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Date of receipt at the International Bureau:	06 July 2023 (06.07.2023)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a),(b) or (b-bis)

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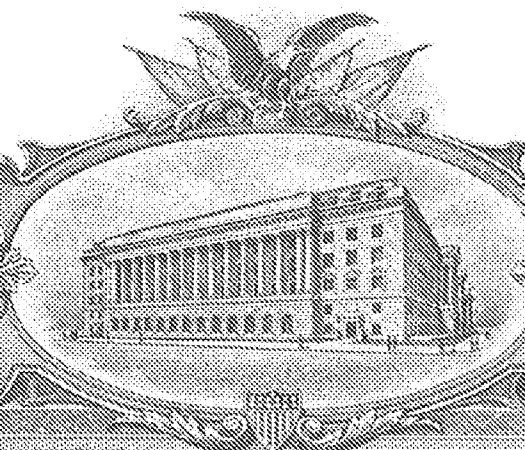
Application number: 63349888

Date of availability of document: 22 Jun 2022 (22.06.2022)

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THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

July 06, 2023

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: 63/349,888
FILING DATE: *June 07, 2022*

THE COUNTRY CODE AND NUMBER OF YOUR PRIORITY APPLICATION, TO BE USED FOR FILING ABROAD UNDER THE PARIS CONVENTION, IS US63/349,888



Certified by

Kathi

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2:

☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
--------------------------	---

Inventor Information:

Inventor 1		Remove	
Legal Name			
Prefix	Given Name	Middle Name	Family Name
	Thomas		Darrah
Residence Information (Select One) • US Residency Non US Residency Active US Military Service			
City	Dublin	State/Province	OH
Country of Residence		US	
Mailing Address of Inventor:			
Address 1		c/o Koloma, Inc.	
Address 2		7251 Sawmill Road, Suite 100	
City	Dublin	State/Province	OH
Postal Code	43016	Country i	US
Inventor 2		Remove	
Legal Name			
Prefix	Given Name	Middle Name	Family Name
	Colin		Wyte
Residence Information (Select One) • US Residency Non US Residency Active US Military Service			
City	Dublin	State/Province	OH
Country of Residence		US	
Mailing Address of Inventor:			
Address 1		c/o Koloma, Inc.	
Address 2		7251 Sawmill Road, Suite 100	
City	Dublin	State/Province	OH
Postal Code	43016	Country i	US
Inventor 3		Remove	
Legal Name			
Prefix	Given Name	Middle Name	Family Name
	Jacob		Harrington
Residence Information (Select One) • US Residency Non US Residency Active US Military Service			

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

City	Dublin	State/Province	OH	Country of Residence ⁱ	US
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Mailing Address of Inventor:

Address 1	c/o Koloma, Inc.				
Address 2	7251 Sawmill Road, Suite 100				
City	Dublin	State/Province	OH		
Postal Code	43016	Country ⁱ	US		
Inventor	4				Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Brent		Lary	

Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service

City	Dublin	State/Province	OH	Country of Residence ⁱ	US
------	--------	----------------	----	-----------------------------------	----

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Address 1	c/o Koloma, Inc.				
Address 2	7251 Sawmill Road, Suite 100				
City	Dublin	State/Province	OH		
Postal Code	43016	Country ⁱ	US		

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button.

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).			
☐ An Address is being provided for the correspondence Information of this application.			
Customer Number	153511		
Email Address	ip.docket.slc@dorsey.com	Add Email	Remove Email

Application Information:

Title of the Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		
Attorney Docket Number	P296929.US.01_515365-6	Small Entity Status Claimed	☒
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	3	Suggested Figure for Publication (if any)	

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
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Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not be** the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)
Customer Number	153511		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.			

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)ⁱ the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ^j (if applicable)	Remove

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
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Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐

B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

☐

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant	1	Remove
------------------	----------	------------------------

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

[Clear](#)

☒ Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.	Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	Koloma, Inc.
-------------------	--------------

Mailing Address Information For Applicant:

Address 1	7251 Sawmill Road, Suite 100		
Address 2			
City	Dublin	State/Province	OH
Country	US	Postal Code	43016
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. [Add](#)

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

Assignee	1
Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.	

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here.

☐

Prefix	Given Name	Middle Name	Family Name	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1				
Address 2				
City		State/Province		
Country i		Postal Code		
Phone Number		Fax Number		
Email Address				

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.

Add

Signature:

Remove

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). However, if this Application Data Sheet is submitted with the **INITIAL** filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Nathan Orme/		Date (YYYY-MM-DD)	2022-06-07	
First Name	Nathan	Last Name	Orme	Registration Number	68918

Additional Signature may be generated within this form by selecting the Add button.

Add

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	P296929.US.01_515365-6
		Application Number	
Title of Invention	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS		

