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In-House Green Fertiliser Production for AgriVoltaics From BIPV Green Hydrogen Laboratory

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Abstract. Brazil currently imports approximately 85% of its fertilisers, making its agricultural sector vulnerable to international supply disruptions and price volatility. In parallel, significant portions of the country face challenges related to energy poverty and food insecurity. Agrivoltaic systems, when coupled with localized production of green fertilisers, offer a promising pathway to simultaneously address these issues. Leveraging Brazil's abundant solar radiation and rainwater availability, this study presents an innovative, integrated system for decentralized fertiliser production. Implemented at the Solar Energy Laboratory of the Universidade Federal de Santa Catarina, the system combines Building-Integrated Photovoltaics (BIPV) with green hydrogen (H_2) production, subsequently enabling the synthesis of ammonia (NH_3) and ammonium sulphate. The outcomes offer a scalable model for enhancing agricultural resilience and energy autonomy in Brazil and similar contexts worldwide.

Keywords: Green Fertiliser, Agrivoltaics, Green Hydrogen

1. Introduction

Agrivoltaic systems have emerged as a promising solution to address the competing demands for land use in agriculture and renewable energy generation [1,2]. By integrating photovoltaic (PV) modules with crop cultivation, these systems seek to optimize both energy production and agricultural output within the same area [3,4].

Sustainable fertiliser production is closely linked to with the development and widespread use of agrivoltaics. Fertilisers play a crucial role in enhancing the productivity of agrivoltaic systems by supporting plant growth under modified light conditions. In this context, the integration of sustainable fertiliser strategies, including localized or green fertiliser production, can significantly contribute to improving the overall efficiency and sustainability of agrivoltaic systems, especially in regions with limited agricultural resources or challenging climatic conditions.

Brazil's strong dependence on imported fertilizers, with around 85% coming from abroad [5], and the concentration of fertilizer use in key biofuel crops pose a strategic risk to the long-term competitiveness of the biofuel sector, particularly under scenarios of limited global supply growth and insufficient domestic industrial support [6].

PV is the fastest-growing segment of the energy market in Brazil and all over the globe [7]. Agrivoltaics is at its very early stages of adoption and development in the country [8], and energy poverty and food insecurity are pressing issues for a large fraction of the population.

Both agrivoltaic systems and sustainable fertiliser production rely on shared resource availability, particularly solar irradiance and water. These common requirements create opportunities for integrated solutions in regions with favourable climatic conditions. In this context, green hydrogen (H_2) produced via renewable-powered electrolysis can serve as a key vector for sustainable fertiliser production, as it directly benefits from abundant solar energy and water resources, helping to generate clean energy in an efficient way, both in Brazil and elsewhere.

2. The Fotovoltaica/UFSC Hydrogen and Solar Research Laboratory

The Solar Energy Laboratory Fotovoltaica/UFSC operates an integrated green H_2 facility in Florianópolis, Brazil, designed to support research on renewable-based fertiliser production for agrivoltaic applications. Since 2023, the laboratory (**Fig. 1**) has been producing green H_2, green NH_3, and ammonium sulfate ($(NH_4)_2SO_4$) using exclusively on-site photovoltaic electricity and harvested rainwater, without external energy or water inputs.

Figure 1. *Electrolyser stacks and Haber-Bosch reactor for green H_2, green NH_3 and green fertiliser $(NH_4)_2SO_4$ at the Solar Energy and Green Hydrogen Research Laboratory at Fotovoltaica/UFSC.*

The laboratory is equipped with dedicated infrastructure for green H_2 production based on renewable-powered electrolysis. The electrolyzer system has a nominal H_2 production capacity of 4.5 Nm³ h⁻¹, where Nm³ denotes normal cubic meters at 0 °C and 1 atm, corresponding to approximately 0.40 kg H_2 h^{-1}, and operates at an electrical power of 25 kW. The produced H_2 has a purity exceeding 99.999%, suitable for subsequent NH_3 and fertiliser synthesis.

Hydrogen is stored in a compressed gas system with a total capacity corresponding to approximately 480 Nm³ of H_2 at normal conditions (approximately 43 kg H_2), with a maximum storage pressure of 300 bar (**Fig. 2**). The specific electricity and water consumption of the system are approximately 62 kWh kg^{-1} H_2 and 9.4 L kg^{-1} H_2, respectively. Under continuous operation, the system can produce up to 9.7 kg of H_2 per day, with a total consumption of 600 kWh of electricity and 90.72 liters of water. Although rainwater is used as the primary water source, it is subjected to appropriate purification and conditioning to meet the water quality requirements of the electrolyzer stacks, ensuring stable operation and long-term system reliability.

