Hydrogen Hub Systems Analysis and Mapping Tool (Paracraft) v1

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The hydrogen (H_2) hub systems analysis and mapping tool "Paracraft" developed using R version 4.3.2 is an integrated life cycle assessment (LCA), techno-economic analysis (TEA), and geospatial analysis tool. The tool quantifies the environmental and economic impacts of a H_2 hub that includes feedstock, production, infrastructure/storage, distribution, and end-use of H_2 within the system boundary. Additional modules and impacts will be integrated into the software throughout the Department of Energy (DOE) ARCHES hydrogen hub project through a multi-institution collaboration involving the Lawrence Berkeley National Laboratory, University of California Davis, University of California, Berkeley, University of California Irvine, Renewables100, National Renewable Energy Laboratory, ARCHES LLC, and Jacobs.

Version 1 of the tool includes modules for the following components:

1. <u>Feedstock</u>: Electricity (grid, power purchase agreement, and renewables), water, and biomass (municipal solid waste and woody waste)

2. <u>Production</u>: Alkaline water electrolysis, Proton exchange membrane (PEM) water electrolysis, Biomass thermochemical conversion, and Biomass gasification.

3. <u>Infrastructure/storage</u>: H_2 compression, H_2 liquefaction, and storage for compressed and liquefied H_2.

4. <u>Distribution</u>:Truck transport of compressed and liquefied H_2 and pipeline transport of compressed H_2.

5. <u>End-use</u>: Refueling stations and medium duty class 6 trucks, transit buses, fuel cell and peaker plant for power generation, and aviation fuel.

The environmental impacts from LCA are quantified as net carbon dioxide equivalent emissions (kg CO_2e/kg H_2), sulfur dioxide emissions (g SO_2/kg H_2), nitrogen oxide emissions (g NO_x/kg H_2), and particulate matter emissions (g PM_{10}/kg H_2 and g $PM_{2.5}$/kg H_2). Health impacts and benefits associated with net changes in air quality will be provided in a subsequent version.

The economic impact from TEA is quantified as total levelized cost ($/kg H_2). Net present value, total revenue, total policy incentives, and other financial performance indicators will be provided in a subsequent version following the approach used in the DOE H2FAST model.

Capabilities of version 1

- <u>Projects</u>: Flexible inclusion, exclusion, and modification of projects in a hub over time.

- <u>LCA</u>: Emissions from feedstock preparation and acquisition, H_2 production, H_2 postprocessing and compression and/or liquefaction, H_2 transport, and avoided emissions from H_2 end-uses that offset current fossil fuel consumption.

- <u>TEA</u>: Total levelized cost (capital, operation and maintenance) of feedstock preparation, H_2 production, H_2 compression and/or liquefaction, and H_2 transport.

End-user markup and total levelized cost to consumers will be available in the next version.

- <u>Geospatial</u>: Linking projects to specific regions in California such as Northern California (NorCal), North Central Valley (NCV), South Central Valley (SCV), and Southern California (SoCal). Linking projects to different legislative districts in California such as senate, congress, and assembly.

- <u>Visualization</u>: Creating summary tables, plots, and maps for individual projects, market sectors, technology types, and geospatial boundaries.

Getting Started

In addition to the R code, which can be run in IDEs (Integrated Development Environments) such as Rstudio and Visual Studio, the tool requires a partially user-defined input Excel spreadsheet ("H2hub_input.xlsx") and GIS (Geographic Information System) shapefiles located in the "Geodata" folder. The "Geodata" folder includes polygon shapefiles for regions, utilities, senate, congressional, and assembly districts obtained from the California State Geoportal Website.

To get started:

<u>Step 1</u>: Preparation of the input data. The input Excel spreadsheet includes six tabs and should be prepared as follows:

1. <u>LCA parameters</u>: Default life cycle inventory including electricity use, water use, and emission factors collected from literature, US DOE H2A model, GREET model, and eGRID. **No user input** is needed in this tab to run the code.

2. <u>TEA parameters</u>: Default capital, electricity costs, water costs and other operation and maintenance costs collected from literature, US DOE H2A model, and HDSAM model. **No user input** is needed in this tab.

3. <u>Producer</u>: Data for each projects including production, liquefaction and/or compression, storage, and transport. **Mandatory user inputs** in this tab are:

   - *Name*: Type project name.

   - *Latitude* and *Longitude*: Type project location in decimal degrees.

   - *H_2 production process*: Type "Alkaline electrolysis", "PEM electrolysis", "Biomass gasification", or "Biomass thermochemical". These inputs are case-sensitive.

   - *Ratio of liquified H_2* and *Ratio of compressed H_2*: Type ratios of produced H2 liquified and/or compressed ranging between 0 and 1.

   - *PV electricity ratio for H_2 production, PPA electricity ratio for H_2 production, Other renewable electricity ratio for H_2 production, PHS electricity ratio for H_2 production,* and *Grid electricity ratio for H_2 production*: Type ratios of various electricity sources used for H_2 production

ranging between 0 and 1. When using multiple electricity sources, user should make sure that the sum of the ratios is 1.

- ○ *Biomass type*: Type "Woody" or "MSW". These inputs are case-sensitive.