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

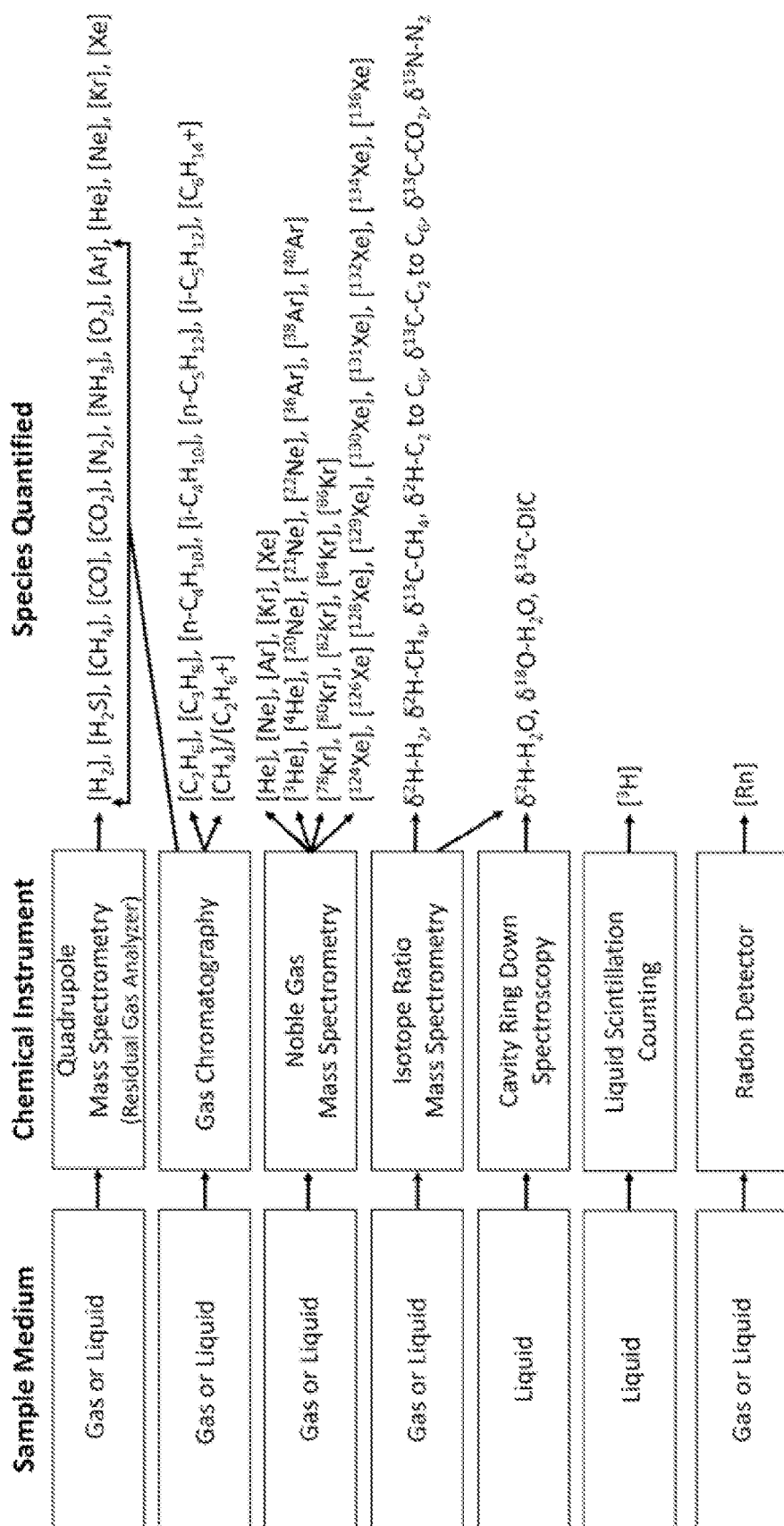


FIG. 1

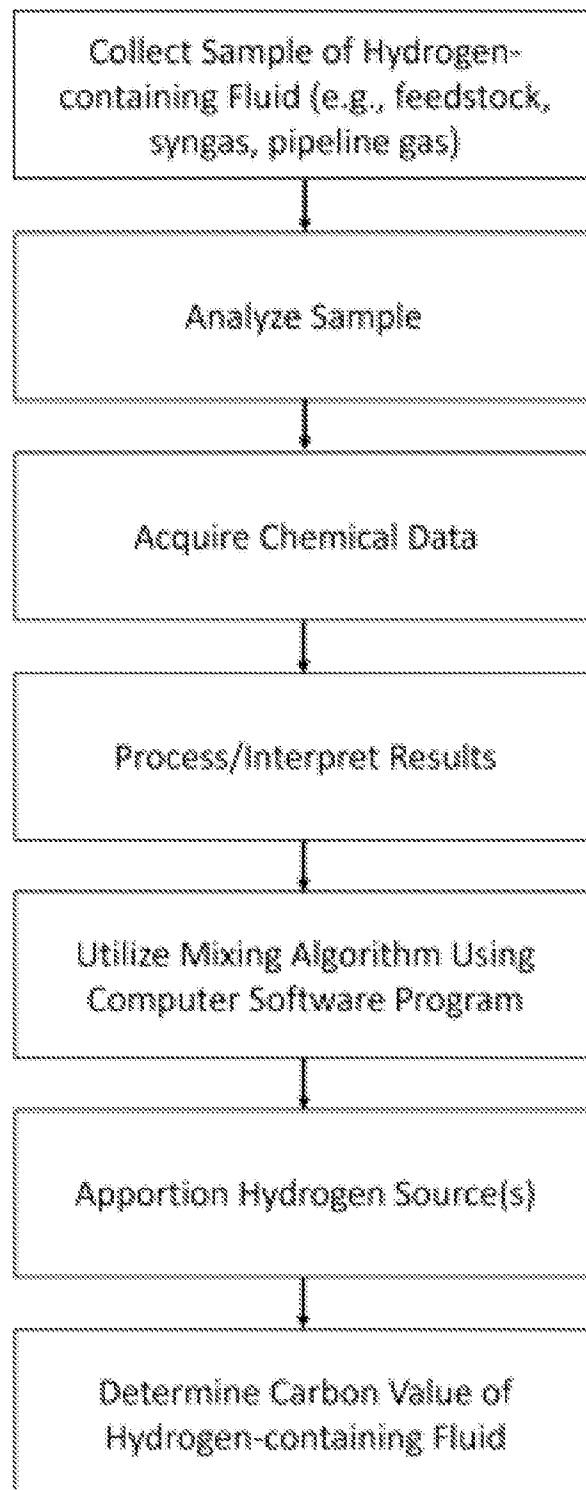


FIG. 2

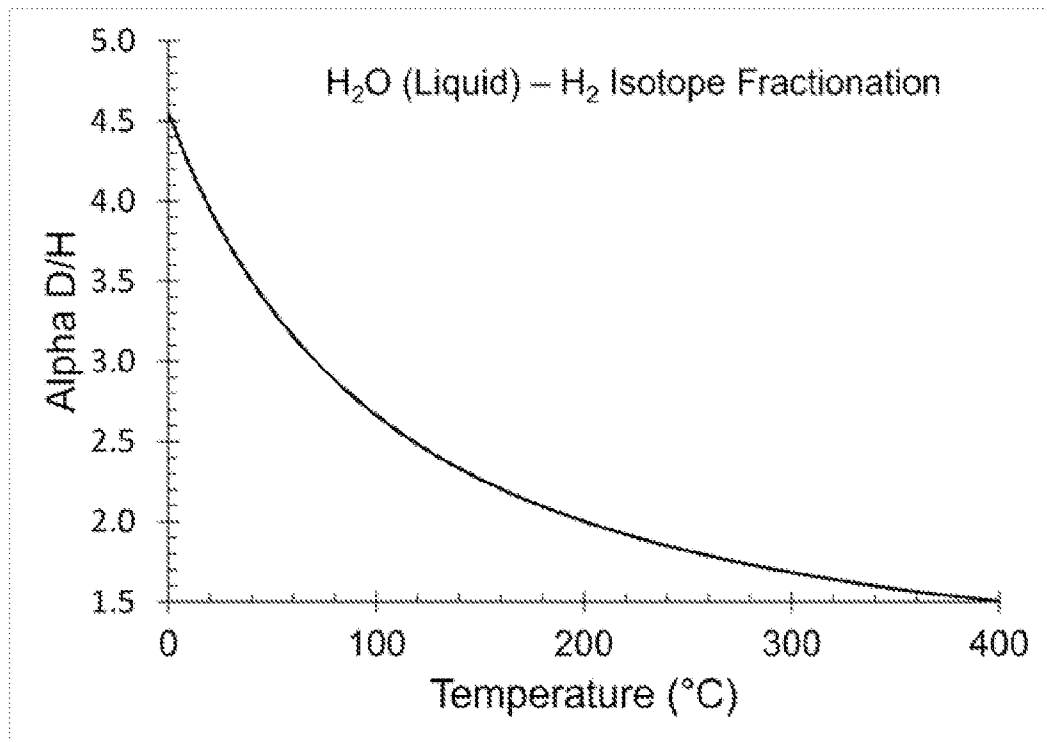


FIG. 3

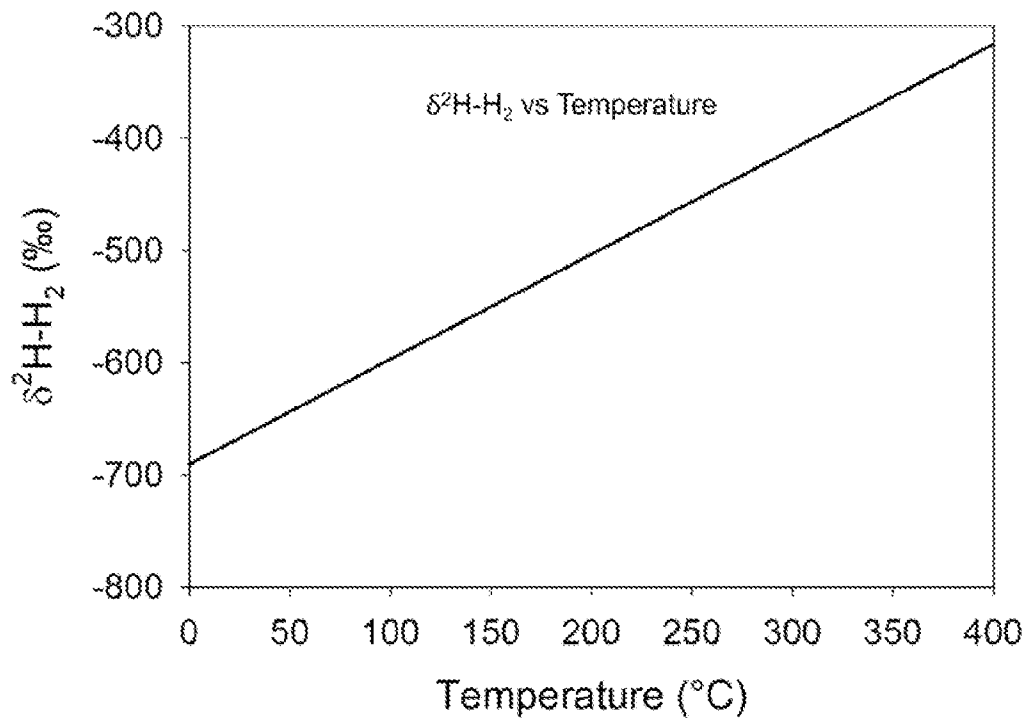


FIG. 4

Electronic Acknowledgement Receipt

EFS ID:	45897354
Application Number:	63349888
International Application Number:	
Confirmation Number:	1057
Title of Invention:	SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS
First Named Inventor/Applicant Name:	Thomas Darrah
Customer Number:	153511
Filer:	Nathan Michael Orme/Eve Stark
Filer Authorized By:	Nathan Michael Orme
Attorney Docket Number:	P296929.US.01_515365-6
Receipt Date:	07-JUN-2022
Filing Date:	
Time Stamp:	18:08:18
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	CARD
Payment was successfully received in RAM	\$ 150
RAM confirmation Number	E202267I08433945
Deposit Account	506181
Authorized User	Eve Stark
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: 37 CFR 1.16 (National application filing, search, and examination fees) 37 CFR 1.17 (Patent application and reexamination processing fees)	

37 CFR 1.19 (Document supply fees)
37 CFR 1.20 (Post Issuance fees)
37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	20220607_P296929US01_515365-6_USProv-ADS.pdf	1256057	no	9
			9b9df9fe4b30ea55cdcbab17b73e4b7d2be4e26d		
Warnings:					
Information:					
2	Drawings-only black and white line drawings	20220607_P296929US01_515365-6_USProv-Drawings.pdf	969423	no	3
			177d8500bcb6617da656ad8d28fc2ecd52a69d57		
Warnings:					
Information:					
3	Specification	20220607_P296929US01_515365-6_USProv-Specification.pdf	327599	no	40
			71e50015b2813fac940bc06f9d1b0d508cb a8927		
Warnings:					
Information:					
4	Fee Worksheet (SB06)	fee-info.pdf	37842	no	2
			f6f2b146ccfafb518690691b9186a1d22c12ca13		
Warnings:					
Information:					
Total Files Size (in bytes):			2590921		

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PROVISIONAL PATENT APPLICATION

of

Thomas Darrah

Colin Whyte

Jacob Harrington

and

Brent Lary

for

**SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT,
AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE
PRODUCTS**

SYSTEMS AND METHODS FOR MONITORING, QUANTITATIVE ASSESSMENT, AND CERTIFICATION OF LOW-CARBON HYDROGEN AND DERIVATIVE PRODUCTS

TECHNICAL FIELD

[0001] Embodiments of the present disclosure relate generally to the fields of hydrogen, energy, production tax credits, carbon tax credits, chemical industry, chemical feedstock, forensic tracking, energy storage, carbon capture, carbon utilization, or carbon or natural gas storage. Some embodiments disclose methods of hydrogen or carbon verification and tracking. More particularly, the present disclosure relates to systems and methods for determining the source of hydrogen, quantifying or certifying the proportion of hydrogen derived from no-carbon, low-carbon, or other sources, determining and quantifying the eligibility of hydrogen for proposed United States Internal Revenue Service 45X production tax credit programs, various Low Carbon Fuel Standards, or other production tax credit or subsidy programs, and determining and quantifying the eligibility of carbon dioxide storage for proposed United States Internal Revenue Service 45Q tax credit programs or these other programs.

[0002] This section is intended to introduce various aspects of the technical field, which may be associated with embodiments described in this disclosure. Thus, the forgoing discussion in this section provides a framework for better understanding the disclosure, and is not to be viewed as an admission of prior art.

SUMMARY

[0003] Embodiments are directed to using chemical instruments to measure elements, molecules, isotopes, or isotopic ratios by visual inspection, quantitative analysis, or supervised or unsupervised computer-assisted machine learning to enable the identification and characterization of the source of hydrogen in the subsurface or in various chemicals, feedstocks, or energy sources at the surface.

[0004] In some embodiments, a method for analyzing a molecular composition can include analyzing hydrogen molecules, hydrocarbon gases, noble gases, carbon dioxide, nitrogen, or mixtures of natural gases of varying composition to determine the source of hydrogen, carbon dioxide, or natural gases. In some embodiments, a method for analyzing the molecular composition of hydrogen and other gas mixtures can include assessing a proportion of hydrogen

derived from sources including geologic hydrogen (“gold hydrogen”), coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, and electrolysis; quantifying the proportion of hydrogen or carbon dioxide derived from the sources; and validating and certifying the proportion of hydrogen derived from various no-carbon, low-carbon, and/or high-carbon sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, and electrolysis.

[0005] In some embodiments, a method for analyzing an isotopic composition can include analyzing at least one of hydrogen molecules, hydrocarbon gases, noble gases, carbon dioxide, nitrogen, or mixtures of natural gases of varying composition to determine the source of hydrogen, carbon dioxide, or natural gases; analyzing water to determine a feedstock for hydrogen formation by electrolysis of the water; or analyzing methane or other hydrocarbon gases to determine a feedstock for hydrogen formation by pyrolysis or steam methane reforming of methane or other hydrocarbon gas feedstocks. A method for analyzing an isotopic composition can include assessing a proportion of hydrogen derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, and electrolysis; quantifying the proportion of hydrogen derived from the sources; and validating and certifying the proportion of hydrogen derived from no-carbon, low-carbon, and/or high-carbon sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, and electrolysis.

[0006] In some embodiments, a method for analyzing the isotopic composition of hydrogen in ammonia can include determining the source of hydrogen feedstocks used in ammonia production; determining the proportion of hydrogen feedstock derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, and electrolysis; quantifying the proportion of hydrogen feedstock derived from the sources; and certifying the proportion of hydrogen feedstock derived from the

sources. A method for analyzing the isotopic composition of hydrogen and carbon in methanol can include determining a source of hydrogen and carbon feedstocks used in methanol production; determining a proportion of hydrogen derived from sources including at least one of geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, or electrolysis; determining the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms; quantifying the proportion of hydrogen feedstock and carbon derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, or electrolysis; certifying the proportion of hydrogen feedstock and carbon derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, or electrolysis; and certifying the proportion of carbon derived from various sources including at least one of coal combustion, natural gas combustion, biomass incineration, steel manufacturing, synthesis of lime and other chemicals, waste incineration, ammonia synthesis, gas processing, atmospheric capture, or other forms.

[0007] In some embodiments, a method for analyzing the isotopic composition of hydrogen and carbon in electrofuels (e.g., synthesized fuels from low-carbon or no-carbon sources) can include determining the source of hydrogen and carbon feedstocks in electrofuels; quantifying the proportion of hydrogen derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, or electrolysis in electrofuels; quantifying the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, biomass incineration, steel

manufacturing, hydrogen produced from biological sources (e.g., archaea, bacterial), synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms, or atmospheric capture in electrofuels; certifying the proportion of hydrogen derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), pyrolysis, hydrogen produced from biological sources (e.g., archaea, bacterial), and electrolysis in electrofuels; and certifying the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, biomass incineration, steel manufacturing, ammonia synthesis, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms, or atmospheric capture in electrofuels. A method for analyzing the isotopic composition of hydrogen and carbon in hydrogen carriers can include determining sources of hydrogen and carbon feedstocks in hydrogen carriers; quantifying the proportion of hydrogen derived from sources including at least one of geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, or electrolysis in hydrogen carriers; quantifying the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, ammonia synthesis, biomass incineration, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms, or atmospheric capture in hydrogen carriers (e.g., methanol); certifying the proportion of hydrogen derived from sources including geologic hydrogen, coal, steam methane reformation, chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), pyrolysis, and electrolysis in hydrogen carriers; and certifying the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, ammonia synthesis, biomass incineration, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms, or atmospheric capture in hydrogen carriers.

[0008] In some embodiments, a method for determining the source of hydrogen in natural

gas, can include determining the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities, including those that generate derivative products such as renewable or low-carbon diesel, electrofuels, plastics, or synthetic methane. In some embodiments, a method for quantifying or apportioning the source of hydrogen in natural gas can include quantifying or apportioning the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities, including those that generate derivative products such as renewable or low-carbon diesel, electrofuels, plastics, or synthetic methane.

