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Article

Assessment of the Potential for Green Ammonia Production from Animal Waste in Ukraine

Sergey A Zhadan[1], Yevhenii B Shapovalov[2], Anatoly I Salyuk[3], Oleksandr M Zhadan[4], Stanislav Usenko[5]

[1] Independent Researcher, Ukraine; serezha.nuft@gmail.com

[2] National Center" Junior Academy of Sciences", 38/44 Degtyarivska Str., Kyiv, 04119, Ukraine; sjb@man.gov.ua

[3] National University of Food Technologies, 68 Volodymyrska Str., Kyiv, 01601, Ukraine; salyuk@i.ua

[4] Separate Structural Subdivision" Shostka Vocational College named after Ivan Kozhedub of Sumy State University", 1 Instytutska Str., Shostka, 41100, Ukraine; serezha.nuft@gmail.com

[5] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37, Prospect Beresteiskyi (former Peremohy), Kyiv, 03056, Ukraine; farkry17@gmail.com

* Correspondence: sjb@man.gov.ua (Ukraine)

Abstract: The intensified global effort to mitigate climate change is currently focused on significantly reducing carbon dioxide emissions, exemplified by the European Union's target to cut greenhouse gas emissions by 55% by 2030. While ammonia acts as a critical carbon-free energy carrier in these decarbonization strategies, its conventional production relies heavily on fossil fuels. Consequently, a sustainable method utilizing nitrogen-rich organic waste has been proposed to facilitate green ammonia production. The primary goal of this study is to assess the feasibility and capacity for producing green ammonia from animal waste within Ukraine. This assessment aims to present a promising, sustainable alternative to the traditional Haber-Bosch method by leveraging agricultural byproducts. The proposed technical approach involves the sorption of ammonia from the gas phase of a biogas reactor using a monoammonium phosphate (MAP) solution, which results in the formation of diammonium phosphate (DAP). The process utilizes thermal energy from a cogeneration plant running on biogas to heat the DAP, thereby releasing ammonia gas and regenerating the MAP for continuous operation. The study estimates that this method could yield up to 263,610 tons of ammonia annually in Ukraine, a figure comparable to the nation's conventional ammonia output in 2019. Geographic analysis identified the Vinitskaya, Cherkasy, and Kyiv regions as having the highest production potential due to their substantial agricultural activity and the availability of organic waste. This innovative approach allows for the generation of clean energy carriers from waste, potentially enhancing Ukraine's energy security. Furthermore, the implementation of this technology supports broader global decarbonization efforts by replacing fossil-fuel-based production methods with renewable alternatives.

Keywords: ammonia production, animal waste, sustainability, green ammonia, nitrogen-rich waste, decarbonization, renewable energy, carbon-neutral.

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1. Introduction

Considerable global focus is currently directed towards mitigating CO2 emissions, aiming to mitigate the adverse impacts of global warming.

To reach its 2030 target, the EU is implementing several policies and measures, including expanding the EU Emissions Trading System (ETS) to cover more sectors of the economy, investing in renewable energy and energy efficiency, promoting low-carbon transportation, and reducing deforestation and forest degradation. Addressing this, the European Union has embarked on an ambitious trajectory, delineating its objective to curtail greenhouse gas emissions by a minimum of 55% relative to 1990 benchmarks by 2030. In a significant move in 2019, the European Commission unveiled its intentions to recalibrate the economic trajectory of the EU, envisaging the establishment of a climate- and carbon-neutral space across Europe by 2050 (Brouwer et al., 2021a).

Many countries have committed to reducing greenhouse gas (GHG) emissions in the coming decades. For example, Japan has set a target of reducing its GHG emissions by 26% by fiscal year 2030, compared to fiscal year 2013 (Ministry of Economy Trade and Industry, 2015). This target is part of Japan's Intended Nationally Determined Contribution (INDC) under the Paris Agreement. Japan has also set a long-term goal of reducing GHG emissions by 80% by the fiscal year 2050 (Kobayashi et al., 2019).

Germany has also set ambitious targets for reducing its GHG emissions. The German government has pledged to reduce emissions by 80% from 1990 to 2050. Great Britain has set a similar target to reduce emissions by 80% by 2050 (Brouwer et al., 2021b).

