Evaluation of the Store Potential of Green Hydrogen in Bahia, Brazil

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The use of green hydrogen (GH_2) as an energy source is considered essential for decarbonizing the world energy matrix. It is a central element of the investment plans announced by many countries toward carbon neutrality. Brazil occupies a privileged position since the national energy matrix is composed of about 85% of renewable energy, mainly hydroelectric, in addition to the growing presence of wind, solar, and biomass energy, combined with an interconnected transmission system and the availability of potable water. However, there are still many challenges for the insertion of this renewable energy source in the Brazilian electrical matrix, including the storage of GH_2. In this context, the present article aims to evaluate the storage potential of GH_2 in the State of Bahia, analyzing the identity of 27 territories at the State.
Keywords: Green Hydrogen. GH_2 Storage. Renewable Energy.

Introduction

Green hydrogen has emerged as a basis for global energy transformation. It can contribute to reducing CO_2 emissions by about 60% until 2050, considering an increase in the world population to approximately 11 billion people [1].

The advent of an industry for hydrogen production will require the planning of new and updated logistical assets such as gas pipelines, road infrastructure, and specific technologies for storage. These actions will demand capital, a continuous and qualified workforce, resources for construction, and access to new technologies.

Brazil occupies a privileged position in the energy transition process underway in the world because of the tremendous competitive potential for producing green hydrogen due to the generation of electricity from renewable sources and the availability of potable water. However, for the insertion of this renewable energy source in the Brazilian electrical matrix, there are still many challenges to be overcome. In this context, the main objective of this article is to evaluate the storage potential of GH_2 in Bahia.

H_2 storage is a big challenge and a key element in its large-scale use. Storing hydrogen on a large scale is necessary to increase its density through high storage pressure, low temperature, or using a material that adsorbs hydrogen molecules [3-6]. The main complexity in the storage of H_2 is its low density under Normal Conditions of Temperature and Pressure (CNTP) (0.084 kg/m^3). This density, whether in the liquid or gaseous state, results in a low density of contained energy, making it necessary to store large volumes. Consequently, it is necessary to modify its density through pressure and/or temperature variations for its storage [7].

Currently, there are four possible techniques for storing hydrogen. They are i) pressurized tanks (gaseous hydrogen), ii) cryogenic tanks (liquid hydrogen), iii) carbon steel tanks (LOHC - Liquid Organic Hydrogen Carriers), and vi) carbon steel tanks (storage in the solid state-adsorption). These different H_2 storage technologies differ mainly in terms of efficiency, energy density, tightness, level of development, safety, availability, installation complexity, and process maturity [8]. Therefore, this study will classify hydrogen storage techniques into two main categories: physical and chemical storage [3].

In physical storage, hydrogen is stored in one of its physical states: gaseous or a supercritical liquid. Equipment such as pressurized, cryogenic spheres,

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or salt caves can be used in this case. Currently, this hydrogen storage method is the most used and mature technology. Despite the high storage pressure, the energy content per weight remains low due to the very low density of H_2. Although it is commercially available, this form of storage generates losses of around 10% [3].

The H_2 liquefaction process ensures better storage in terms of higher energy density. However, this technique requires a cryogenic system to maintain the hydrogen in the liquid state under pressures of 0.1 MPa and temperatures of -253 °C [8]. The liquefaction of hydrogen presents substantial advantages since, in this case, hydrogen's density enormously increased (by about 833 times). However, this process consumes much energy (in the H_2 liquefaction stage), and there are evaporative losses (in the storage stage). Because of this, the losses of this technique reach 40% of the energy content [8,9]. Underground storage of H_2 in salt caverns is an alternative to large-scale storage. Despite its storage potential, low operating cost, and the fact that underground salt locations are well known, only a few salt caves have been created to store hydrogen. Salt caverns in Brazil are known to exist in Bahia (Down Química) and Alagoas (Braskem).