[0009] In some embodiments, a method for certifying the source of hydrogen in natural gas for a US IRS 45X production tax credit, various Low Carbon Fuel Standards, and other hydrogen incentive, subsidy, or credit programs can include certifying the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities, including those that generate derivative products such as renewable or low-carbon diesel, electrofuels, plastics, or synthetic methane. A method for determining a source of hydrogen can include determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of exploration of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases; determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of drilling, including measurement-while-drilling, drill-stem test, or pressure-volume-temperature (PVT) operations, for oil, natural gas, hydrogen, carbon dioxide, helium, or other gases; determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of production of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases; determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, or carbon dioxide in subsurface reservoirs; determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, or carbon dioxide in subsurface caverns; determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, carbon dioxide, or other gases in surface tanks, subsurface tanks, or other industrial facilities; and determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation the presence of leaks or fugitive, stray,

or other gas emissions in boreholes, oil, natural gas, or hydrogen wells, pipelines, water wells, surface seeps, springs, or other storage facilities.

[0010] In some embodiments, a method for determining the composition of matter for hydrogen using the isotopic composition of hydrogen molecules can include using the isotopic composition of hydrogen of at least one of ammonia, methanol, synthetic fuels, renewable or low-carbon diesel, electrofuels, plastics, synthetic methane, various other electrofuels, or in processes that utilize other no-carbon or low-carbon hydrogen sources. The method can further include the compositions of fluids collected at surface regions including springs and surface seeps or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, carbon dioxide, or other gases in surface tanks, subsurface tanks, or other industrial facilities; and fluids collected at surface regions or from the subsurface for the purposes of monitoring and evaluation the presence of leaks or fugitive, stray, or other gas emissions in boreholes, oil, natural gas, or hydrogen wells, pipelines, water wells, surface seeps, springs, or other storage facilities.

[0011] Features from any of the disclosed embodiments may be used in combination with one another, without limitation. In addition, other features and advantages of the present disclosure will become apparent to those of ordinary skill in the art through consideration of the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The drawings illustrate several embodiments of the invention, wherein identical reference numerals refer to identical or similar elements or features in different views or embodiments shown in the drawings.

[0013] FIG. 1 is a list of analytical chemical instrumentation, the types of samples that can be analyzed with each instrument, and the elements and compounds that can be measured that are relevant to determining hydrogen and carbon dioxide sources, residence times, gas saturations, and temperatures of hydrogen formation, according to embodiments.

[0014] FIG. 2 is a general workflow relating to the collection of fluids or solid samples, chemical analyses, geochemical data acquisition, interpretation of the samples, and utilization during exploration that guides the drilling of new wells, according to an embodiment.

[0015] FIG. 3 is a graph of the degree of fractionation (i.e., alpha or the fractionation factor)

between hydrogen isotopic compositions of liquid water ($\delta^2\text{H-H}_2\text{O}$) and molecular hydrogen ($\delta^2\text{H-H}_2$) as a function of temperature in the paired liquid water-molecular hydrogen system that occurs during the serpentinization process.

[0016] FIG. 4 is a graph of the relationship between the isotopic composition of molecular hydrogen ($\delta^2\text{H-H}_2$) and temperature of hydrogen formation during the serpentinization process.

DETAILED DESCRIPTION

[0017] Embodiments disclosed herein are related to systems and methods for using chemical instruments to measure elements, molecules, isotopes, or isotopic ratios by visual inspection, quantitative analysis, or supervised or unsupervised computer-assisted machine learning enable the identification and characterization of the source of hydrogen or carbon dioxide in the subsurface or various chemicals, in chemical feedstocks, in products derived using hydrogen as a feedstock (e.g., ammonia, methanol, synthetic fuels, renewable or low-carbon diesel, electrofuels, plastics, synthetic methane, various other electrofuels, or in processes that utilize other no-carbon or low-carbon hydrogen sources), or other energy sources at the surface. Analysis of the combination of chemical species forms the basis of the systems and methods used to determine the source of hydrogen. For example, the methods and systems herein can track and verify the source of naturally occurring hydrogen and other forms of hydrogen or carbon dioxide when sold as no-carbon or low-carbon hydrogen (“green premium”) and track and verify chemical species for which hydrogen is used as a feedstock or incorporated into another chemical product (e.g., “green” ammonia, methanol, synthetic fuels, renewable or low-carbon diesel, electrofuels, plastics, synthetic methane, various other electrofuels, or in processes that utilize other no-carbon or low-carbon hydrogen sources).

[0018] In the production of natural resources from formations within the earth, a well or borehole is drilled into the earth to the location where the natural resource is believed to be located. Similarly in the sequestration of greenhouse gases in formations within the earth, a well or borehole is drilled into the earth to the location where the greenhouse gas will be injected, located and sequestered. These natural resources may be hydrogen; helium; carbon dioxide; dihydrogen sulfide; methane, or other hydrocarbon gases; a dihydrogen sulfide reservoir; a hydrogen reservoir; a helium reservoir; a carbon dioxide reservoir; a natural gas reservoir; a reservoir rich in dihydrogen sulfide; a reservoir rich in hydrocarbons; a reservoir rich in helium;

the natural resource may be fresh water, brackish water, or brine; it may be a heat source for geothermal energy; or it may be some other natural resource, ore deposit, mineral, metal, or gem that is located within the ground.

[0019] These resource-containing formations may be a few hundred feet, a few thousand feet, or tens of thousands of feet below the surface of the earth, including under the floor of a body of water, e.g., below the sea floor or beneath other natural resources, e.g., below aquifers. In addition to being at various depths within the earth, these formations may cover areas of differing sizes, shapes, and volumes.

[0020] Typically, and by way of general illustration, in drilling a well an initial borehole is made into the earth, e.g., the surface of land or seabed, and then subsequent and smaller diameter boreholes are drilled to extend the overall depth of the borehole. In this manner as the overall borehole gets deeper its diameter becomes smaller; resulting in what can be envisioned as a telescoping assembly of holes with the largest diameter hole being at the top of the borehole closest to the surface of the earth.

[0021] Thus, by way of example, the starting phases of a subsea drill process may be explained in general as follows. Once the drilling rig is positioned on the surface of the water over the area where drilling is to take place, an initial borehole is made by drilling a 36" hole in the earth to a depth of about 200 - 300 ft. below the seafloor. A 30" casing is inserted into this initial borehole. This 30" casing may also be called a conductor. The 30" conductor may or may not be cemented into place. During this drilling operation a riser is generally not used and the cuttings from the borehole, e.g., the earth and other material removed from the borehole by the drilling activity are returned to the seafloor. Next, a 26" diameter borehole is drilled within the 30" casing, extending the depth of the borehole to about 1,000 - 1,500 ft. This drilling operation may also be conducted without using a riser. A 20" casing is then inserted into the 30" conductor and 26" borehole. This 20" casing is cemented into place. The 20" casing has a wellhead secured to it. (In other operations an additional smaller diameter borehole may be drilled, and a smaller diameter casing inserted into that borehole with the wellhead being secured to that smaller diameter casing.) A BOP (blow out preventer) is then secured to a riser and lowered by the riser to the sea floor, where the BOP is secured to the wellhead. From this point forward all drilling activity in the borehole takes place through the riser and the BOP.

[0022] It should be noted that riserless subsea drilling operations are also contemplated.

[0023] For a land-based drill process, the steps are similar, although the large diameter tubulars, 30" – 20" are typically not used. Thus, and generally, there is a surface casing that is typically about 13 3/8" diameter. This may extend from the surface, e.g., wellhead and BOP, to depths of tens of feet to hundreds of feet. One of the purposes of the surface casing is to meet environmental concerns in protecting ground water by preventing surface casing ventflow to groundwater aquifers or prevent surface casing ventflow of greenhouse gases or flammable gases to groundwater aquifers or the atmosphere. The surface casing should have sufficiently large diameter to allow the drill string, production equipment such as electronic submersible pumps (ESPs) and circulation mud to pass through. Below the casing one or more different diameter intermediate casings may be used. (It is understood that sections of a borehole may not be cased, which sections are referred to as open hole.) These can have diameters in the range of about 9" to about 7," although larger and smaller sizes may be used, and can extend to depths of thousands and tens of thousands of feet. Inside of the casing and extending from a pay zone, or production zone of the borehole up to and through the wellhead on the surface is the production tubing. There may be a single production tubing or multiple production tubings in a single borehole, with each of the production tubing endings being at different depths.

[0024] Fluid communication between the formation and the well can be greatly increased by the use of hydraulic fracturing or other stimulation techniques. The first uses of hydraulic fracturing date back to the late 1940s and early 1950s. In general, hydraulic fracturing treatments involve forcing fluids down the well and into the formation, where the fluids enter the formation and crack, e.g., by forcing the layers of rock to break apart or fracture. These fractures create channels or flow paths that may have cross sections of a few microns, to a few millimeters, to several millimeters in size, and potentially larger. The fractures may also extend out from the well in all directions for a few feet, several feet, and tens of feet or further. The fractures may be kept open by using a proppant (e.g., various sized sand or other mineral grains) that are forced down the well with the fracturing fluid in a single operation. It should be remembered that the longitudinal axis of the well in the reservoir may not be vertical: it may be on an angle (either sloping up or down) or it may be horizontal. The section of the well located within the reservoir, i.e., the section of the formation containing the natural resources, can be called the pay zone.

[0025] As used herein, unless specified otherwise, the terms "hydrogen exploration and production," "carbon dioxide exploration and production," "helium exploration and production,"

“dihydrogen sulfide exploration and production,” “exploration and production activities,” “E&P,” and “E&P activities,” and similar such terms are to be given their broadest possible meaning, and include surveying, geological analysis, chemical assessment, well planning, reservoir planning, reservoir management, drilling a well, workover and completion activities, hydrogen production, flowing of hydrogen from a well, collection of hydrogen, secondary and tertiary recovery from a well, the management of flowing hydrogen from a well, carbon dioxide injection, carbon dioxide sequestration, carbon dioxide mineralization, dihydrogen sulfide injection, dihydrogen sulfide sequestration, dihydrogen sulfide mineralization, and any other upstream activities.

[0026] As used herein, unless specified otherwise, the terms “sulfur mineralization,” “sulfur sequestration,” “sulfur mitigation,” “carbon dioxide mineralization,” “carbon dioxide sequestration,” “carbon dioxide mitigation,” “carbon mineralization,” “carbon sequestration,” “carbon mitigation,” and similar such terms are to be given their broadest possible meaning, and include surveying, geological analysis, well planning, reservoir planning, reservoir management, drilling a well, workover and completion activities, sulfur injection, dihydrogen sulfide injection, carbon injection, carbon dioxide injection, the management of flowing sulfur, dihydrogen sulfide, carbon, carbon dioxide to a well, and any other upstream activities.

[0027] As used herein, unless specified otherwise, the term “production tax credit,” “hydrogen production tax credit,” “45X,” “U.S. IRS 45X,” “U.S. IRS 45X production tax credit” “hydrogen production payments,” “hydrogen stimulus,” “Low Carbon Fuel Standards,” “LCFS,” or other similar terms should be given its broadest possible meaning and would include any production tax credit or production payments issued in the United States, by an individual state, or abroad. As used herein, unless specified otherwise, the terms “storage,” “gas storage,” “hydrogen storage,” “carbon storage,” and similar terms, are to be given their broadest possible meanings and would include all locations, areas, and geological features within the earth in which hydrogen, carbon dioxide, helium, dihydrogen sulfide, mixtures of natural gas, or other fluids can be injected or otherwise placed into the subsurface either for days, weeks, months, years, or longer or permanently.

[0028] As used herein, unless specified otherwise, the terms “sequestration” and similar terms, are to be given their broadest possible meanings and would include the act of injecting or otherwise placing gases, liquids, other fluids, or mixtures thereof in any and all locations, areas,

and geological features within the earth. Sequestration can be in the gaseous (e.g., carbon dioxide or dihydrogen sulfide gas), liquid (e.g., supercritical carbon dioxide or dihydrogen sulfide), or solid phases (e.g., various forms of carbonate or sulfide minerals).