Cities are a significant source of greenhouse gas emissions, accounting for up to 70% of global anthropogenic emissions. More than 100 cities have committed to becoming carbon neutral by 2050 in response to this challenge. Some cities have even aimed to reach this goal earlier, such as Stockholm (2040) and Copenhagen (2025).

Apple and Microsoft have set ambitious goals to reduce greenhouse gas emissions. The goals set by Apple and Microsoft are a significant step forward in the fight against climate change. These companies are leading the way in corporate sustainability, and their actions are inspiring other companies to take action. Apple has pledged to achieve net-zero emissions across its entire supply chain by 2030 (Brouwer et al., 2021b), while Microsoft has committed to achieving negative emissions by 2030 and carbon neutrality by 2050. Net-zero emissions mean a company's emissions are balanced by removing greenhouse gases from the atmosphere. Negative emissions mean a company removes more greenhouse gases from the atmosphere than it emits in 2050 (Brouwer et al., 2021b).

Key technologies include ammonia stripping, membrane separation, and microbial fuel cells. A. Abbá et al., 2023 demonstrated up to 81% ammonium removal from livestock manure digestate without external reagents (Abb et al., 2023), while McKenzie Burns et al., 2023 achieved 40-60% nitrogen removal using microbial fuel cells (Burns et al., 2023).

The process offers significant environmental benefits, including reduced nitrogen pollution, potential fertilizer production, and decreased greenhouse gas emissions (Yang et al., 2022). Rizzioli et al., 2022 notes that recovery technologies can produce fertilizers at relatively low costs (2-7 € per kg of nutrient) (Rizzioli et al., 2023), making them economically viable alternatives to synthetic fertilizers.

One of the key elements of a successful decarbonization strategy is the transition to carbon-free fuels. By carbon-free fuel, we mean one that does not contain carbon in its composition and, when burned, does not produce carbon dioxide. This includes hydrogen and ammonia. Moreover, the latter has several advantages.

Regarding energy density, liquid ammonia contains 15.6 MJ/dm3 (Megajoules per cubic decimeter), which is 70% more than liquid hydrogen or almost three times more than compressed hydrogen (Brown, 2017b). Ammonia is much cheaper to store for a long time than hydrogen and transport (Bartels & Pate, 2008a). The infrastructure for handling and transporting ammonia (Bartels & Pate, 2008b), as well as the supply chain and regulations for its handling, already exist.

The production method is extremely important in the context of using ammonia in carbon-free energy. Today, ammonia production is carried out using the so-called Haber-Bosch process. The process is based on the synthesis of ammonia from Nitrogen and hydrogen at a temperature of 380-450 °C and a pressure of 250 atm using an iron catalyst. Such production involves using fossil fuels as feedstock to produce hydrogen and significant carbon dioxide emissions.

The production of green ammonia, which in this article means ammonia produced from renewable raw materials using renewable energy sources, is promising.

Developing and implementing green ammonia production from nitrogen-rich animal waste present a sustainable and economically viable solution to reducing greenhouse gas emissions, enhancing Ukraine's energy security, and supporting global decarbonization efforts.

We have developed a new method of green ammonia production based on regulating ammonia nitrogen (AN) concentration in the biogas reactor (Zhadan et al., 2021a). It involves sorbing ammonia from the gas phase using a monoammonium phosphate (MAP) solution, obtaining diammonium phosphate (DAP), and subsequently heating to release ammonia. In this case, part of the thermal energy from the cogeneration plant, which runs on biogas, is used.

The study aimed to assess the potential for ammonia production in Ukraine from animal waste, which is characterized by a high nitrogen content.

Bridging the Gap: Addressing Critical Deficiencies in Sustainable Energy and Ammonia Production

2. Methodology for Assessing the Potential of Green Ammonia Production

2.1. Method of green ammonia production

During anaerobic digestion, organic waste with a high nitrogen content decomposes to form AN. The AN is in the liquid in the form of ammonium ions and free undissociated ammonia. There is an equilibrium between free ammonia in the liquid, which is the substrate digested by the methanogenic community, and ammonia in the gas space of the biogas reactor. An open container with absorbent, which is a solution of MAP, is placed above the liquid surface. As a result of interaction of ammonia in the gas space with MAP, DAP is formed (Figure 1).