In physicochemical storage, hydrogen can be stored through the chemical composition of pure H_2 with metal hydrides or chemical hydrides, adsorbed on carbon, stored in glass microspheres, or using Liquid Organic Hydrogen Carriers (LOHC). LOHC - Liquid Organic Hydrogen Carriers are among the most promising options for H_2 storage in large volumes. Compared to pressure storage, the advantages are reduced weight and volume and easier handling. This storage is done in two stages: initially, the H_2 is charged in the LOHC molecule (hydrogenation), and later, after transport and storage, the H_2 unloading (dehydrogenation) is carried out at the point of consumption [3]. The leading carriers used as LOHC are petroleum-based liquids, dibenzyltoluene (DBT), N-ethylcarbazole (NEC), and toluene (TOL) [10]. LOHC has excellent potential to handle hydrogen as an ordinary liquid, requiring similar environmental conditions to petroleum-based liquids (e.g., diesel, gasoline). This characteristic allows the LOHC to be stored using existing infrastructure in conventional crude oil tanks [11].

The State of Bahia has the production chain for the main LOHCs mentioned above due to the petrochemical industry and local refineries, which makes it possible to sell hydrogen and Liquid Organic Hydrogen Carriers (LOHCs). Ammonia (NH_3) is also an alternative for hydrogen storage as it allows storage in the liquid phase under mild pressure and temperature conditions with a higher volumetric density of hydrogen than liquid H_2. It also has a relatively high ignition temperature, increasing safety during storage. However, these techniques are still under development and are not considered mature.