[0029] As used herein, unless specified otherwise, the terms “mineralization” or “permanent storage” and similar terms, are to be given their broadest possible meanings and would include the storage of chemical species (e.g., carbon dioxide, dihydrogen sulfide, or other chemicals) in solid phases, mineral precipitates, or in various forms of carbonate or sulfide minerals) either above the surface or in the subsurface.

[0030] As used herein, unless specified otherwise, the term “carbon sequestration tax credit,” “carbon dioxide sequestration tax credit,” “carbon mineralization tax credit” “carbon tax credit,” “carbon storage tax credit,” “carbon mineralization tax credit,” “45Q,” “U.S. IRS 45Q,” “U.S. IRS 45Q carbon storage tax credit,” “U.S. IRS 45Q carbon tax credit,” or other similar terms should be given its broadest possible meaning and would include any carbon tax credit or carbon offset payment issued in the United States, within individual states, or abroad.

[0031] As used herein, unless specified otherwise, the term “earth” should be given its broadest possible meaning, and includes the ground, all natural materials, such as rocks, and artificial materials, such as concrete, borehole casing, piping, or fill, that are or may be found in the ground.

[0032] As used herein, unless specified otherwise “offshore” and “offshore drilling activities” and similar such terms are used in their broadest sense and would include drilling activities on, or in, any body of water, whether fresh or salt water, whether manmade or naturally occurring, such as for example rivers, lakes, canals, inland seas, oceans, seas, such as the North Sea, bays and gulfs, such as the Gulf of Mexico. As used herein, unless specified otherwise the term “offshore drilling rig” is to be given its broadest possible meaning and would include fixed towers, tenders, platforms, barges, jack-ups, floating platforms, drill ships, dynamically positioned drill ships, semi-submersibles and dynamically positioned semi-submersibles. As used herein, unless specified otherwise the term “seafloor” is to be given its broadest possible meaning and would include any surface of the earth that lies under, or is at the bottom of, any body of water, whether fresh or salt water, whether manmade or naturally occurring.

[0033] As used herein, unless specified otherwise, the term “borehole” should be given its broadest possible meaning and includes any opening that is created in the earth that is

substantially longer than it is wide, such as a well, a well bore, a well hole, a micro hole, a slimhole and other terms commonly used or known in the arts to define these types of narrow long passages. Wells would further include exploratory, discovery, production, abandoned, reentered, reworked, recirculation, and injection wells. They would include both cased and uncased wells, and sections of those wells. Uncased wells, or section of wells, also are called open holes, boreholes, open boreholes, open bores, or open hole sections. Boreholes may further have segments or sections that have different orientations, they may have straight sections, arcuate sections, or combinations thereof. Thus, as used herein unless expressly provided otherwise, the "bottom" of a borehole, the "bottom surface" of the borehole and similar terms refer to the end of the borehole, i.e., that portion of the borehole furthest along the path of the borehole from the borehole's opening, the surface of the earth, or the borehole's beginning. The terms "side" and "wall" of a borehole should be given their broadest possible meaning and include the longitudinal surfaces of the borehole, whether or not casing or a liner is present, as such, these terms would include the sides of an open borehole or the sides of the casing that has been positioned within a borehole. Boreholes may be made up of a single passage, multiple passages, connected passages, (e.g., branched configuration, fishboned configuration, duallateral configuration, trilateral configuration, quadrilateral configuration, pitchfork configuration, pinnate configuration, or comb configuration), and combinations and variations thereof.

[0034] Boreholes are generally formed and advanced by using mechanical drilling equipment having a rotating drilling tool, e.g., a bit. For example, and in general, when creating a borehole in the earth, a drilling bit is extended to and into the earth and rotated to create a hole in the earth. To perform the drilling operation the bit must be forced against the material to be removed with a sufficient force to exceed the shear strength, compressive strength or combinations thereof, of that material. The material that is cut from the earth is generally known as cuttings or drill cuttings, e.g., waste, which may be chips of rock, dust, rock fibers and other types of materials and structures that may be created by the bit's interactions with the earth. These cuttings are typically removed from the borehole by the use of fluids, which fluids can be liquids, foams or gases, or other materials known to the art.

[0035] As used herein, unless specified otherwise, the term "drill pipe" is to be given its broadest possible meaning and includes all forms of pipe used for drilling activities; and refers to a single section or piece of pipe. As used herein the terms "stand of drill pipe," "drill pipe stand,"

"stand of pipe," "stand" and similar type terms should be given their broadest possible meaning and include two, three, or four sections of drill pipe that have been connected, e.g., joined together, typically by joints having threaded connections. As used herein the terms "drill string," "string," "string of drill pipe," "string of pipe" and similar type terms should be given their broadest definition and would include a stand or stands joined together for the purpose of being employed in a borehole. Thus, a drill string could include many stands and many hundreds of sections of drill pipe.

[0036] As used herein, unless specified otherwise, the terms "formation," "reservoir," "pay zone," and similar terms, are to be given their broadest possible meanings and would include all locations, areas, and geological features within the earth that contain, may contain, or are believed to contain, hydrogen, carbon dioxide, helium, dihydrogen sulfide, or natural gas.

[0037] As used herein, unless specified otherwise, the terms "field," "oil field," "gas field" and similar terms, are to be given their broadest possible meanings, and would include any area of land, sea floor, or water that is loosely or directly associated with a geologic formation, and more particularly with a resource containing formation, thus, a field may have one or more exploratory and producing wells associated with it, a field may have one or more governmental body or private resource leases associated with it, and one or more field(s) may be directly associated with a resource containing formation.

[0038] As used herein, unless specified otherwise, the terms "conventional hydrogen," "conventional carbon dioxide," "conventional helium," "conventional dihydrogen sulfide," "conventional natural gas," "conventional," "conventional production" and similar such terms are to be given their broadest possible meaning and include hydrogen, carbon dioxide, helium, or dihydrogen sulfide that are trapped in structures in the earth. Generally, in these conventional formations the hydrogen, carbon dioxide, helium, dihydrogen sulfide, or natural gas have migrated in permeable, or semi-permeable formations to a trap, or area where they are accumulated. Typically, in conventional formations a non-porous, relatively impermeable layer is above, or encompassing the area of accumulated hydrogen, carbon dioxide, helium, dihydrogen sulfide, or natural gas in essence trapping the hydrogen, carbon dioxide, helium, dihydrogen sulfide, or natural gas in the accumulation. Conventional reservoirs have been historically the sources of the vast majority of hydrogen, carbon dioxide, natural gas, helium, and dihydrogen sulfide observed. As used herein, unless specified otherwise, the terms

“unconventional hydrogen,” “unconventional carbon dioxide,” “unconventional helium,” “unconventional dihydrogen sulfide,” “unconventional natural gas,” “unconventional,” “unconventional production” and similar such terms are to be given their broadest possible meaning and includes hydrogen, carbon dioxide, helium, dihydrogen sulfide, or natural gas that are held in impermeable rock, or which have not migrated to traps or areas of accumulation.

[0039] As used herein, unless specifically stated otherwise, the term “gold hydrogen” should be given its broadest possible meaning, and generally refers to hydrogen produced from the subsurface by drilling into and producing from a formation with hydrogen gas contained in pore- or fracture-space via conventional gas production methods (e.g., perforation of a target reservoir allowing fluids to flow up a tubing string or steel casing) or by drilling into and stimulating iron-rich rock, mafic rock, pyrite, iron-rich sandstone, or iron-rich sediments with or without fracturing or other forms of mechanical stimulation that can provide an abundant source of low emission, low cost, fully dispatchable energy.

[0040] As used herein, unless specifically stated otherwise, the term “element” should be given its broadest possible meaning, and generally refers to each of more than one hundred chemical substances that cannot be chemically interconverted or broken down into simpler substances and are primary constituents of matter, each which can be distinguished by its atomic number, i.e., the number of protons in the nuclei of its atoms.

[0041] As used herein, unless specifically stated otherwise, the term “molecule” should be given its broadest possible meaning, and generally refers to a group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction.

[0042] As used herein, unless specifically stated otherwise, the term “isotope” should be given its broadest possible meaning, and generally refers to each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass, but not in chemical properties. Isotopes can be stable in that they do not experience radioactive decay, or they can be radioactive in that they decay to other isotopes over time, with time constants referred to as decay constants that can be used to calculate half-lives).

[0043] As used herein, unless specifically stated otherwise, the term “isotopic ratio” should be given its broadest possible meaning, and generally refers to the relative proportions or

abundances of isotopes of the same element (e.g., $^2\text{H}/^1\text{H}$, $^{13}\text{C}/^{12}\text{C}$ or $^{18}\text{O}/^{16}\text{O}$). Among other things, the isotope ratio can be used to provide information on the origin of chemical species, the processes that influence them after their formation, physicochemical conditions under which they are formed.

[0044] As used herein, unless specifically stated otherwise, the term “measurement” should be given its broadest possible meaning, and generally refers to the act of measuring something. Examples of geochemical measurements for elements, molecules, isotopes, and isotope ratios described above can be performed with various chemical instruments for methods including chromatography, mass spectrometry, spectroscopy, or other chemical measurement techniques.

[0045] As used herein, unless specifically stated otherwise, the term “chemical instrument” should be given its broadest possible meaning, and generally refers to a device or tool used for scientific purposes, including the study of natural, laboratory-based, and theoretical samples, processes, phenomena, and purposes.

[0046] As used herein, unless stated otherwise, room temperature is 25°C. And, standard temperature and pressure is 25°C and 1 atmosphere.

[0047] Generally, the term “about” as used herein unless specified otherwise is meant to encompass a variance or range of $\pm 10\%$, the experimental or instrument error associated with obtaining the stated value, and preferably the larger of these.

[0048] As used herein unless specified otherwise, the recitation of ranges of values herein is merely intended to serve as a shorthand method of referring individually to each separate value falling within the range. Unless otherwise indicated herein, each individual value within a range is incorporated into the specification as if it were individually recited herein.

[0049] The term “CO_{2e}” is used to define carbon dioxide equivalence of other, more potent greenhouse gases, to carbon dioxide (i.e., methane and nitrous oxide) on a global warming potential basis of 100 years, based on IPCC AR5 methodology. The term “carbon intensity” is taken to mean the lifecycle CO_{2e} generated per unit mass of a product.

[0050] CO₂ is widely recognized as a greenhouse gas (GHG), and the continued accumulation of CO₂ and other GHGs in the atmosphere are expected to cause problematic changes to global ecosystems and contribute to myriad other problems, such as ocean acidification and sea level rise. The two primary causes of carbon emissions globally are the use of fossil fuels for power generation and transportation.

[0051] Given the risks of CO₂ emissions, significant work has gone into finding replacements to existing high carbon energy sources, or ways to decarbonize existing energy sources. However, many of these low carbon alternatives have been uneconomic or not dispatchable enough to replace the current options.

[0052] The term “sulfur equivalents” of “SO_x” is used to define dihydrogen sulfide or sulfur dioxide offset equivalence of sulfur emissions. The term “sulfur intensity” is taken to mean the lifecycle SO_x generated per unit mass of a product.

[0053] Sulfur, in various forms, including but not limited to dihydrogen sulfide, sulfur dioxide, sulfuric acid, and sulfate, is widely recognized as a toxic and harmful atmospheric pollutant and the deposition of sulfur in soil, waterways, and other environments are expected to cause problematic changes to global ecosystems and contribute to myriad of other problems, such as acid rain, soil acidification, deforestation, ocean acidification, and other toxic impacts. The primary causes of dihydrogen sulfide emissions globally are related to petroleum and natural gas extraction and refining, pulp and paper manufacturing, rayon textile production, waste disposal, landfills, water and sewage treatment facilities, and general waste disposal. Additionally, natural factors such as volcanoes, hot springs, thermal vents, geysers, fumaroles, “sour” natural gas fields, biodegraded oil fields, and geothermal power plants also constitute major naturally occurring sources of dihydrogen sulfide.

[0054] Given the risks of dihydrogen sulfide and other forms of sulfur emissions, significant work has gone into sulfur removal technologies, the development of low sulfur fuels, or ways to desulfurize existing energy sources and processes. However, many of these low sulfur alternatives themselves create cost prohibitions, are uneconomic, or limit the dispatchability of energy sources.