The green H_2 laboratory adopts a building-integrated photovoltaic (BIPV) concept based on large-area bifacial PV modules integrated into the rooftop and façades. These elements simultaneously function as the building envelope, rainwater collection surfaces for H_2 production, and the electricity generator for the energy-intensive electrolysis and downstream synthesis processes. The BIPV system has a total installed capacity of approximately 190 kWp (**Fig. 3**), enabling on-site, renewable electricity supply.

Figure 2. *Compressor (left) and two racks with 16 cylinders each for H_2 storage (right) at the Solar Energy and Green Hydrogen Research Laboratory at Fotovoltaica/UFSC.*

Figure 3. *The Solar Energy and Green Hydrogen Research Laboratory at Fotovoltaica/UFSC.*

The project objectives include the optimization of green H_2 production, so that it can be replicated in any sunbelt country with plenty of sunshine and rainwater.

3. From Solar and Rainwater to Hydrogen, Ammonia and Fertiliser for Agrivoltaics

Ammonium sulphate is a quick acting, nitrogen fertiliser which encourages leafy growth, and is especially beneficial for crops such as lettuce, spinach, leeks and onions [9]. The process involves chemical reactions, evaporation, and crystallisation, that require significant amounts of energy. In the direct synthesis method adopted in this study, NH_3 reacts with sulfuric acid (H_2SO_4) to form ammonium sulphate ($(NH_4)_2SO_4$).

Hydrogen required for NH_3 synthesis is produced on-site via water electrolysis powered by the BIPV system, using harvested rainwater. Nitrogen (N_2) and sulfuric acid (H_2SO_4) are supplied from external industrial sources. Accordingly, the system operates with fully on-site, renewable energy and water supply, while selected chemical feedstocks are externally provided. **Figure 4** discribes the process for fertiliser development.

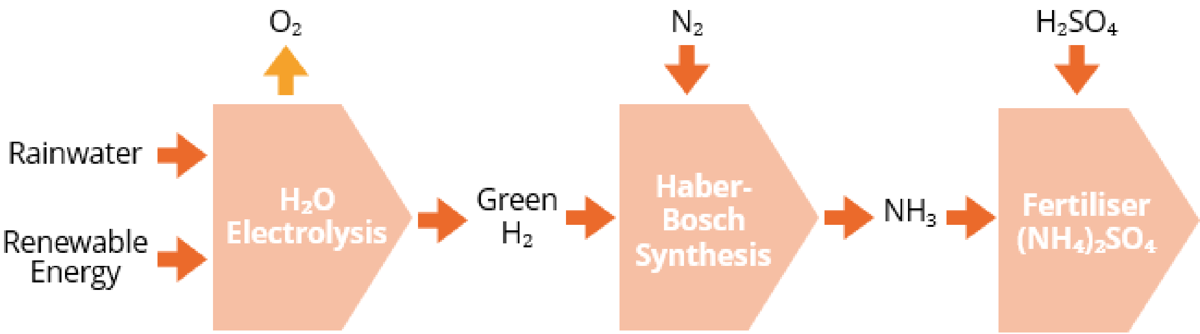

Figure 4. *Process for fertiliser development.*

Producing ammonia is an energy intensive process, in which the Haber-Bosch reactor is fed with green H_2 produced by the electrolysis using rainwater and solar electricity, both collected directly from the laboratory buildings' roofs and façades. In the agrivoltaic system, the PV modules also double as both energy and water harvesters.

The agrivoltaic pilot project at the Solar Energy Research Laboratory (Fotovoltaica UFSC) (**Fig. 5**) includes a total of seven distinct PV system configurations, each combining different structural topologies and module technologies to assess energy production, crop yield, and system performance under varying conditions. The agrivoltaic systems incorporate both standard and semi-transparent modules installed across vertical, fixed-tilt, and single-axis tracking structures.

Figure 5. *Agrivoltaic system of The Solar Energy and Green Hydrogen Research Laboratory at Fotovoltaica/UFSC.*

Table 1 summarizes the main agrivoltaic system characteristics and the energy intensity associated with the on-site production of ammonium sulfate fertiliser. “L” denotes liters of aqueous ammonium sulfate solution at a concentration of 0.1 $kg \cdot L^{-1}$. The specific energy consumption ($kWh \cdot L^{-1}$) includes electricity demand for water electrolysis and ammonia synthesis. PV installed power and annual PV energy yield refer to the agrivoltaic photovoltaic system supplying electricity to the fertiliser production process (sum of the seven systems).