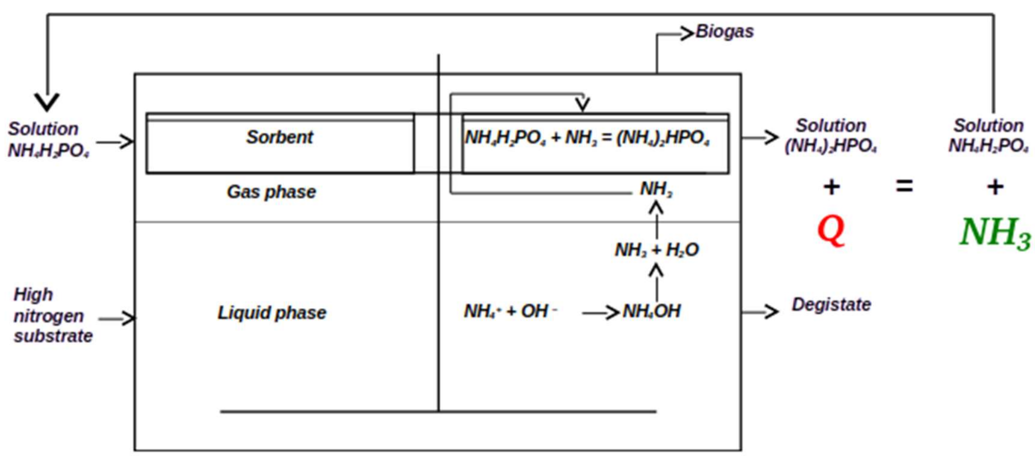

Figure 1. Production of green ammonia from organic waste with high nitrogen content

As a consequence of this absorption of ammonia by the absorbent, its amount in the gas space decreases, however, its loss is compensated by the transfer of ammonia from the liquid because there is an equilibrium in the concentration of ammonia in the liquid and gas phases and it is continuously restored/maintained. Thus, absorption of ammonia by MAP solution from the gas space leads to the transition of ammonia from the liquid, which in turn causes a decrease in the amount of ammonia in it. In the biogas reactor ammonia accumulates in the form of DAP. The absorbent is periodically drained from the biogas reactor when a certain pH value is reached, which corresponds to the neutralization of MAP to DAP, and is fed for regeneration. Regeneration consists in heating the solution of DAP to a temperature above 70 °C, which is accompanied by the formation of MAP and the release of ammonia gas. The MAP solution is returned back to the biogas reactor. Heat from a cogeneration plant that uses biogas as fuel is used to regenerate the absorbent.

2.2. Assessment of the Potential for Green Ammonia Production from Animal Waste in Ukraine

When assessing the potential for ammonia production using a new method, relevant information was used based on data from the State Statistics Service of Ukraine as of January 1, 2021. More recent data is not available due to the current situation in Ukraine.

The data presented in Table 1 were harnessed to evaluate the potential for ammonia production in Ukraine.

Table 1. Parameters of manures related to evaluation of ammonia potential

Animal waste type	Total Nitrogen, % of dry weight	Moisture content, %	Waste mass from one animal, kilograms per animal per day
Poultry	4.6	75	0.16
Pigs	3.9	86	5.1
Cattle	2.6	86	55
Cows	2.9	86	55

This data as well as chemical parameters of the technology of ammonia production were used to calculate the potential for daily ammonia production from the waste of a single animal, the potential for ammonia production in Ukraine within the main livestock sectors, share of main livestock sectors in green ammonia production potential in Ukraine, the potential for green ammonia production across different regions of Ukraine (Geochart).

To evaluate the economic feasibility and production capacity of green ammonia in Ukraine, we utilized a bottom-up approach based on livestock statistics and nitrogen availability. The total potential for ammonia production (P_{NH_3}) was calculated by aggregating the nitrogen recovery potential from specific animal waste streams (poultry, pigs, cattle, and cows) (Zhadan et al., 2021b).

The calculation was performed using the following equation (1), based on coefficients established in previous studies:

$$P_{NH_3} = \sum_{i=1}^{n} * (N_i \times M_{waste,i} \times C_{N,i} \times \eta_{conv}) \tag{1}$$

Where:

- N_i is the population of animal type i (based on State Statistics Service of Ukraine data).
- $M_{waste,i}$ is the daily mass of waste produced per animal (kg/day).
- $C_{N,i}$ is the nitrogen content percentage of the dry weight of the waste.
- η_{conv} is the conversion efficiency factor of Ammonium Nitrogen (AN) to ammonia gas using the proposed sorption-desorption method.