[0055] Based on the risks of sulfur emissions, the U.S. EPA (IRC 45H) has created a cap-and-trade sulfur credit program for offset, sulfur abatement, and sequestration. The U.S. IRS 45Q tax credit program is a similar tax credit program for carbon dioxide sequestration.

[0056] In power generation, the alternatives to the highly reliable, low cost, but high emission sources (gas and coal) are either dispatchable and expensive (e.g., nuclear, hydroelectric, green hydrogen, or blue hydrogen), or inexpensive and intermittent (e.g., solar and wind, green hydrogen in some cases). There is only one existing source that is both lower cost and dispatchable, and that is geothermal. However, geothermal resources are limited, many of

the economically productive geothermal resources have already been developed and are nearing end of life, and many geothermal resources are already in decline. As such, the growth outlook for geothermal energy resources is limited without significant technical advances.

[0057] Green hydrogen (hydrogen produced from water without the utilization of fossil fuels), which is generated by electrolysis powered from either solar, wind, hydroelectric, renewable natural gas combustion, or geothermal energy can be a reliable source of low-carbon energy when coupled with storage, but high capital cost, intermittent production due to intermittent energy sources or high cost of energy when grid connected, and the high cost and low availability of suitable hydrogen storage resources limits applicability. In addition, electrolysis consumes significantly more energy to produce the hydrogen than what is stored in the hydrogen, resulting in a low round trip efficiency in the system.

[0058] Blue hydrogen faces a similar set of problems to green hydrogen: it takes a low cost, high emission fuel source like coal or natural gas, and by adding expensive and parasitic carbon capture facilities, converts this low-cost-high-emission source of energy into a high-cost-low-emission source. Thus, even though large volumes of hydrogen can be formed in processes that subsequently prevent greenhouse gas emissions from reaching the atmosphere, the newly developed hydrogen resource is not cost competitive with other forms of energy derived from fossil fuels. Additionally, the challenges around finding carbon sequestration resources that can be used to permanently store the captured carbon from these processes result in limited opportunities to deploy these technologies today.

[0059] Natural hydrogen (or “gold hydrogen”), produced from the subsurface by drilling into and producing from formations containing hydrogen gas in its pore or fracture space or by drilling into and stimulating iron-rich rock, mafic rock, pyrite, iron-rich sandstone, or iron-rich sediments with or without fracturing or other forms of mechanical stimulation can provide an abundant source of low emission, low cost, fully dispatchable energy.

[0060] Each of these energy sources and their inherent advantages and limitations are also relevant to transportation. When considering transportation fuels, by far the major sources of fuel are diesel and gasoline, both derived from crude oil production. Additionally, in recent years, electric vehicles have been gaining market share, but the cost for electric vehicles is still more expensive than fossil fueled equivalents and limitations exist regarding cost, recharge time, and primary resources for battery and energy storage. Given the weight of batteries, electric long-

haul trucking is also challenged, and most long-haul truck manufacturers are in search of affordable, low carbon options such as hydrogen-fueled trucking.

[0061] Natural hydrogen would be an answer to the low-, no- or negative-carbon, low cost, reliable transportation problem for long-haul trucking and potentially other forms of transportation. As for other types of transportation, natural hydrogen as a compressed or liquified product, or as a feedstock for synthetic liquid fuel (“efuels”), would be a reliable low cost, low-, no-, or negative-carbon solution. Additionally, natural hydrogen could be combined with nitrogen to produce a carbon-free ammonia (or other) product, which is being widely discussed as a potential replacement for bunker fuel for shipping and as a feedstock for synthetic fertilizer manufacturing.

[0062] Direct Emissions Reduction: Because there are no direct CO₂ emissions from the combustion or typical use of hydrogen, the reduction in CO₂ emissions is a function of what the hydrogen is replacing. In many cases, low-carbon (or negative-carbon) hydrogen would be replacing hydrogen from steam methane reforming (SMR) as a chemical feedstock for ammonia production, oil refining, and other forms of chemical manufacturing. In some cases, low-carbon (or negative-carbon) hydrogen may replace natural gas, diesel fuel, gasoline, or jet fuel as a heat source or transportation fuel.

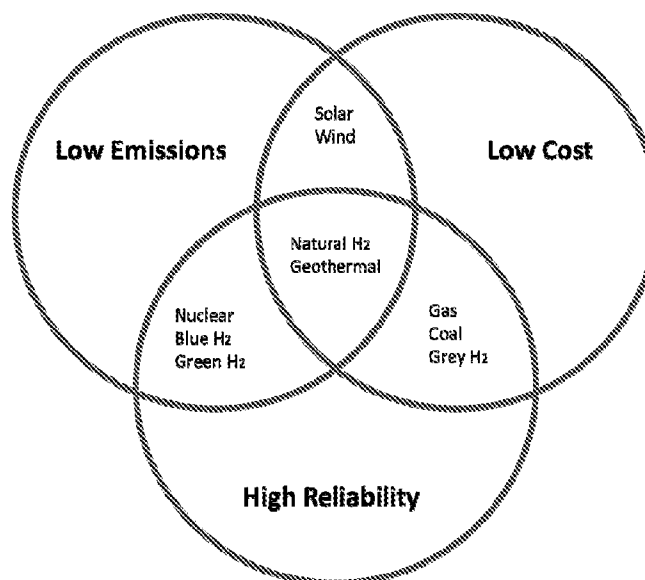
[0063] In the case of ammonia production and refining, natural gas is used to produce hydrogen via steam methane reformation reactions, which is used as a chemical feedstock in both the refining process and the ammonia production process. Today, more than 95% of hydrogen is produced using natural gas in steam methane reformers (SMRs). The carbon intensity of hydrogen production using SMRs without carbon capture is 10.4 tonnes of CO₂ emitted for each tonne of hydrogen produced. As such, direct replacement of natural hydrogen for hydrogen manufactured by SMR processes results in a CO₂ reduction of 10.4 tonnes CO₂/tonne H₂.

[0064] In power generation with gas turbines, hydrogen must displace the energy (btu) equivalent of natural gas. The energy density of hydrogen is 290 btu/cf or 51,682 btu/lb. By comparison, the energy density of natural gas is 983 btu/cf or 20,267 btu/lb, while the carbon intensity of natural gas is 52.91 kg CO₂/mmbtu CH₄ or 54.87 kg CO₂/mcf CH₄, or 3.5 kg CO₂/kg CH₄.

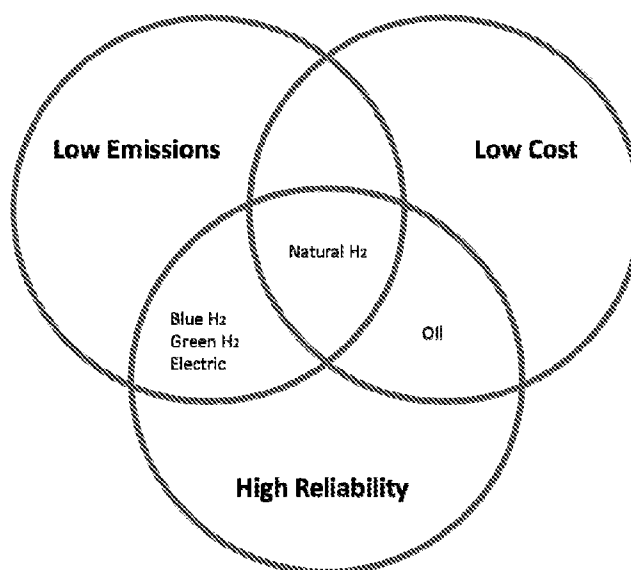
[0065] Because hydrogen is 2.6 times more energy dense per unit mass than natural gas, only 40% of the gross tonnage of fuel is required to achieve the same energy output. As such, burning one tonne of H₂ for power generation reduces natural gas consumption by about 2.6 tonnes, and thus CO₂ emissions by 9.1 tonnes.

[0066] Indirect Emissions Reduction: An analysis of the lifecycle carbon intensity of natural hydrogen using the Oil Production Greenhouse Gas Emissions Estimator (“OPGEE”) has shown the lifecycle carbon intensity of natural hydrogen to be in the range of 0.1 to 0.4 tonnes CO₂/tonne H₂ with an additional emissions reduction equivalent to the mass of carbon dioxide mineralized. Similar studies are not available for other methods of hydrogen production. However, using an average grid intensity of 0.5 tonnes CO₂/MWh, and given that electrolysis requires approximately 50 MWh/tonne H₂ produced, the indirect emissions associated with electrolysis are about 25 tonnes CO₂/tonne H₂ produced assuming grid power. Of course, electrolysis unit operators can purchase Renewable Energy Credits to synthetically reduce the carbon footprint of their power usage, but market recognition of this as a method for eliminating real time carbon emissions may not be permanent.

[0067] The realization of abundant natural hydrogen can achieve significant reductions in equivalent carbon emissions.



[0068] Power source Cost, Emissions, and Reliability.



[0069] Transportation fuel Cost, Emissions, and Reliability.

[0070] Hydrogen as a chemical feedstock and fuel source to replace hydrocarbons and other fossil fuels has long been a long term, but unobtained goal. Once formed, hydrogen provides a clean energy source, that eliminates greenhouse gases associated with direct use of fossil fuels as an energy source and the carbon burden produced from using hydrocarbons as a feedstock for hydrogen generation. As a result, various mechanisms for producing low-carbon or “blue” (e.g., steam methane reformation combined with carbon capture utilization and storage), “green” (e.g., electrolytic or methane pyrolysis by methods that do not emit carbon dioxide), and “gold” (e.g., hydrogen recovered from or produced within the earth) hydrogen can be included in various industrial sectors. Hydrogen is a very useful and important chemical that can be used in various industries. The present disclosure provides systems, methods and devices that address and provide solutions to the quantification, verification, and certification of low- or no-carbon hydrogen.

[0071] Gold hydrogen (a.k.a., geological hydrogen, native hydrogen, natural hydrogen) can be considered a potential energy source to transition to low-carbon fuel. Methods and systems for the quantitative assessment and monitoring of the source of hydrogen and derivative products for which hydrogen is a feedstock (ammonia, methanol, hydrogen-derived synthetic/electrofuels, such as renewable or low-carbon kerosene, diesel, jet fuel, plastics, synthetic methane, or other hydrogen carriers), can include the measurement of molecular species (H_2 , N_2 , NH_3 , CO , CO_2) or elemental gases (e.g., noble gases: He, Ne, Ar, Kr, Xe, Rn) and isotopes of gases (e.g., δ^2H - H_2 ,

$\delta^2\text{H-CH}_4$, $\delta^{13}\text{C-CH}_4$, $\delta^{13}\text{C-CO}_2$, $\delta^{15}\text{N-N}_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , and their derivative isotopic ratios), water ($\delta^2\text{H-H}_2\text{O}$, $\delta^{18}\text{O-H}_2\text{O}$), or the concentrations of carbon dioxide or dissolved forms of carbon and their isotopic compositions (i.e., $\delta^{13}\text{C-DIC}$) sampled directly or indirectly from natural samples (e.g., fluid samples of various types), chemical feedstocks, other industrial chemicals, or chemicals and products that used hydrogen and carbon feedstocks. Further low-carbon sources of hydrogen can include hydrogen produced by electrolysis (e.g., using wind, solar, hydroelectric, or other forms of power to split water molecules into hydrogen and oxygen); methane pyrolysis or plasma reforming with partial oxidation (catalytic steam reforming from heavier hydrocarbons); chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), syngas ($\text{H}_2 + \text{CO}$) formation from coal, oil, or petroleum coke; steam methane reformation, or the like, each with varying carbon intensities. Further gases, isotopes, or materials may be measured and analyzed according to the techniques disclosed herein.

[0072] The use of chemical instruments to measure elements, molecules, isotopes, or isotopic ratios by visual inspection, quantitative analysis, or supervised or unsupervised computer-assisted machine learning can enable the identification and characterization of hydrogen, hydrogen carriers, and products derived using hydrogen feedstocks. FIG. 1 is a list of analytical chemical instrumentation, the types of samples that can be analyzed with each instrument, and the elements and compounds that can be measured that are relevant to determining the genetic source of hydrogen, hydrogen carriers, and products derived using hydrogen feedstocks, according to embodiments.