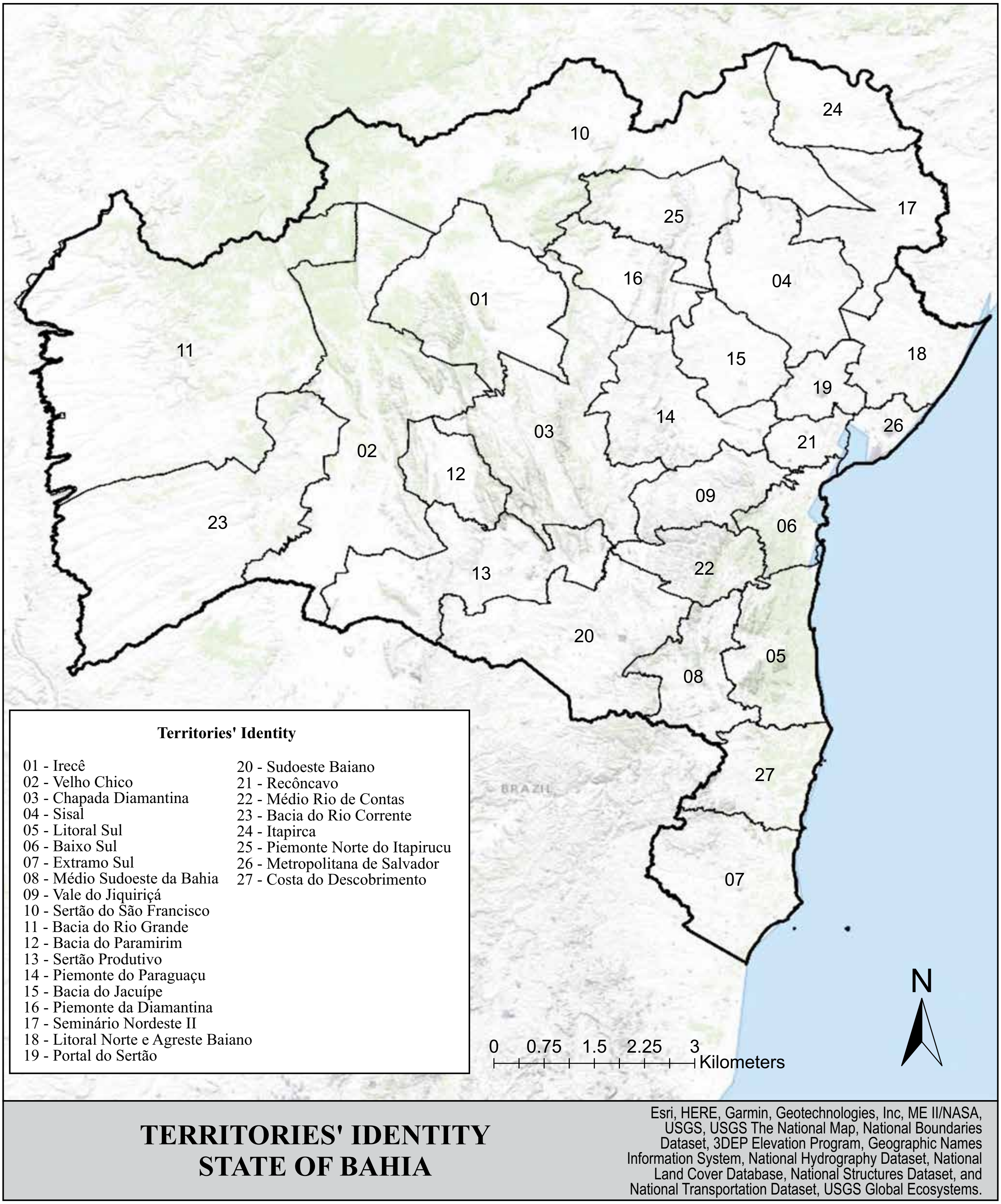
Materials and Methods

Study Area Description

Figure 1 presents the sample space under the study, which is composed of 27 regions of Bahia. In this article, the GH_2 storage potential in Bahia was mapped to show a spatial distribution of this potential in the 27-Identities of Territory. The maps were made using the Geoprocessing software ArcGIS Pro version 2.9.2 using shapefile files from the database of the "Superintendence of Economic and Social Studies of Bahia", "Map Biomass" and the "Portal de Mapas do IBGE", (2021).

These potential territories differ because of the existing facilities and infrastructure such as Oil Refineries, Private Use Terminals (TUP), Storage and Distribution Terminals, Liquefied Petroleum Gas Bases (GLP), Processing Units Natural Gas (UPGN) and Compressor Stations. These facilities and structures have technologies for the physical storage of H_2, such as tank parks that are composed of spheres, pressurized tanks, cryogenic tanks, compression stations, decompression stations, devices for receiving, moving, and delivering gases and liquefied products, as well as, they also

Figure 1. Territories' identitity in Bahia, Brazil.



Source: Authors, 2022.

have safety and cleaning equipment, a network of internal and external pipelines.

In addition, refineries use special process conditions to keep the product below its boiling point, which is of great importance due to the difficulty of storing H_2 in the liquid state. Therefore, the storage units of this product are made up of liquefaction systems.