The economic assessment relies on the technical viability of the sorption from Biogas Reactors method described in our previous work. This method utilizes a Monoammonium Phosphate (MAP) solution to sorb ammonia from the gas phase of a biogas reactor, forming Diammonium Phosphate (DAP) (Zhadan et al., 2021b).

The core chemical mechanism governing the process is the reversible reaction between ammonia and phosphate solutions. The regeneration phase, which dictates the energy cost, involves the thermal decomposition of DAP back into MAP and ammonia gas at temperatures exceeding 70 °C (2):

$$(NH_4)_2HPO_4 \overset{\Delta T>70^{\circ}C}{\rightarrow} NH_4H_2PO_4 + NH_3 \uparrow \quad (2)$$

This reaction allows for the continuous recycling of the sorbent (MAP) and the recovery of pure green ammonia.

To determine the energy inputs required for the economic model (specifically the heat required for sorbent regeneration), experimental data regarding voltage, current, and time were extrapolated (Zhadan et al., 2021b).

The specific energy consumption (E_{spec}) required to produce one ton of ammonia was calculated using the Joule heating formula (3) applied to the laboratory regeneration setup:

$$E_{spec} = \frac{\int_0^t * (U(\tau) \times I(\tau))d\tau}{m_{NH_3}} \quad (3)$$

Where:

- $U(\tau)$ is the voltage applied to the heating element (Volts).
- $I(\tau)$ is the current strength (Amperes).
- t is the total duration of the heating process (seconds).
- m_{NH_3} is the mass of ammonia released during the regeneration cycle (kg), determined by the volume of gas displaced in a saturated sodium chloride solution.

The kinetic data regarding ammonia release rates and temperature correlations were processed using SciDAVis (Scientific Data Analysis and Visualization**)** software.

SciDAVis was employed to:

1. Plot the non-linear kinetics of ammonia release from the DAP solution over time.
2. Perform numerical integration of the power consumption curves to derive the total energy (E_{spec}) values.

Analyze the equilibrium concentrations of Ammonium Nitrogen (AN) in the liquid and gas phases to optimize the sorption efficiency parameters used in the economic potential model.

3. Results and Discussion

3.1. Potential for ammonia production in Ukraine in the main livestock sectors

The suggested method for producing ammonia can be used to process various wastes with high nitrogen content, including pig, poultry, cattle, horse, and sheep manure, slaughterhouse waste, and sewage sludge.

For example, a poultry farm with a population of 750,000 laying hens, under the conditions that prevailed in our previous experiment (Salyuk et al., 2017), can produce 132 tons of ammonia per year.

An assessment of the potential for ammonia production in Ukraine was carried out. Based on the data in Table 1, the maximum amount of ammonia that can be obtained from one animal per day was calculated (Table 2).

Table 2. The potential for daily ammonia production from the waste of a single animal

Farm animals	Ammonia production, kilograms per animal per day
Poultry	0.002
Pigs	0.034
Cattle	0.243
Cows	0.271

Considering the amount of ammonia obtained from one animal (Table 2) and the number of domestic animals, we get the following potential for ammonia production in the main livestock sectors, presented in Figure 2.

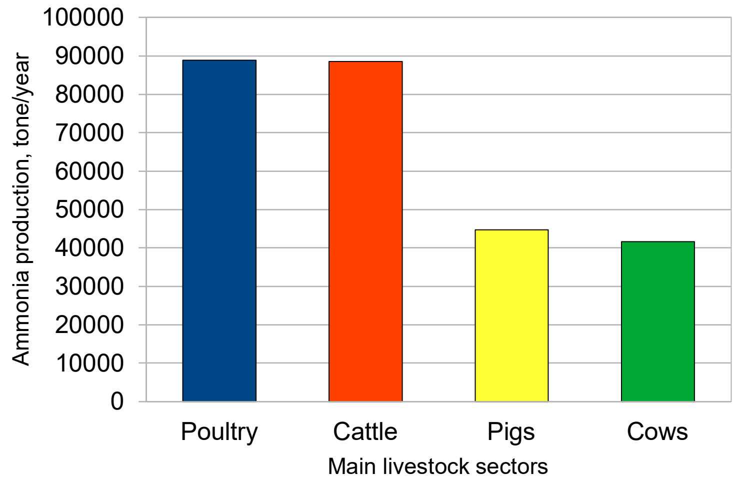

Figure 2. The potential for ammonia production in Ukraine within the main livestock sectors

When assessing the potential for ammonia production, industrial livestock was considered, but livestock located on household farms was not. This is because a significant volume of livestock waste must be collected centrally using mechanization and automation.