- ○ *Biomass consumption*: Type biomass used for H_2 production in in specified units.

- ○ *Biomass emissions avoidance source*: Type "Landfill" or "N/A". These inputs are case-sensitive.

- ○ *H_2 Distribution*: Type "Truck" or "Pipeline". These inputs are case-sensitive.

- ○ *H_2 travel distance*: Type distance liquefied and/compressed H_2 travels via truck and/or pipeline in specified units.

- ○ *H_2 transport cost*: Type cost of transporting H_2 via truck and/or pipeline in specified units.

Among **optional user inputs** in this tab are: *Electrolyzer size, Total uninstalled CAPEX, Stack CAPEX, BoP CAPEX, Liquefier CAPEX, Storage tank CAPEX, Misc. electricity usage, Water consumption,* and *Water cost.* "N/A" should be typed unless project-specific values are known in the specified units.

Apart from the mandatory and optional user inputs, there are **default inputs** (*Labor cost, Electrolyzer maintenance cost, KOH and/or N_2 cost, Liquefier maintenance cost, Natural gas consumption by biomass conversion, Diesel consumption by biomass conversion, Biomass transport and preparation emissions, Biomass conversion maintenance emissions, Soil carbon storage, SO_2 emissions from biomass conversion, NO~x~ emissions from biomass conversion,* and *PM10 emissions from biomass conversion*), which if known by user should be typed in the specified units.

4. <u>Supply</u>: Year-specific average daily hydrogen production data in specified units for each of the producers entered in the "Producer" tab. **User input is mandatory** for this tab to run the code.

5. <u>End-user</u>: Data for each end-user projects. **All inputs are mandatory** in this tab:

- ○ *Name*: type project name.

- ○ *Latitude* and *Longitude*: type project location in decimal degrees.

- ○ *Use type*: type "TRANSIT", "TRUCK", "POWER", or "AVIATION". These inputs are case-sensitive.

- ○ *Fuel type*: type "Natural gas" or "Ultra low sulfur diesel". These inputs represent the type of fuel avoided by H_2. These inputs are case-sensitive.

6. <u>Demand</u>: Year-specific average daily hydrogen demand data in specified units for each of the endusers entered in the "Enduser" tab. **User input is mandatory** for this tab to run the code.

<u>Step 2</u>: Open the code in an IDE and set the directory for the input Excel spreadsheet and shapefiles folder so that the code can pull the data for analysis and modeling.

<u>Step 3</u>: Run the code. Note that after the first run, installing the packages is not required and can be deactivated by putting "#" in front of the "install.packages()" to make the later runs quicker.

<u>Step 4</u>: Once the code run is complete, the results will be saved in the same directory under the "Results" folder (note that the existing files will be replaced by newer files with each run. Hence, change the name of the main folder if needed for later comparison):

1. <u>District_results.xlsx</u>: This spreadsheet includes a summary of the environmental and economic impacts, categorized into senate, congressional, and assembly districts and producers and end-users.

2. <u>Producer</u>:

   a. <u>Emissions_CO2</u>: Net CO_2 emissions from feedstock preparation, H_2 production, H_2 compression and/or liquefaction, and H_2 transport.

      i. <u>Regional_CO2_emissions.jpg</u>: Map with regional CO_2 emissions.

      ii. <u>Temporal_CO2_emissions.jpg</u>: Plot with temporal CO_2 emissions.

      iii. <u>Breakdown_CO2_emissions.jpg</u>: Plot with breakdown of CO_2 emissions.

   b. <u>Emissions_other</u>: Other criteria emissions from feedstock preparation, H_2 production, H_2 compression and/or liquefaction, and H_2 transport.

      i. <u>Regional_SO2_emissions.jpg</u>: Map with regional SO_2 emissions.

      ii. <u>Regional_NOx_emissions.jpg</u>: Map with regional NO_x emissions.

      iii. <u>Regional_PM10_emissions.jpg</u>: Map with regional PM10 emissions.

   c. <u>Costs</u>: Total costs from feedstock preparation, H_2 production, H_2 compression and/or liquefaction, and H_2 transport.

      i. <u>Regional_cost.jpg</u>: Map with regional total costs.

      ii. <u>Temporal_cost.jpg</u>: Plot with temporal total costs.

      iii. <u>Breakdown_cost.jpg</u>: Plot with breakdown of total costs.

3. <u>Enduser</u>:

   a. <u>Emissions_CO2</u>: Net CO_2 emissions avoided by endusers.

      i. <u>Regional_CO2_avoided.jpg</u>: Map with regional CO_2 emissions.

      ii. <u>Temporal_CO2_avoided.jpg</u>: Plot with temporal CO_2 emissions.

      iii. <u>Breakdown_CO2_avoided.jpg</u>: Plot with breakdown of CO_2 emissions.

   b. <u>Emissions_other</u>: Other criteria emissions avoided by endusers.

      i. <u>Regional_SO2_emissions.jpg</u>: Map with regional SO_2 emissions.

    ii. <u>Regional_NOx_emissions.jpg</u>: Map with regional NO_x emissions.

    iii. <u>Regional_PM10_emissions.jpg</u>: Map with regional PM10 emissions.

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