Results and Discussion

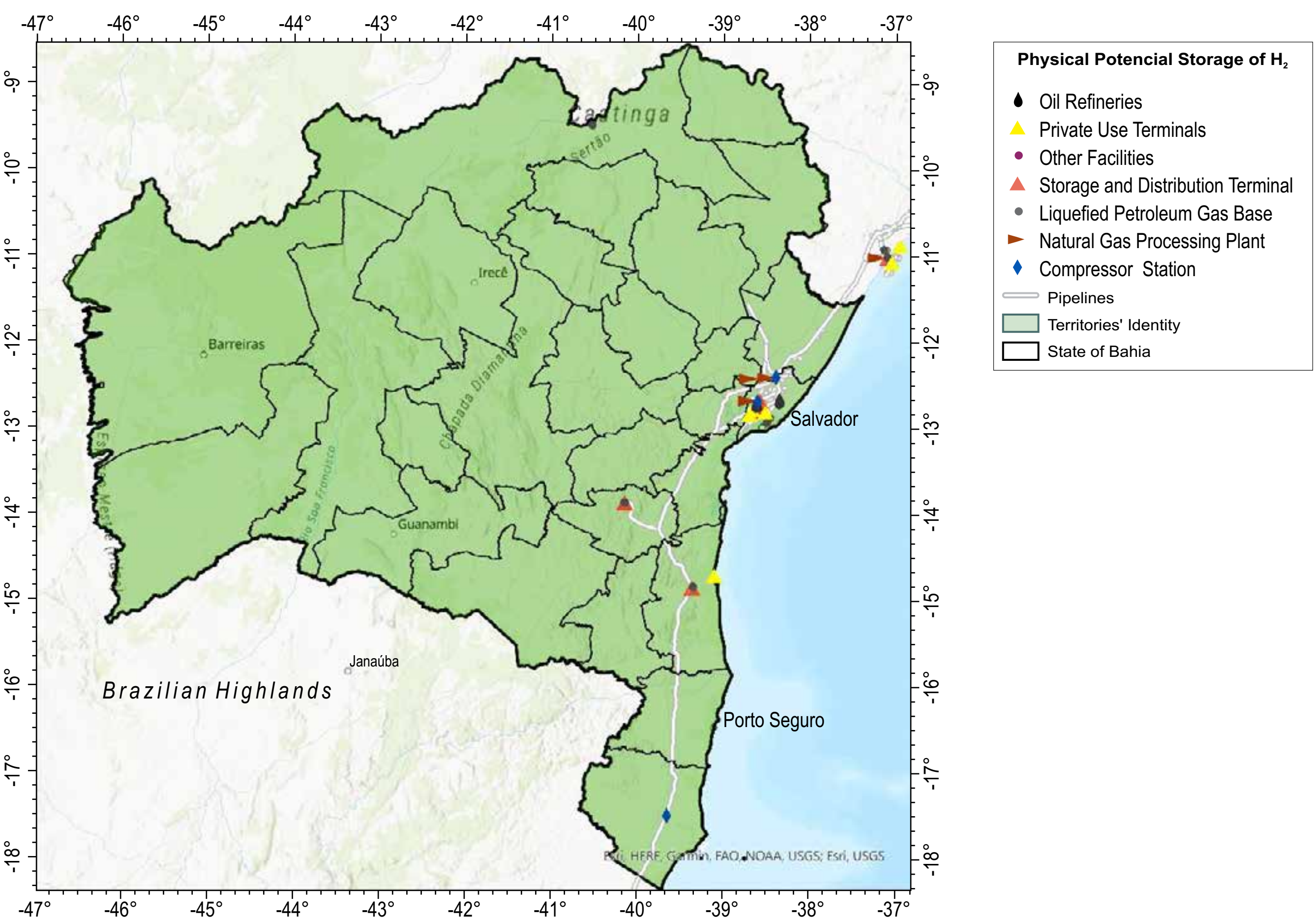
Figure 2 presents the updated infrastructure map with the potential for physical storage in Bahia and the existing pipeline network in the identified territories.

Bahia has six regions with infrastructure, facilities, and technologies for the storage of gases and petroleum products, and petrochemicals. The regions are Extremo Sul, Litoral Sul, Médio Rio de Contas, Litoral Norte and Agreste Baiano, Metropolitana de Salvador, and Sertão do São Francisco.

The Region Metropolitana de Salvador (RMS) has the highest concentration of facilities, infrastructure, and technologies for storing gases, petroleum products, and petrochemicals. In this region is located the Landulpho Alves Refinery (new AELEN), Petrochemical Complex, Gas Terminals, GLP Bases, and Ports specialized in gases, petroleum, and petrochemical products.

The region Litoral Sul disposes of the Oil Storage Terminal and its derivatives, the Private Use Terminal, and a GLP Base. The region Médio Rio de Contas also has an Oil Storage Terminal and

Figure 2. Physical storage potential of H_2 in Bahia.