The annual potential for ammonia production in the main livestock sectors of Ukraine has a production level of 263,610 tons which is comparable to the traditional ammonia levels (Zhadan et al., 2021b). Production in the country in 2019, was 183 thousand tons. Poultry and cattle have the most significant potential for ammonia production, with estimated volumes of 88,844 and 88,468 tons, respectively (Zhadan et al., 2021b). The share of the leading livestock sectors in the green ammonia production potential in Ukraine is shown in Figure 3.

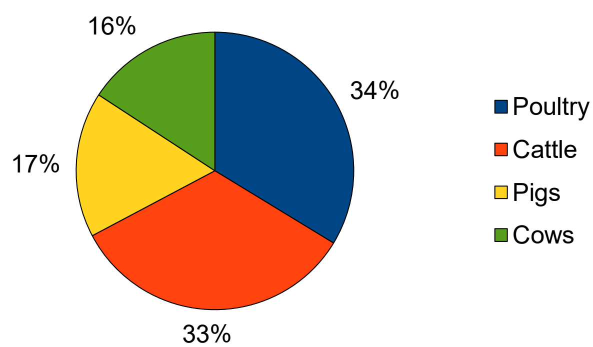

Figure 3. Share of main livestock sectors in green ammonia production potential in Ukraine

An analysis was conducted to identify the most promising regions for potential ammonia production volumes. The potential for green ammonia production in the main livestock sectors by region of Ukraine is shown in Figure 4.

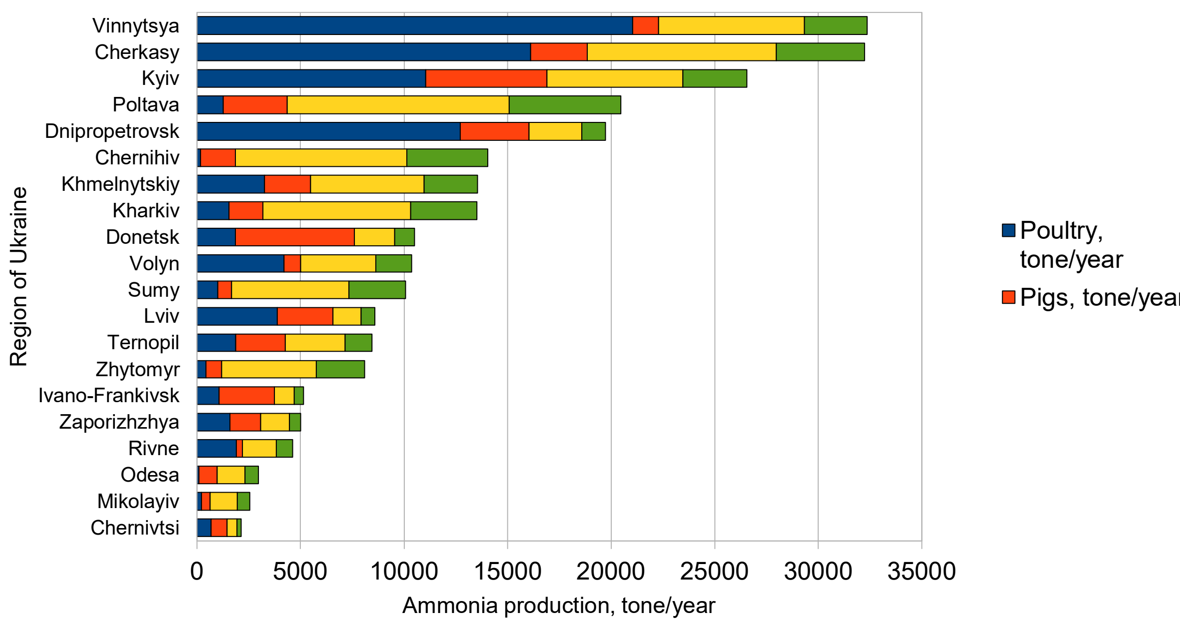

Figure 4. Potential for green ammonia production by region of Ukraine

The most promising regions in terms of ammonia production potential are Vinnytsia, Cherkasy, and Kyiv. These three regions contribute 34.6% (or 91,091 tons) of the total potential ammonia production, considering that Ukraine has 24 regions. It is noteworthy that these three areas constitute a geographically coherent cluster (Figure 5).