Table 1. *Agrivoltaic system parameters and energy intensity of on-site ammonium sulfate production.*

Planted area	373	m^2
Crop Cycles	6	cycles/year
Ammonium Sulphate Concentration	0.1	kg/L
Ammonium Sulphate Energy Consumption	2.67	kWh/L
PV Installed Power	107.2	kWp
AgriVoltaics Area	1000	m^2
PV Power Density	1.1	MWp/ha
PV Energy Yield	126	MWp/year

Table 2 presents the annual ammonium sulfate demand per hectare for different soil organic matter conditions, expressed as fertiliser mass ($kg \cdot ha^{-1} \cdot cycle^{-1}$ and $kg \cdot ha^{-1} \cdot yr^{-1}$), equivalent solution volume ($L \cdot ha^{-1} \cdot yr^{-1}$), and associated electrical energy demand ($MWh \cdot ha^{-1} \cdot yr^{-1}$). Energy demand includes electrolysis and ammonia synthesis. The “% of PV” column indicates the fraction of the total annual agrivoltaic PV energy yield required to supply fertiliser production for one hectare.

***Table 2.** Annual ammonium sulfate demand and corresponding energy requirements under different soil organic matter scenarios.*

Scenario	Kg/ha.cycle	Kg/ha.yr	L/ha.yr	MWh/ha.yr	% of PV
High Organic Matter (>5%)	177	1063	10629	1.1	2%
Medium Organic Matter (2.5%-5%)	248	1488	14880	1.5	3%
Low Organic Matter (<2.5%)	319	1913	19131	1.9	4%

The model is replicable across sunbelt countries and helps close the food-energy-water loop in a climate-resilient and decentralized way.

In commercial farming systems in Brazil, after a spike in cost in 2021 [10], fertilisers typically represent an annual cost in the range of 283 USD ha^{-1} [11], depending on crop type, soil conditions, and market volatility. Fertilization commonly accounts for 19-32% of variable production costs in intensive cropping systems [11-14], making it a financially and strategically relevant input for farmers.

When interpreted in an agricultural context, the fertiliser quantities and energy demands reported in Tables 1 and 2 indicate that on-site ammonium sulfate production could offset a non-negligible share of annual nitrogen input requirements at the hectare scale, while consuming only a small fraction (2–4%) of the associated agrivoltaic PV energy yield. Although fertiliser costs represent only a portion of total production expenses, their volatility and import dependence make local production economically relevant from a risk mitigation and resilience perspective. The primary economic value of the proposed system lies not in minimizing total production costs, but in reducing exposure to fertiliser price volatility and supply disruptions. A full techno-economic assessment, including capital expenditure, operating costs, and fertiliser levelized cost, is beyond the scope of this study and will be addressed in future work.

4. Conclusions

This study presented a laboratory-scale demonstration of an integrated system for in-house green fertiliser production tailored to agrivoltaic applications, combining BIPV, rainwater harvesting, solar-powered water electrolysis, and downstream ammonia and ammonium sulfate synthesis. The results demonstrate the technical feasibility of coupling renewable electricity generation with fertiliser production in a single infrastructure, highlighting the potential for synergies between energy, water, and agricultural inputs within agrivoltaic systems.

From a practical perspective, the proposed concept addresses two critical challenges faced by agrivoltaics: access to low-carbon energy and the availability of fertilisers compatible with sustainable agricultural practices. By leveraging on-site renewable resources, the system illustrates a pathway to reduce dependence on externally supplied fossil-based inputs, which is particularly relevant in regions with high solar potential and significant fertiliser import dependency. This aspect is particularly relevant in regions with high solar potential and strong agricultural output, such as Brazil, where long-term structural dependence on imported fertilisers, especially nitrogen-based products, poses economic and strategic risks. Within this context, decentralized and renewable-based fertiliser production concepts, even at small or modular scales, may contribute to improving resilience at the farm or regional level.

Nevertheless, the present work is subject to important limitations. The system operates at laboratory scale and does not yet represent a fully closed material cycle, as key inputs such as nitrogen and sulfuric acid are externally supplied. In addition, no comprehensive techno-economic or life-cycle assessment has been conducted. Future research should therefore focus on system scaling, material sourcing strategies, and economic viability under real agricultural operating conditions. Particular attention should be given to the availability and logistics of nitrogen inputs, land and PV area requirements, and the integration of fertiliser production within existing agrivoltaic and farming practices. Assessing transferability across different climatic regions and regulatory frameworks will be essential to determine the broader applicability of the proposed concept beyond a laboratory-scale demonstration.

Author contributions

CRediT authorship contribution statement Ricardo Rüther: Writing – original draft ,Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. Marília Braga: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. Laís Cassanta Vidotto: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. Amanda Mendes Ferreira Gomes: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. Daniel Odilio dos Santos: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. Gustavo Xavier de Andrade Pinto: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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