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GLP Bases. Also, the Extremo Sul and Litoral Norte and Agreste Baiano Territories have Compression Stations, and the region do Sertão do São Francisco has a GLP Base. Finally, the other 20 regions do not have facilities, infrastructure, or technologies for storing gases.

Table 1 details the existing storage facilities, infrastructure, and technologies (atmospheric tanks, pressurized tanks, and spheres) with the potential for H_2 storage. The advantage of using existing facilities is to lower the infrastructure costs necessary for handling this new fuel.

Figure 3, in turn, presents the updated map of infrastructure with the potential for physicochemical storage of GH_2 in Bahia and the existing pipeline network in the territories' identity.

Figure 3 shows that only RMS has pre-existing infrastructure, facilities, and technologies for physicochemical storage, thus reducing the cost of implementation. In this territory are the

Table 1. Physical storage potential of H_2 in Bahia

Territories' Identity	Storage Technologies
N° 18 Litoral Norte	Compression System and Compressor Station (Catu)
N° 26 Região Metropolitana de Salvador	Compression System (São Francisco do Conde); **Petroleum and Derivatives Storage Terminals:** Chemical Terminal of Aratu (Candeias); VOPAK (Candeias); Transpetro (Candeias); Transpetro (Madre de Deus); **Gas Storage Terminal:** Regasification Terminal of GNL (TRBA) (Madre de Deus); Waterway Dock of Madre de Deus (Madre de Deus); Dow Aratu Ship Dock (Candeias); Cotegipe Ship Dock (Candeias); **Oil Refineries:** Landulpho Alves Refinary (RLAM), new ACELEN (Madre de Deus and São Francisco do Conde); **Other Facilities:** Braskem Basic Inputs (Camaçari); White Martins (Camaçari); Air Liquide (Camaçari); Unigel (Camaçari); Petrobrás (Candeias); UPGN: Petrobrás (São Francisco do Conde); Petrobrás (Pojuca); Petro Recôncavo (Mata de São João) Alvopetro (Mata de São João); Bases GLP: BahiaGás e NGB (Salvador); NGB, Liquigás, SuperG. and BahiaGás (São Francisco do Conde)
N° 07 Extremo Sul	Compressor Station (Alcobaça)
N° 22 Médio Rio de Contas	Petroleum and Derivatives Storage Terminal: Transpetro (Jequié); GLP Bases: Super Gás and NGB (Jequié)
N° 05 Litoral Sul	Petroleum and Derivatives Storage Terminal: Transpetro (Itabuna); GLP Bases: NGB (Itabuna)
N° 10 Sertão do S. Francisco	GLP Bases: BahiaGás e NGB (Juazeiro)

Table 2. Physical-chemical storage potential of H_2.

Territories' Identity	LOHC	Ammonia	Methanol	Natural Gas
N° 26 (RMS)	Braskem and ACELEN	Unigel	Metanor	BahiaGás

Landulpho Alves Refinery (new ACELEN), Unigel – Fafen, Metanor, Braskem, and BahiaGás. Table 2 details the existing facilities, infrastructure, and technologies with the potential for physicochemical storage of H_2.