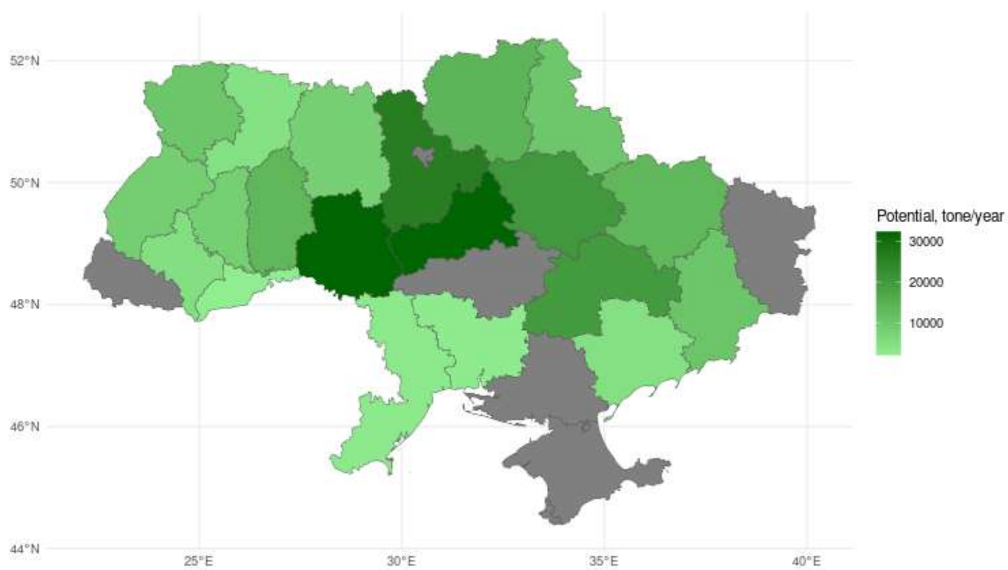

Figure 5. Potential for green ammonia production across different regions of Ukraine

The ammonia production potential in the Zakarpattya, Kirovograd, Lugansk and Kherson regions of Ukraine is not shown in the figure because poultry population data for these regions are not publicly available. However, given the number of other animals and the total number of poultry in these four regions, which can be defined as the difference between the number of poultry in the country and in the other 24 regions, these regions are not significant for comparison with other regions.

During the evaluation of ammonia production potential, we assumed the utilization of all Nitrogen in animal manure, although this may not be feasible in practice. Therefore, the values obtained represent the potential upper limits for ammonia production volumes.

3.2. Usage of the produced ammonia

The consideration of existing technologies and commercial solutions shows that green ammonia has many potential applications as a carbon-free fuel. Green ammonia demonstrates significant potential as a carbon-free fuel across multiple technological applications. Industrial implementations have progressed substantially, showcasing the feasibility of ammonia across diverse energy systems.

Power Generation (using Turbines) Advancements in ammonia combustion have progressed from micro-turbines to commercial scale. Early demonstrations of ammonia combustion technology began in 2014, when researchers successfully operated a 50-kW ammonia-fueled combustion turbine, achieving stable output on mixed fuel blends and subsequently on pure ammonia (Ammonia Energy Association, 2015; Kurata et al., 2021). By 2018, industrial testing on a 2 MW dual-fuel turbine confirmed stable operation across ammonia mixing ratios from zero to 20%, with combustion efficiency exceeding 99.8% (IHI Corporation, 2019). The approach is discovered by scientists (Ahmad et al., 2022; Pashchenko, 2024)

Concurrently, co-firing ammonia with coal has seen significant scaling. Following CEPCO's 1% co-firing demonstration in 2017 (Crolius, 2019), IHI Corporation successfully adapted existing boilers to accommodate a 20% ammonia mixture (Crolius, 2018). More recently, China Energy achieved a benchmark 35% co-firing ratio in a 40 MW boiler with reduced NOx emissions (Atchison, 2022). In 2023, Mitsubishi Heavy Industries validated high-ratio co-firing and successful single-fuel ammonia combustion, confirming emission reductions and flame stability (Njovu, 2024b).