[0073] FIG. 2 is a general workflow relating to the collection of hydrogen-containing fluids, chemical analyses, data acquisition, interpretation, and apportioning the sources of hydrogen within the fluid, which can be used to determine the carbon credit value of the fluid, according to an embodiment. Some or all of the blocks shown in FIG. 2 may be utilized in one or more embodiments. Aspects of the blocks are disclosed herein.

[0074] Methods and systems for identifying and characterizing hydrogen, whether as a gas or compressed to a liquid, and its derivative products (e.g., ammonia, methanol, hydrogen-derived synthetic/electrofuels, such as renewable or low-carbon kerosene, diesel, jet fuel, plastics, synthetic methane, or other hydrogen carriers or products) are disclosed herein. The methods and

systems can apply to hydrogen from inputs and offtakes of natural gas in pipelines; inputs and offtakes of natural gas transported by other means (e.g., trucking, railcar, pipelines); biologically- or organically-derived hydrogen or molecules containing hydrogen; hydrogen formed by electrolysis (e.g., using wind, solar, hydroelectric, or other forms of power to split water molecules into hydrogen and oxygen); methane pyrolysis or plasma reforming with partial oxidation (catalytic steam reforming from heavier hydrocarbons); chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), syngas synthetic/electrofuels containing hydrogen (e.g., synthetic renewable or low-carbon ammonia, methanol, kerosene, diesel, jet fuel, methane or others); synthetic plastics, prospective leaks or fugitive or stray natural gas investigations involving hydrogen; storage in subsurface reservoirs, formations, caverns, or other facilities; or usage in other industrial facilities (e.g., refineries, ammonia plants, synthetic/electrofuels generators, synthetic plastic manufacturing, direct reduced steel manufactured, or high grade heat), among others.

[0075] Methods and systems herein provide for the quantitative assessment and monitoring of the source of hydrogen and derivative products for which hydrogen is a feedstock (ammonia, methanol, hydrogen-derived synthetic/electrofuels, such as renewable or low-carbon kerosene, diesel, jet fuel, plastics, synthetic methane, or other hydrogen carriers or products; other hydrogen carriers; or synthetic plastics), which can be performed using measurement(s) of one or more chemical species (H_2 , N_2 , NH_3 , CO , CO_2) and elemental gas(es) (noble gases: He, Ne, Ar, Kr, Xe, Rn), isotopes of gas(es) (e.g., δ^2H-H_2 , δ^2H-CH_4 , $\delta^{13}C-CH_4$, $\delta^{13}C-CO_2$, $\delta^{15}N-N_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , and their derivative isotopic ratios), or isotopes of water (δ^2H-H_2O , $\delta^{18}O-H_2O$), or the concentrations of carbon dioxide or dissolved forms of carbon and their isotopic compositions (i.e., $\delta^{13}C-DIC$) sampled directly or indirectly from natural samples (e.g., fluid samples of various types), chemical feedstocks, or other industrial chemicals. Using the techniques for measurements disclosed herein, the source and proportion of various hydrogen supplies can be determined and verification of low-carbon hydrogen status (e.g., electrolytic, pyrolysis, geological, biological, or carbon reduction through chemical looping) for the proposed United State Internal Revenue Service 45X production tax credit, various Low Carbon Fuel Standards, or other incentive, subsidy, or tax credit programs, can be determined in inputs and

offtakes of natural gas in pipelines; inputs and offtakes of natural gas transported by other means (e.g., trucking, railcar, pipelines); biologically- or organically-derived hydrogen molecules or other molecules containing hydrogen; synthetic/electrofuels containing hydrogen; prospective leaks or fugitive or stray natural gas investigations involving hydrogen; storage in the subsurface reservoirs, formations, caverns, or other facilities; usage in other industrial facilities (e.g., refineries, ammonia plants, synthetic/electrofuels generators, synthetic plastic manufacturing, direct reduced steel manufactured, or high grade heat). The utilization of this method can enable low-carbon or “green” certification of hydrogen and tracking of “green” hydrogen and derivative chemicals for which hydrogen is a feedstock.

[0076] Hydrocarbon gases can be formed naturally by inorganic or biological processes that can result in distinct molecular and stable isotopic signatures of methane (e.g., $\delta^2\text{H-CH}_4$, $\delta^{13}\text{C-CH}_4$) and hydrocarbon species of higher molecular weight hydrocarbon species (e.g., $\delta^2\text{H-C}_2$, $\delta^{13}\text{C-C}_2$). Thermogenic hydrocarbons (e.g., oil, shale gas) can be formed from the thermocatalytic cracking of organic matter and result in $\delta^2\text{H-CH}_4$ generally greater than about -250‰ and $\delta^{13}\text{C-CH}_4$ generally between about -55‰ and -25‰. As thermal maturity of the organic matter increases, the stable isotopic signatures of carbon and hydrogen in the produced hydrocarbons can become more positive in predictable fashions. In contrast, microbial methane (e.g., coalbed methane) can be formed from methanogenic archaea utilizing the reduction of CO_2 or fermentation of acetate in the shallow subsurface, which result in $\delta^{13}\text{C-CH}_4$ values generally less than about -55‰ and $\delta^2\text{H-CH}_4$ values generally greater than about -250‰ but less than about -100‰. Abiotic methane can be the result of Sabatier reactions between H_2 and CO_2 at elevated (about 150°C or more) temperatures and may be observed in geothermal systems, which result in isotopically heavy $\delta^{13}\text{C-CH}_4$ (about -20‰ or more) and $\delta^2\text{H-CH}_4$ (about -400‰ or more).

[0077] Hydrogen can be formed by inorganic or biological processes. The isotopic composition of hydrogen generated by either mechanism displays molecular or isotopic characteristics that can be used to determine the source of hydrogen. For example, like microbial methane, hydrogen produced by biological species (e.g., microbes) is associated with highly elevated levels of dissolved inorganic carbon and dissolved inorganic carbon that is isotopically enriched (e.g., $\delta^{13}\text{C-DIC}$ greater than about -10‰) relative to that produced from CO_2 dissolution or the oxidation of organic matter (e.g., $\delta^{13}\text{C-DIC}$ commonly ranging from -30‰ to -

10‰). Hydrogen produced by microbes also displays hydrogen isotopic compositions that are significantly depleted in deuterium relative to protium (i.e., $\delta^2\text{H-H}_2$ less than about -750‰).

[0078] The most dominant geologic process that produces natural hydrogen is the serpentinization of iron-rich minerals such as olivine and pyroxene, which are minerals most commonly found in mantle-derived mafic and ultramafic igneous rocks (e.g., basalt, gabbro, and peridotite). Olivine and pyroxene minerals also contain trapped ^3He , therefore a fluid rich in hydrogen produced from serpentinization may be enriched in ^3He relative to other crust-derived or microbially-derived hydrogen-rich fluids. This is most often observed in geothermal environments but has also been seen in intracontinental settings where mafic and ultramafic igneous rocks have intruded and elevated natural hydrogen has been found. Further, while carbon dioxide has many sources in the crust (e.g., microbial respiration, dissolution of calcium carbonates, post-mature kerogen), mantle-derived fluids have characteristic $\delta^{13}\text{C-CO}_2$ (about -2‰ to -8‰) and $[\text{CO}_2]/[^3\text{He}]$ ratios (about 1×10^9 to 10×10^9). Mantle-derived helium displays a $[\text{He}]/[\text{He}]$ of up to about 6 to $8R_A$ (where R_A is the $[\text{He}]/[\text{He}]$ in air or 1.384×10^{-6}) or higher in mantle plume environments, while the helium isotopic ratio in the atmosphere is about $1R_A$ and the helium isotopic ratio of crustal gases is about $0.02R_A$. Together, these geochemical signatures can be used as evidence for identifying the source of naturally occurring hydrogen in the subsurface. In most crustal systems, the relative contributions of each component can be resolved using a combination of helium, neon, or argon isotopes or various ratios of helium or other noble gases to other atmospheric noble gases (e.g., He/Ne, He/Ar, He/Kr, He/Xe, or to specific isotopes of one of these elements).

[0079] Hydrogen produced by various inorganic processes displays a predictable relationship with temperature and the original source of water from which hydrogen is derived (example shown in FIGS. 3 and 4). FIG. 3 is a graph of the degree of fractionation (i.e., alpha or the fractionation factor) between hydrogen isotopic compositions of liquid water ($\delta^2\text{H-H}_2\text{O}$) and molecular hydrogen ($\delta^2\text{H-H}_2$) as a function of temperature in the paired liquid water-molecular hydrogen system that occurs during the serpentinization process. Similar graphs for other hydrogen-forming reactions (e.g., pyritization) that quantify the degree of fractionation between a given reactant and the hydrogen product (e.g., dihydrogen sulfide and hydrogen) are also conceived of as part of embodiments. Because hydrogen can be formed by the reduction of water by a variety of mechanisms (e.g., serpentinization), there is a strong temperature-fractionation

relationship for $\text{H}_2\text{O}-\text{H}_2$ systems (FIG. 3). For example, thermochemical calculations show that in very reducing conditions (e.g., low oxygen fugacity) fractionation factors between oxygen and hydrogen during the olivine-water or pyroxene-water interactions (i.e., serpentinization) are well calibrated from temperatures ranging from about 20°C to 700°C . As a result, if the $\delta^2\text{H}-\text{H}_2\text{O}$ and $\delta^2\text{H}-\text{H}_2$ values of a given water- H_2 (gas) pair can be measured, or if the $\delta^2\text{H}-\text{H}_2$ values of a fluid containing hydrogen can be measured while the isotopic composition of the original water can be reasonably assumed (i.e., if the $\delta^2\text{H}-\text{H}_2\text{O}$ value is known, e.g., based on local porewater isotopic values, seawater isotopic values, or known isotopic composition of water sources used in electrolysis or other reactions), the temperatures of gas formation can be calculated based on measuring the $\delta^2\text{H}-\text{H}_2$ and calculating the temperature-dependent degree of fractionation relative to the original hydrogen-carrying molecule (i.e., water in the case of serpentinization, electrolysis, or others). These calculated temperatures can be compared to local geothermal gradients to determine the genetic source of natural hydrogen gas and by comparison to a range of parameters (e.g., concentration of other gases, concentration of dissolved inorganic carbon, mineralogy) in other approaches to determine the mechanism responsible for the formation of hydrogen (e.g., serpentinization compared to pyritization). FIG. 4 is a graph of the relationship between the isotopic composition of molecular hydrogen ($\delta^2\text{H}-\text{H}_2$) and temperature of hydrogen formation during the serpentinization process. Similar graphs for other hydrogen-forming reactions (e.g., pyritization) that quantify the degree of fractionation between a given reactant and the hydrogen product (e.g., dihydrogen sulfide and hydrogen) are also conceived of as part of embodiments. A small amount of re-equilibration between ambient H_2O and H_2 can be expected above 100°C in higher temperature regimes, suggesting these calculated temperatures may represent a minimum. Whether plotted manually, with a computer, or by other form of graphing or statistical tool, graphs of $\delta^2\text{H}-\text{H}_2$ can be plotted relative to either water isotope data ($\delta^2\text{H}-\text{H}_2\text{O}$) or calibration lines of anticipated temperature based on the thermodynamics of equilibrium between water and newly generated hydrogen gas assuming a fractionation factor between the two species that is dependent on mineralogy, porewater chemistry, and temperature.