Conclusion

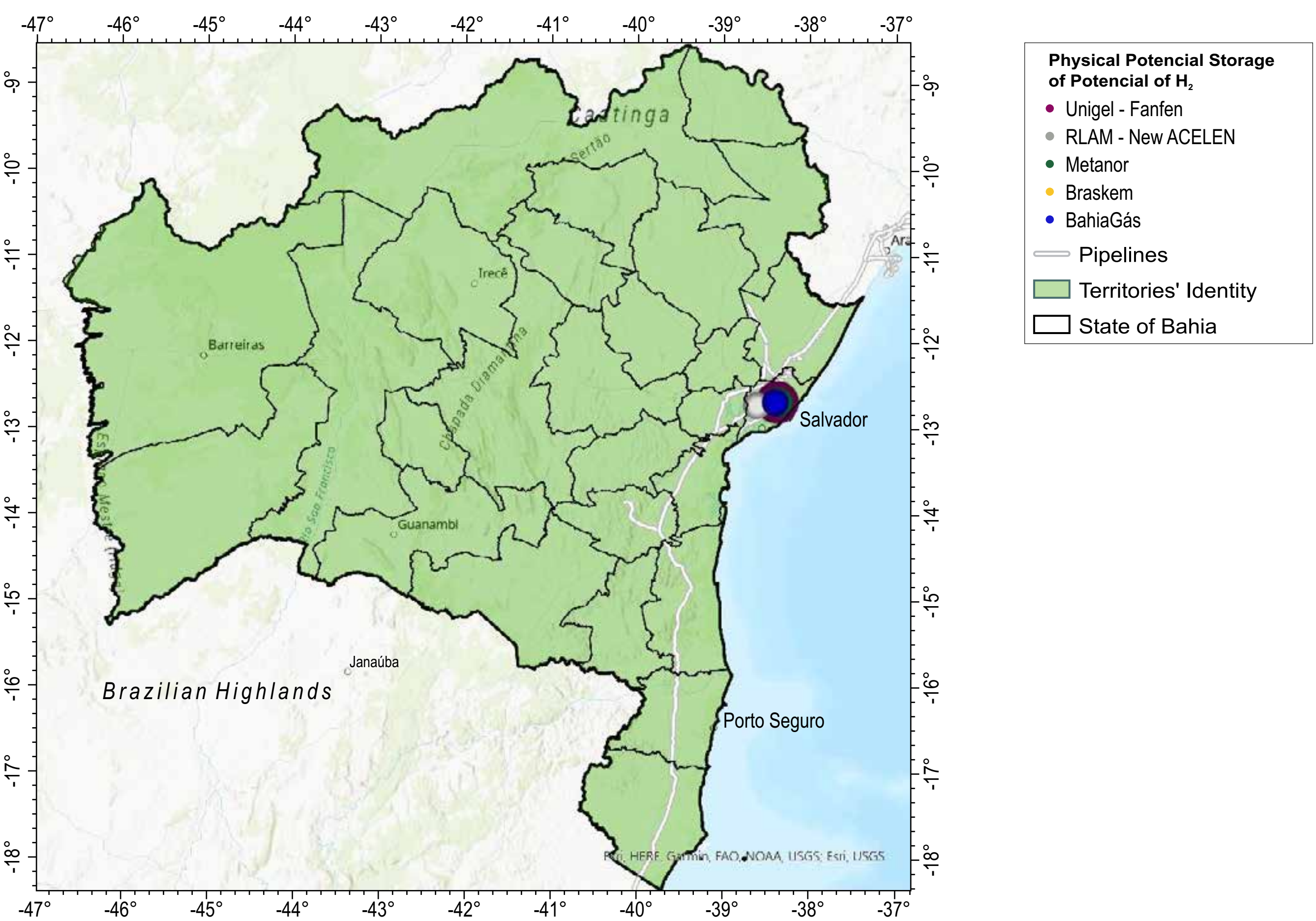
This article sought to evaluate the potential for GH_2 storage in the State of Bahia. The results show that the RMS has the most significant potential for physical storage and physicochemical storage in Bahia due to the existence of infrastructure and storage technologies.

Storage is a significant challenge for the development of the H_2 economy, and the choice of the best storage technology depends on the type of application and the specific context of each situation. Several methods have proved to be technically viable for storing hydrogen, but few options have reached technical maturity and, consequently, commercial maturity for large-scale use.

Regarding the national energy transition, the gaseous storage method will be the most used at the beginning of the penetration of H_2. However, the technical difficulties of conservation and high energy demand for liquefaction mean that liquid hydrogen storage systems are not yet strong candidates for widespread use, even considering that they have an energy density twice more significant than that of H_2 compressed.

This work contributes to decision-making in analyzing the technical and economic feasibility of implementing GH_2 hubs in Bahia.

Figure 3. Physicochemical storage of H_2 in Bahia.



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