Recent academic literature further validates the industrial shift toward ammonia co-firing, particularly as a transitional strategy for decarbonizing existing coal-fired infrastructure. Wang et al. (2024) highlight that ammonia co-firing is technically feasible and economically practical because it utilizes existing power plant assets to significantly reduce CO_2 emissions without requiring a complete overhaul of the power grid[1]. However, the integration of ammonia into combustion systems requires careful optimization of operating conditions to manage nitrogen oxide (NO_x) emissions.

Simulation studies by Yuan et al. (2022) on the co-firing characteristics of ammonia and coal confirm that while increasing the ammonia ratio effectively lowers CO_2 and CO concentrations, it alters the thermal profile of the main combustion zone. Their research indicates a non-linear relationship between ammonia content and pollutant formation; specifically, while a 20% ammonia mixture maximized outlet N$ concentrations, increasing the ratio to 40% actually resulted in lower outlet NO levels compared to the 20% case, despite higher temperatures in the combustion zone. This suggests that high-ratio co-firing may offer a sweet spot for balancing decarbonization with emission control, reinforcing the potential for the large-scale application of the green ammonia produced by the proposed method.

Internal Combustion Engines (ICE) While ammonia often requires blending to accelerate combustion, recent innovations favor dual-fuel and direct-injection systems. In the automotive sector, GAC unveiled a 120-kW ammonia engine in 2023 capable of 90% carbon reduction (Atchison, 2023), while KIMM, Hyundai, and Kia developed a 2-liter direct liquid injection engine in 2025 (Atchison, 2025). In the maritime industry, Wärtsilä released the commercial Wärtsilä 25 platform in 2023 (Wärtsilä, 2025), and Fortescue achieved the first marine use of ammonia-diesel dual-fuel combustion in 2024 (Atchison, 2024).

Fuel Cells and Industrial Applications Solid Oxide Fuel Cell (SOFC) technology has scaled rapidly. Prototypes grew from 200 W in 2015 to 1 kW in 2018, culminating in Alma Clean Power's successful testing of a 100-kW direct ammonia SOFC system in 2024 (Njovu, 2024a). Beyond energy generation, ammonia is utilized in industrial heating, exemplified by AGC's 2023 demonstration of low-emission glass production using ammonia fuel.

Direct ammonia fuel cells offer an efficient decarbonization pathway for transportation by eliminating the need for intermediate hydrogen storage, resulting in a more economical power system. Huang et al. (2025) classify these systems into high-temperature solid oxide fuel cells, which have achieved peak power densities exceeding one thousand milliwatts per square centimeter suitable for heavy-duty transport, and low-temperature anion exchange membrane fuel cells better suited for light-duty vehicles.

To further optimize efficiency, Ho et al. (2025) identify bimetallic catalysts and anion exchange membranes as the most effective materials for reducing energy losses. Practical implementations are rapidly emerging, evidenced by Nissan developing a prototype vehicle with a six-hundred-kilometer range and techno-economic analyses indicating that ammonia-powered trains could reduce costs by thirty percent compared to hydrogen alternatives (Huang et al., 2025).

3.3. Advances in ammonia-based energy

The development of ammonia fuel technologies is showing steady progress: it is being successfully used in gas turbines, coal-fired power plants, internal combustion engines, and fuel cells, providing stable operation and reduced greenhouse gas emissions. Both blended and fully ammonia-based solutions are being developed for transportation and industry, including marine engines and glass-melting furnaces. Ammonia is also being considered as a promising option for long-duration energy storage. All of this demonstrates its real potential in the transition to carbon-free energy. Figure 6 provided Potential uses of green ammonia as a carbon-free fuel. Figure 6 provided Potential uses of green ammonia as a carbon-free fuel.