[0080] Natural hydrogen can also be produced by biologically-mediated (e.g., bacterial production) or other inorganic processes, including magma oxidation, basalt alteration, magmatic degassing, cataclasis, pyritization (“metal-sulfide precipitation”), lava crystallization, radiolysis, graphitization, and lava-seawater interactions. For those reactions that involve interactions with

water (i.e., magma oxidation, basalt alteration, low-temperature weathering, magma crystallization, lava-seawater interactions), there is a similarly predictable, temperature-dependent relationship between the original source of water and the derived hydrogen. In this case, the same process described for serpentinization can be applied and used to determine the source of hydrogen. For other mechanisms, similar thermodynamic relationships exist between the original hydrogen-containing molecule, such as dihydrogen sulfide in pyritization (“metal-sulfide precipitation”), methane or other heavier molecular weight hydrocarbons in graphitization, water in radiolysis or cataclasis, or hydroxyls in radiolysis or cataclasis, and the evolved hydrogen. For example, thermodynamic calculations show that fractionation factors between dihydrogen sulfide and hydrogen formed during the olivine-dihydrogen sulfide or pyroxene-dihydrogen sulfide reaction (i.e., pyritization (“metal-sulfide precipitation”)) are well-calibrated according to temperature ranging from about 20°C to 700°C. As a result, if the $\delta^2\text{H-H}_2\text{S}$ and $\delta^2\text{H-H}_2$ values of a given $\text{H}_2\text{S-H}_2$ (gas) pair can be measured, or if the $\delta^2\text{H-H}_2$ values of a fluid containing hydrogen can be measured while the isotopic composition of the original dihydrogen sulfide can be reasonably assumed, the temperatures of gas formation can be calculated based on measuring the $\delta^2\text{H-H}_2$ and calculating the temperature-dependent degree of fractionation relative to the original hydrogen-carrying molecule. These calculated temperatures and a range of parameters can be used to determine mechanism responsible (i.e., genetic source) for the formation of hydrogen (e.g., pyritization compared to serpentinization) especially when compared to other geochemical parameters (e.g., concentration of other gases, concentration of dissolved inorganic carbon, mineralogy) and the source rock of the hydrogen gas based on a comparison to the local geothermal gradient. Whether plotted manually, with a computer, or by another form of graphing or statistical tool, graphs of $\delta^2\text{H-H}_2$ can be plotted relative to either the isotopic composition of the hydrogen-carrying molecule (e.g., $\delta^2\text{H-H}_2\text{S}$) or calibration lines of anticipated temperature based on the thermodynamics of equilibrium between the hydrogen-carrying molecule and newly generated hydrogen gas assuming a fractionation factor between the two species that is dependent on mineralogy, porewater chemistry, and temperature.

[0081] The concentrations of other gases and chemical species (e.g., H_2 , N_2 , NH_3 , CO , CO_2 ; noble gases: He, Ne, Ar, Kr, Xe, Rn; and the isotopes of these gases (e.g., $\delta^2\text{H-CH}_4$, $\delta^{13}\text{C-CH}_4$, $\delta^{13}\text{C-CO}_2$, $\delta^{15}\text{N-N}_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , among others)) can also be used to differentiate hydrogen formed by various synthetic processes, electrolysis (e.g., using wind,

solar, hydroelectric, or other forms of power to split water molecules into hydrogen and oxygen); methane pyrolysis or plasma reforming with partial oxidation (catalytic steam reforming from heavier hydrocarbons); chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea, bacterial), syngas ($\text{H}_2 + \text{CO}$) formation from coal, oil, or petroleum coke; steam methane reformation, or the like, each with varying carbon intensities. This method can distinguish sources of hydrogen based on the measurable abundances of common tracers (e.g., CH_4 , N_2 , ^4He , Ne , Ar , Kr , Xe) and their isotopic values (e.g., $\delta^2\text{H}-\text{CH}_4$, $\delta^{13}\text{C}-\text{CH}_4$, $\delta^{13}\text{C}-\text{CO}_2$, $\delta^{15}\text{N}-\text{N}_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , among others) compared to anticipated values. In each process, temperature, pressure, and salinity dependent variables can dictate the predictable degree of the fractionation in gas tracers throughout the hydrogen synthesis process and later gas separation or purification processes. For example, during the membrane separation, pressure-swing absorption, or cryogenic separation, these and other chemical species are predictably separated. The physicochemical parameters (e.g., temperature, pressure, and salinity) can be used to determine initial compositions, apportion the amount of hydrogen sourced from various natural and synthetic formation mechanisms, or certify the source of hydrogen. For example, hydrogen formed by methane steam reforming that is later processed for carbon capture utilization and storage exhibits predictable fractionation of chemical species that be used to determine the source, apportion the amount of hydrogen sourced from various natural and synthetic formation mechanisms, or certify the source of hydrogen. Whether plotted manually, with a computer, or by other form of graphing or statistical tool, graphs of $\delta^2\text{H}-\text{H}_2$ can be plotted relative to either water isotope data ($\delta^2\text{H}-\text{H}_2\text{O}$) or calibration lines of anticipated temperature based on the thermodynamics of equilibrium between water and newly generated hydrogen gas assuming a fractionation factor between the two species that is dependent on mineralogy, porewater chemistry, and temperature.

[0082] Hydrogen can also be produced by various synthetic processes, including electrolysis (e.g., using wind, solar, hydroelectric, or other forms of power to split water molecules into hydrogen and oxygen); methane pyrolysis or plasma reforming with partial oxidation (catalytic steam reforming from heavier hydrocarbons); chemical looping of gases from various sources (e.g., biomass, renewable natural gas, pressure swing absorption rejectate, refinery emissions, sewage treatment emissions), hydrogen produced from biological sources (e.g., archaea,

bacterial), syngas ($\text{H}_2 + \text{CO}$) formation from coal, oil, or petroleum coke; steam methane reformation, or the like, each with varying carbon intensities. For those reactions, there is a similarly predictable, temperature-dependent relationship between the original source of the hydrogen-carrying molecule (e.g., water, methane) and the derived hydrogen. Like the natural processes described above, in other synthetic processes (e.g., electrolysis, pyrolysis), the temperatures calculated from chemical measurements (e.g., chemical abundances or their isotopic composition) can be compared to known sources of water, methane or other forms of natural gas, dihydrogen sulfide, or other hydrogen carries and temperatures of reactions to determine the source of synthetic hydrogen produced by various reactions or other reactions that utilize these hydrogen-carrying molecules. Thus, by comparison to measured, known, or assumed compositions of source waters, sources of methane or other forms of natural gas, or sources of dihydrogen sulfide and temperature ranges of affiliated reactions the source of hydrogen can be identified, apportioned or certified as green (e.g., formed by electrolysis), blue (e.g., formed steam methane reformation with carbon capture utilization, and storage; methane pyrolysis), gold (e.g., natural hydrogen formed by various mechanisms), or others forms of hydrogen synthesis. In addition to isotopic measurements, a range of parameters (e.g., concentration of other gases (e.g., H_2 , N_2 , NH_3 , CO , CO_2 ; noble gases: He , Ne , Ar , Kr , Xe , Rn ; and the isotopes of these gases (e.g., $\delta^2\text{H-CH}_4$, $\delta^{13}\text{C-CH}_4$, $\delta^{13}\text{C-CO}_2$, $\delta^{15}\text{N-N}_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , among others)), can be included in other approaches to determine the source of hydrogen formed by various processes. Whether plotted manually, with a computer, or by other form of graphing or statistical tool, graphs of $\delta^2\text{H-H}_2$ can be plotted relative to either water isotope data ($\delta^2\text{H-H}_2\text{O}$) or other hydrogen-carrying molecules (e.g., methane: $\delta^{13}\text{C-CH}_4$, $\delta^2\text{H-CH}_4$ or other forms of natural gases (e.g., $\delta^{13}\text{C-C}_2\text{H}_6$, $\delta^2\text{H-C}_2\text{H}_6$), or dihydrogen sulfide (e.g., $\delta^2\text{H-H}_2\text{S}$)) or calibration lines of anticipated temperature based on the thermodynamics of equilibrium between water and newly generated hydrogen gas assuming a fractionation factor between the two species that is dependent on temperature, pressure, and salinity.

[0083] The same thermodynamic calculations and measurements can be applied and used to determine the source of hydrogen and delineate the process used to synthesize hydrogen formation. These same chemical parameters can be used to determine the mechanism responsible (i.e., source) for the formation of hydrogen (e.g., steam methane reforming, electrolysis, and

pyrolysis, purified by chemical looping, as compared to various forms of natural hydrogen) especially when in combination with other geochemical parameters (e.g., concentration of other gases). Whether plotted manually, with a computer, or by another form of graphing or statistical tool, graphs of $\delta^2\text{H-H}_2$ can be plotted relative to either the isotopic composition of the hydrogen-carrying molecule (e.g., $\delta^2\text{H-H}_2\text{O}$, $\delta^{13}\text{C-CH}_4$, $\delta^2\text{H-CH}_4$, $\delta^2\text{H-H}_2\text{S}$) or calibration lines of anticipated temperature based on the thermodynamics of equilibrium between the hydrogen-carrying molecule and newly generated hydrogen gas assuming a fractionation factor between the two species that is dependent on temperature, pressure, and salinity. These methods can be used to determine, apportion, or certify natural hydrogen (“gold hydrogen”) or other synthetic forms of hydrogen.

[0084] In some embodiments, characteristics such as the concentration of methane compared to the concentration of hydrogen (e.g., $[\text{CH}_4]/[\text{H}_2]$), can help provide important information as to the origin of natural hydrogen. Generally, as the temperature increases, the kinetic rate of the Sabatier reaction converts more hydrogen to methane in the presence of ambient gaseous or dissolved carbon dioxide. During this process, the newly formed methane (i.e., abiogenic methane) can have unique isotopic compositions (i.e., $\delta^{13}\text{C-CH}_4$ greater than -20‰). As a result, a generally positive correlation between $[\text{CH}_4]/[\text{H}_2]$ and $\delta^2\text{H-H}_2$ or $\delta^{13}\text{C-CH}_4$ can be taken as an indication of increasing temperature of gas formation (and vice versa). Whether plotted manually, with a computer, or by other form of graphing or statistical tool, graphs of these data can be used to determine temperature and resolve the mixing of multiples sources or generations of gas. In some embodiments, a system and method for determining the source of hydrogen can derive or infer the source based on determining the temperature of hydrogen formation. By determining the thermal conditions (“genetic source”) of hydrogen, hydrogen production can be monitored, the fate of fugitive hydrogen can be tracked, or a “fingerprint” of natural hydrogen can be identified that can be used to track its utilization in various commercial processes. For example, determining the thermal conditions at which hydrogen from an industrial facility was formed may allow the determination of which natural hydrogen reservoirs the facility sources from.

[0085] In some embodiments, accurately determining the source may be important in evaluating the likelihood that hydrogen formed at a specific depth would migrate into a specific reservoir or be emplaced below a specific seal and/or in estimating the volume of gas that would

accumulate in a given 3-dimensional trap. The source fingerprint may be important for various efforts to apportion the source of gas, identify chemicals derived that use this or other forms of hydrogen as a feedstock, or track its downstream utilization or environmental fate. In some embodiments, as the source fingerprint can also be used to identify, apportion, or verify or authenticate its qualification for the proposed United States Internal Revenue Service 45X production tax credit, various Low Carbon Fuel Standards, and various other hydrogen subsidy, incentive, or credit programs.

[0086] In some embodiments, for classification of hydrogen, one or more of a suite of geochemical analyses may be conducted on a fluid sample(s) or from samples collected from various other sources of hydrogen formation. Fluid samples can be taken from a well at one or more depths or may be taken from the surface. Adequate sample containers for gas samples can include refrigeration-grade copper tubes sealed with brass, steel, or other forms of refrigeration clamps; seamless stainless-steel cylinders; Isotubes®; gas-tight septum vials, or the like. The fluid may be extracted from the sample container on a vacuum line and, if necessary, may be sonicated (e.g., for about 30 minutes) to ensure complete transfer of dissolved gases from the extraction vessel to the sample inlet line.

[0087] Major gas/dissolved gas components (e.g., H₂, N₂, NH₃, CO, CO₂, C₁-C₆+) in the sample can be measured by a Residual Gas Analyzer (RGA), Quadrupole Mass Spectrometer, gas-source mass spectrometers, a Gas Chromatograph (GC) fitted with a Flame Ionizing Detector (FID) and Thermal Conductivity Detector (TCD), or other suitable analytical equipment and techniques. Noble gases and their stable isotopes can be measured by a gas source mass spectrometer, such as following purification of an aliquot of the sample, cavity ringdown, or other suitable technique. The stable isotopic composition of gas molecules (e.g., δ²H-H₂, δ²H-CH₄, δ¹³C-CH₄, δ¹³C-CO₂, δ¹⁵N-N₂) can be measured by an isotope ratio mass spectrometer (IRMS), cavity ring down spectroscopy, or another suitable method. If necessary, the IRMS can be used to also measure the stable isotopes of hydrogen and oxygen in water (i.e., δ²H-H₂O, δ¹⁸O-H₂O). Any other technique disclosed herein may be utilized to measure isotopes in fluid samples.

