in the modernization of biogas plant technologies?
6) Are you interested in modernizing technology?

Researchers in the respective paper have analysed expert evaluations on plans to use a 'hydraulic piston' or other technology to compress biomethane at the plant as it is important for future developments. The answers on the stated question and the offered options for evaluations are analysed below using main indicators of descriptive statistics and correlation analysis – tables 1-6.

Table 1

Main indicators of descriptive statistics on expert evaluations on 'Do you plan to use a 'hydraulic piston' or other technology to compress biomethane at the plant?'

Statistical indicators		Gas for car refuelling	For filling cylinders for gas stoves	Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure
N	Valid	9	8	8
	Missing	1	2	2
Mean		5.33	1.63	2.50
Std. Error of Mean		1.143	0.498	0.627
Median		7	1	2
Mode		1.8	1	1
Std. Deviation		3.428	1.408	1.773
Range		8	4	4
Minimum		1	1	1
Maximum		9	5	5

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes.

Table 2

Distribution of expert evaluations on use 'Gas for car refuelling'

Evaluation		Frequency	%	Valid %	Cumulative %
Valid	1	3	30.0	33.3	33.3
	5	1	10.0	11.1	44.4
	7	1	10.0	11.1	55.6
	8	3	30.0	33.3	88.9
	9	1	10.0	11.1	100.0
	Total	9	90.0	100.0	
Missing	System	1	10.0		
Total		10	100.0		

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes.

Table 3

Distribution of expert evaluations on use 'For filling cylinders for gas stoves'

Evaluation		Frequency	%	Valid %	Cumulative %
Valid	1	6	60.0	75.0	75.0
	2	1	10.0	12.5	87.5
	5	1	10.0	12.5	100.0
	Total	8	80.0	100.0	
Missing	System	2	20.0		
Total		10	100.0		

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes.

Table 4

Distribution of expert evaluations on use 'Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure'

Evaluation		Frequency	%	Valid %	Cumulative %
Valid	1	4	40.0	50.0	50.0
	3	2	20.0	25.0	75.0
	5	2	20.0	25.0	100.0
	Total	8	80.0	100.0	
Missing	System	2	20.0		
Total		10	100.0		

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes.

Table 5

Indicators of non-parametric correlation analysis with Spearman Correlation

Analysed aspect	Indicator on Spearman non-parametric correlation	Gas for car refuelling	For filling cylinders for gas stoves	Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure	Years
Gas for car refuelling	Correlation Coefficient	1.000	-0.016	0.517	-0.187
	Sig. (2-tailed)	.	0.970	0.189	0.658
	N	9	8	8	8
For filling cylinders for gas stoves	Correlation Coefficient	-0.016	1.000	0.572	0.212
	Sig. (2-tailed)	0.970	.	0.138	0.648
	N	8	8	8	7
Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure	Correlation Coefficient	0.517	0.572	1.000	-0.062
	Sig. (2-tailed)	0.189	0.138	.	0.895
	N	8	8	8	7
Years	Correlation Coefficient	-0.187	0.212	-0.062	1.000
	Sig. (2-tailed)	0.658	0.648	0.895	
	N	8	7	7	9

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes, for years – years of operation in the field.

The analysed results indicate that there is no statistically significant correlation between the discussed aspects and between time of operation in Latvia; there are different plans for producers even if they have operated rather long time in the respective market – even 13 years. Unfortunately, still in Latvia the use of hydrogen is not regulated by national legislation; therefore, the strategic planning guidelines contained in the relevant EU directives and other agreements should be taken into account.

Conclusions

The analysed cases of the introduction of hydrogen in an agricultural enterprise show that biogas producers in Latvia can already switch to hydrogen today; the only investments would be in hydrogen infrastructure that are available and tested in several pilot projects, but their cost could be very high due to low demand.

The largest majority of more than 50 biogas plants in Latvia emerged at the beginning of the 21st century with the aim of producing electricity for sale.

Table 6

Indicators of correlation analysis with Pearson Correlation

Analysed aspect	Indicator	Gas for car refuelling	For filling cylinders for gas stoves	Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure	Years
Gas for car refuelling	Pearson Correlation	1	0.058	0.552	-0.103
	Sig. (2-tailed)		0.892	0.156	0.809
	N	9	8	8	8
For filling cylinders for gas stoves	Pearson Correlation	0.058	1	0.601	0.162
	Sig. (2-tailed)	0.892		0.115	0.729
	N	8	8	8	7
Provision of cylinder gas for heating of public buildings or individual households in places where there is no centralized natural gas infrastructure	Pearson Correlation	0.552	0.601	1	-0.052
	Sig. (2-tailed)	0.156	0.115		0.912
	N	8	8	8	7
Years	Pearson Correlation	-0.103	0.162	-0.052	1
	Sig. (2-tailed)	0.809	0.729	0.912	
	N	8	7	7	9

Evaluation scale 1-10, where 1 – definitely no; 10 definitely yes, for years – years of operation in the field.

Their gas generators, with a total installed electricity capacity of about 56 MW, burn untreated biogas. Currently, the vague change in the conditions and requirements in the country in regulatory enactments threatens the goals set by biogas producers in the production of renewable energy. There is a risk of reducing the share of renewable energy already achieved in the energy sector, or even of closing down a number of large agricultural holdings. Given that the right to state aid in the framework of mandatory procurement of electricity generation is no longer granted, the government should plan investments for the conversion of biogas plants to biomethane production for the decarbonisation of the natural gas network and road transport. Therefore, more proactive communication from research institutions and information availability is highly recommended by authors. Expert evaluations on question 'Do you plan to use a 'hydraulic piston' or other technology to compress biomethane at the plant?' with several proposed options for evaluations indicate that the highest evaluations by experts were for 'Gas for car refuelling' with highest average evaluations but also with the highest variability of evaluations, the lowest average evaluations were 'For filling cylinders for gas stoves', there was also the lowest variability of expert evaluations. There was no correlation between the time operating biogas plant in the respective field and the evaluated aspects.

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