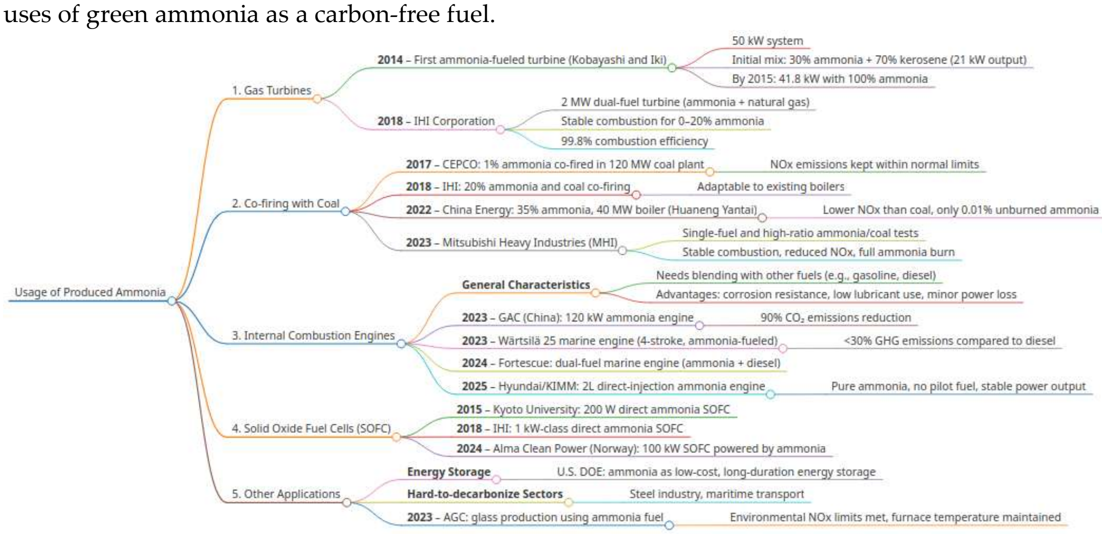

Figure 6. Potential uses of green ammonia as a carbon-free fuel

The development of technologies for the use of ammonia as a carbon-free fuel and the development of a method for the production of green ammonia from animal waste with a potential comparable to the traditional Haber-Bosch process opens the way for Ukraine to energy independence, environmental sustainability and economic growth. This is particularly relevant in the context of the country's strong agricultural sector and the global transition to carbon-neutral energy. If successful, Ukraine can take an important place on the world stage as a producer and supplier of green ammonia, strengthening its role in a sustainable future.

4. Conclusions

The proposed method of producing ammonia by sorbing it from the gas phase of the biogas reactor, followed by the subsequent regeneration of the sorbent, is a promising alternative to the traditional Haber-Bosch process. Various nitrogen-rich organic wastes, including poultry manure, pig manure, cow manure, sewage sludge, and slaughterhouse waste, can be used as feedstock. The sorbent can be regenerated using thermal energy generated by a cogeneration plant.

The study's results indicate that the proposed method has the potential to produce up to 263,610 tons of ammonia annually in the main livestock sectors of Ukraine. This is comparable to the country's conventional ammonia output in 2019. The most promising livestock sectors in terms of ammonia production potential are poultry and cattle. The regions with the most potential are Vinitskaya, Cherkasy, and Kyiv. Geographically they form a cluster.

The development of technologies for the use of ammonia as a carbon-free fuel and the development of a method for the production of green ammonia from nitrogen-rich waste with a potential comparable to the traditional Haber-Bosch process opens the way for Ukraine to energy independence, environmental sustainability and economic growth.

This study addresses critical technical and data gaps in the transition to sustainable energy. First, it presents a viable alternative to the carbon-intensive Haber-Bosch process by utilizing nitrogen-rich organic waste and biogas-derived thermal energy, effectively decoupling ammonia synthesis from fossil fuels. Crucially, the integrated MAP sorption technique resolves the issue of methanogenic inhibition in anaerobic digestion; this ensures continuous waste processing while converting a traditional liability into a valuable energy asset.

Furthermore, the research bridges a significant void in regional quantitative assessments, providing the first data-driven evaluation of Ukraine's potential to contribute to EU decarbonization targets through its agricultural sector. Finally, by validating domestic production, the study reinforces ammonia's strategic advantage over hydrogen—citing superior energy density and compatibility with existing infrastructure—offering a practical pathway for enhancing energy security in agriculturally dominant nations.

Author Contributions: Conceptualization, SZ and YS; methodology, SZ and YS; validation, OZ, SU; formal analysis, OZ, SU; investigation, SZ and YS; resources, SZ, YS, OZ, SU; data curation, SZ and YS; writing—original draft preparation, YS; writing—review and editing, SZ, OZ, SU; visualization, SZ; supervision, SZ; project administration, SZ. All authors have read and agreed to the published version of the manuscript.

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