[0088] Determining the characteristics of hydrogen, carbon, or any other material in a subsurface geological formation may include retrieving a fluid sample from a borehole or well. The borehole or well may be drilled for the characterization if necessary. The sample may be

collected at the surface, such as from a water or other fluid source at the surface. The sample may be tested as set forth above. Determining the characteristics of hydrogen, carbon, or any other material in other forms of gases may include retrieving a fluid sample from various inputs and outputs of processes that make synthetic hydrogen (e.g., electrolysis, pyrolysis, chemical looping), collected from various mechanisms of hydrogen transport (e.g., pipelines, trucks, cryogenic trucks, tanks, or other forms), storage (e.g., tanks, tube trailers, salt caverns, subsurface gas storage reservoirs, or collected in chemicals for which various forms of hydrogen were utilized as feedstocks (e.g., ammonia, methanol, synthetic fuels, renewable or low-carbon diesel, electrofuels, plastics, synthetic methane, various other electrofuels, or in processes that utilize other no-carbon or low-carbon hydrogen sources, synthetic plastics, or other energy sources at the surface). The measurements may be compared to measurements from known samples or standards using any of the analytical techniques disclosed herein. The comparison may be carried out on a computing device using electronic instructions to carry out any of the analytical techniques disclosed herein. For example, software may be utilized to automatically carry out any of the analytical techniques disclosed herein. Such comparisons may be carried out in real time. The computing device may be in electronic communication (e.g., via an internet, WIFI, Bluetooth, or LAN connection) with the chemical testing or measuring equipment disclosed herein to receive the measurements (e.g., data) therefrom. In some embodiments, the measurements may be transferred via a memory storage device (e.g., flash drive, disc, or the like). The computing device may fetch data for comparison to sample measurement data from one or more data libraries.

[0089] Although the present specification focusses on hydrogen and carbon dioxide, it is understood that the techniques disclosed herein are not so limited and can find application in the identification and quantitative assessment of other subsurface materials, including other gases, minerals and gems, as well as, materials found in large structures such as foundations, dams, hydroelectric facilities and nuclear facilities to name a few.

[0090] It is noted that there is no requirement to provide or address the theory underlying the novel and groundbreaking production rates, performance or other beneficial features and properties that are the subject of, or associated with, embodiments of the present inventions. Nevertheless, various theories are provided in this specification to further advance the art in this important area, and in particular in the important area of hydrogen, dihydrogen sulfide, carbon

dioxide, and helium exploration, production and downstream conversion or utilization. These theories put forth in this specification, and unless expressly stated otherwise, in no way limit, restrict or narrow the scope of protection to be afforded the claimed inventions. These theories may not be required or practiced to utilize the present inventions. It is further understood that the present inventions may lead to new, and heretofore unknown theories to explain the conductivities, fractures, drainages, resource production, chemistries, and function-features of embodiments of the methods, articles, materials, devices and system of the present inventions; and such later developed theories shall not limit the scope of protection afforded the present inventions.

[0091] The invention may be embodied in other forms than those specifically disclosed herein without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting. The various embodiments of devices, systems, activities, methods and operations set forth in this specification may be used with, in or by, various processes, industries and operations, in addition to those embodiments of the Figures and disclosed in this specification. The various embodiments of devices, systems, methods, activities, and operations set forth in this specification may be used with: other processes, industries, and operations that may be developed in the future: with existing processes industries and operations, which may be modified, in-part, based on the teachings of this specification; and with other types of gas recovery and valorization systems and methods. Further, the various embodiments of devices, systems, activities, methods, and operations set forth in this specification may be used with each other in different and various combinations. Thus, for example, the configurations provided in the various embodiments of this specification may be used with each other. For example, the components of an embodiment having A, A' and B and the components of an embodiment having A'', C and D can be used with each other in various combination, e.g., A, C, D, and A. A'' C and D, etc., in accordance with the teaching of this specification. Thus, the scope of protection afforded the present inventions should not be limited to a particular embodiment, configuration or arrangement that is set forth in a particular embodiment, example, or in an embodiment in a particular Figure.

CLAIMS

What is claimed is:

1. A method for analyzing a molecular composition, the method comprising:
analyzing hydrogen molecules, hydrocarbon gases, noble gases, carbon dioxide, nitrogen, and mixtures of natural gases of varying composition to determine the source of hydrogen, carbon dioxide, or natural gas.
2. A method for analyzing the molecular composition of hydrogen and other gas mixtures, comprising:
assessing a proportion of hydrogen derived from sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources;
quantifying the proportion of hydrogen derived from the sources; and
validating and certifying the proportion of hydrogen derived from no-carbon, low-carbon, and/or high-carbon sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources.
3. A method for analyzing an isotopic composition, the method comprising:
analyzing at least one of hydrogen molecules, hydrocarbon gases, noble gases, carbon dioxide, nitrogen, or mixtures of natural gases of varying composition to determine the source of hydrogen, carbon dioxide, or natural gas;
analyzing water to determine a feedstock for hydrogen formation by electrolysis of the water; and
analyzing methane or other hydrocarbon gases to determine a feedstock for hydrogen formation by pyrolysis, steam methane reforming, or steam methane reforming combined with carbon capture utilization and storage of methane or other hydrocarbon gas feedstocks.
4. A method for analyzing an isotopic composition, the method comprising:
assessing a proportion of hydrogen, carbon dioxide, or natural gas derived from sources including one or more of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis;
quantifying the proportion of hydrogen or carbon dioxide derived from the sources;

validating and certifying the proportion of hydrogen derived from no-carbon, low-carbon, and/or high-carbon sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis.

5. A method for analyzing the isotopic composition of hydrogen in ammonia, the method comprising:

determining the source of hydrogen feedstocks used in ammonia production;

determining the proportion of hydrogen feedstock derived from sources including geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis;

quantifying the proportion of hydrogen feedstock derived from the sources; and

certifying the proportion of hydrogen feedstock derived from the sources.

6. A method for analyzing the isotopic composition of hydrogen and carbon in methanol, the method comprising:

determining a source of hydrogen or carbon feedstocks used in methanol production;

determining a proportion of hydrogen derived from sources including at least one of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis;

determining the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms;

quantifying the proportion of hydrogen feedstock or carbon derived from the sources including one or more of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis;

certifying the proportion of hydrogen feedstock and carbon derived from the sources including one or more of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis; and

certifying the proportion of carbon derived from the sources including one or more of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms.

7. A method for analyzing the isotopic composition of hydrogen and carbon in synthetic/electrofuels, such as renewable or low-carbon kerosene, diesel, jet fuel, plastics, synthetic methane, or other hydrogen carriers, the method comprising:

determining the source of hydrogen and carbon feedstocks in synthetic/electrofuels, such as renewable or low-carbon kerosene, diesel, jet fuel, plastics, synthetic methane, or other hydrogen carriers;

quantifying the proportion of hydrogen derived from sources including one or more of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources in synthetic/electrofuels;

quantifying the proportion of carbon derived from sources including one or more of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms in electrofuels;

certifying the proportion of hydrogen derived from the sources including one or more of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources in electrofuels; and

certifying the proportion of carbon derived from the sources including one or more of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms in electrofuels.

8. A method for analyzing the isotopic composition of hydrogen and carbon in hydrogen carriers, the method comprising:

determining sources of hydrogen and carbon feedstocks in hydrogen carriers;

quantifying the proportion of hydrogen derived from sources including at least one of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources in hydrogen carriers;

quantifying the proportion of carbon derived from sources including at least one of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms in hydrogen carriers;

certifying the proportion of hydrogen derived from the sources including at least one of geologic hydrogen, coal, steam methane reformation, pyrolysis, chemical looping, or electrolysis sources in hydrogen carriers; and

certifying the proportion of carbon derived from the sources including at least one of coal combustion, natural gas combustion, biomass incineration, ammonia synthesis, steel manufacturing, synthesis of lime and other chemicals, waste incineration, gas processing, atmospheric capture, or other forms in hydrogen carriers.

9. A method for determining the source of hydrogen in natural gas, the method comprising:

determining the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities.

10. The method of claim 9 wherein determining the source of hydrogen includes comparing a measurement of an isotopic ratio of hydrogen from a sample with data for isotopic ratios of hydrogen for known samples of hydrogen.

11. A method for quantifying or apportioning the source of hydrogen in natural gas, the method comprising:

quantifying or apportioning the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities.

12. A method for certifying the source of hydrogen in natural gas for a US IRS 45X production tax credit, Low Carbon Fuel Standards, or other hydrogen incentive, subsidy, or credit programs, the method comprising:

certifying the source of hydrogen in at least one of natural gas pipelines, hydrogen pipelines, oil pipelines, water pipelines, railcars, trucks, or industrial facilities.

13. A method for determining a source of hydrogen, the method comprising:

determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of exploration of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases;

determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of drilling, including measurement while drilling, drill-stem test, or

pressure-volume-temperature (PVT) operations, for oil, natural gas, hydrogen, carbon dioxide, helium, or other gases;

determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of production of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases;

determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases in subsurface reservoirs;

determining the source of hydrogen in fluids collected at the surface or the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases in subsurface caverns;

determining the source of hydrogen in fluids collected at the surface or the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, hydrogen, carbon dioxide, helium, or other gases in surface tanks, subsurface tanks, or other industrial facilities; and

determining the source of hydrogen in fluids collected at the surface or from the subsurface for the purposes of monitoring and evaluation the presence of leaks or fugitive, stray, or other gas emissions in boreholes, oil, natural gas, or hydrogen wells, pipelines, water wells, surface seeps, springs, or other storage facilities.

14. A method for determining the composition of matter for hydrogen using the isotopic composition of hydrogen, the method comprising:

using the isotopic composition of hydrogen of at least one of:

ammonia;

methanol;

synthetic or electrofuels;

plastics;

various other green hydrogen sources;

various other chemicals where hydrogen is used as a feedstock;

fluids collected at surface regions including springs and surface seeps or from the subsurface for the purposes of monitoring and evaluation of the storage of oil, natural gas, or hydrogen in surface tanks, subsurface tanks, or other industrial facilities; or

fluids collected at the surface regions or from the subsurface for the purposes of monitoring and evaluation the presence of leaks or fugitive, stray, or other gas emissions in boreholes, oil, natural gas, or hydrogen wells, pipelines, water wells, surface seeps, springs, or other storage facilities.

15. Any of the methods disclosed herein.

16. Any of the methods of disclosed herein for determining a molecular composition of fluids including hydrogen and other molecular gases (e.g., H₂, N₂, NH₃, CO, CO₂) or elemental gases (e.g., He, Ne, Ar, Kr, Xe) or isotopes of gases (e.g., $\delta^2\text{H-H}_2$, $\delta^2\text{H-CH}_4$, $\delta^{13}\text{C-CH}_4$, $\delta^{13}\text{C-CO}_2$, $\delta^{15}\text{N-N}_2$, ^3He , ^4He , ^{20}Ne , ^{21}Ne , ^{22}Ne , ^{36}Ar , ^{38}Ar , ^{40}Ar , and their derivative isotopic ratios), water ($\delta^2\text{H-H}_2\text{O}$, $\delta^{18}\text{O-H}_2\text{O}$), or other dissolved constituents ($\delta^{13}\text{C-DIC}$).

17. Any of the systems disclosed herein.

ABSTRACT

Embodiments are directed to analyzing the molecular composition of hydrogen molecules, hydrocarbon gases, noble gases, carbon dioxide, nitrogen, mixtures of natural gases of varying composition, and other gases to determine a source of hydrogen, carbon dioxide, or natural gases.