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Abstract Submission

PROGRAM TOPIC AREAS:
CLEAN HYDROGEN

Exact Title of Paper:

Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends with Washed and Unwashed Legacy Coals and Other Waste Fuels to Generate White Hydrogen

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Abstract:
The objective of this effort, primarily funded by the United States Department of Energy (DOE), and led by the Electric Power Research Institute, Inc. (EPRI), with support by Hamilton Maurer International (HMI) and Sotacarbo S.p.A. (Sotacarbo), has been to qualify coal, biomass, and plastic waste blends based on performance testing of selected fuel pellet compositions in a pilot-scale updraft moving-bed (UDMB) gasifier. The testing provided relevant data to advance the commercial-scale design of the moving-bed gasifier to be able to successfully use these feedstocks to produce hydrogen. In particular, the effects of waste plastics on feedstock development (i.e., blending and pelletizing) and the resulting products (i.e., syngas compositions, organic condensate production, and ash characteristics) are the focus. The gasifier used for testing is HMI's moving-bed gasifier, which has been proven capable of gasifying nearly all coal ranks. It has also shown the ability in prior testing work to gasify wood chips (biomass). However, mixtures of these fuels with plastic wastes have not been prepared and gasified together. The three feedstocks were densified and pelletized by California Pellet Mill (CPM) to meet the feedstock size required by Sotacarbo's 30mm ID UDMB gasifier, under contract to HMI.

The technical tasks and results from this two-year research project included:
(1) Feed Procurement and Preparation: Nine different tri-fuel pellets were prepared from varying compositions of fresh mined PRB coal, corn stover biomass, and car fluff waste plastics. Tri-fuel pellets were produced by CPM and shipped to Sotacarbo's test facility in Carbonia, Sardinia, Italy.
(2) Test Plan Development: A test plan was created to define the test runs to be performed. The test plan detailed the different UDMB gasification tests to be performed in Sotacarbo's 12-inch ID pilot scale gasifier, the process monitoring instrumentation used, and the extractive samples recovered for analysis of the total gasification process mass and energy balance.
(3) Gasifier Testing: Nine different gasification runs were performed in the pilot-scale gasifier at Sotacarbo using nine different fuel feedstock compositions generated from varying mixtures of PRB coal, biomass, and plastic wastes. The testing generated performance data on gasification reaction efficiency and performance, yielding relevant data for models used to scale up the gasifier design. This task also included work to refurbish and reassemble the pilot gasifier at Sotacarbo and perform a baseline 100% PRB coal run.
(4) Data Analysis and Reporting: Review of the data, determination of figures of merit, and interpretation of the results are reported in the project's final report, published in March 2024. The results show that all tri-fuel pellets gasified well and maintained structural integrity throughout the gasification process. The syngas generated can be shifted to hydrogen by using commercial syngas shifting technologies.
(5) High Fidelity computational fluid dynamics (CFD) Simulation: The National Energy Technology Laboratory (NETL) team performed CFD simulations of the UDMB gasifier for two of the tri-fuel pellets gasified in Sotacarbo's pilot scale gasifier. The kinetic mechanisms for the pyrolysis of each constituent, PRB coal, corn stover biomass, and waste plastics are based on thermogravimetric analysis performed by Sotacarbo. The gasification model was validated by comparing the predicted syngas composition at the exit of the gasifier with the measured syngas composition. In addition, the reactor's measured internal temperature profile agreed well with the predicted internal reactor temperature profile. These results validate that the model can be used to predict the performance of the updraft moving bed gasifier for different feedstocks and operating conditions.

This paper summarizes the results of the completed work in which the pelletizing procedure was validated to ensure the viability of the tri-fuel pellets for the gasification runs performed at Sotacarbo's 30 mm UDMB gasifier. The gasification performance data from this series of nine runs will enable modeling of a full-scale HMI industrial scale gasifier supporting both combined heat and power, and Hydrogen production from coal (both fresh mined and legacy) combined with various biomass and waste plastics. Additionally, plans and progress on a follow-up project, being executed by the same project team, will be presented. In this project, a total of twenty (20) different feedstocks are being prepared from varying compositions of biomass (both woody biomass and corn stover) with a mixture of legacy coal waste, plastic waste, and refuse-derived fuel (RDF). The testing will provide information on gasification reaction efficiency/performance, yielding relevant data for models used to scale up the gasifier design to 50 megawatt electric (MWe) (equivalent hydrogen production). Tests will also be performed on a bench-scale fluidized-bed gasifier for comparison purposes. The results of this testing will be used to specify the range of feedstock blends that can be successfully gasified as well as quantify gasifier outputs based on specific blends.

Performance Testing of a Moving Bed Gasifier Using Coal Biomass and Waste Plastic Blends with Washed and Unwashed Legacy Coals

Supported by US Department of Energy Awards DE-FE0032044 & DE-FE0032180

Horst Hack, Technical Executive (Presenting Author)
Electric Power Research Institute

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Project Participants

- Electric Power Research Institute
  - George Booras, Principal Investigator on DE-FE0032044
  - Horst Hack, Principal Investigator on DE-FE0032180
- Hamilton Maurer International, Inc.
  - Rolf E. Maurer, David P. Thimsen, Elijah Thimsen
- Sotacarbo Società Tecnologie Avanzate Low Carbon S.p.A.
  - Alberto Pettinau, Simone Meloni, Gabriele Calli
- National Energy Technology Laboratory
  - Hang Zhou, Yupeng Xu, Mehrdad Shahnam

Project Goals

- Qualify blends of coal, biomass, plastic waste and RDF based on performance testing of selected pellet compositions in a laboratory-scale updraft moving-bed gasifier
- Testing will provide relevant data to advance the commercial-scale design of the moving-bed gasifier to use these feedstocks to produce hydrogen
- Effects of the waste plastics on feedstock preparation (i.e., blending and pelletizing) and the resulting products (i.e., syngas compositions, organic condensate production, and ash characteristics) will be a focus

Two Related DOE-Funded Projects

- **DOE Award Number:** DE-FE0032044 - **COMPLETED**
  - **Project Title:** Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen
  - **Funding:** $625,000 ($500,000 gov't, $125,000 cost share)
  - **Period of Performance:** 7/1/2021 – 3/31/2024
- **DOE Award Number:** DE-FE0032180 - **ONGOING**
  - **Project Title:** Performance Testing to Advance Modular, Moving-Bed Gasification for the Generation of Low-Cost, Clean Hydrogen from Biomass Mixed with Legacy Coal Waste, Waste Plastic, and/or Other Waste
  - **Funding:** $1,410,044 ($1,128,034 gov't, $282,010 cost share)
  - **Period of Performance:** 9/1/2023 – 8/31/2025

Technical Objectives of the Projects

- Prepare pellet feedstocks using biomass (both woody biomass and corn stover) with a mixture of legacy coal waste, plastic waste, and refuse-derived fuel (RDF)
- Qualify feedstocks based on performance testing of selected fuel blend compositions in updraft moving-bed gasifier
- Obtain relevant data to advance the modular design of the moving-bed gasification process, and successfully use these feedstocks to produce a high hydrogen content raw syngas that can be shifted to produce clean hydrogen
- Determine the effects of the various fuels on feedstock development, the resulting products (i.e., syngas compositions, organic condensate production, and ash characteristics), and impacts on gasifier operations

Project Benefits

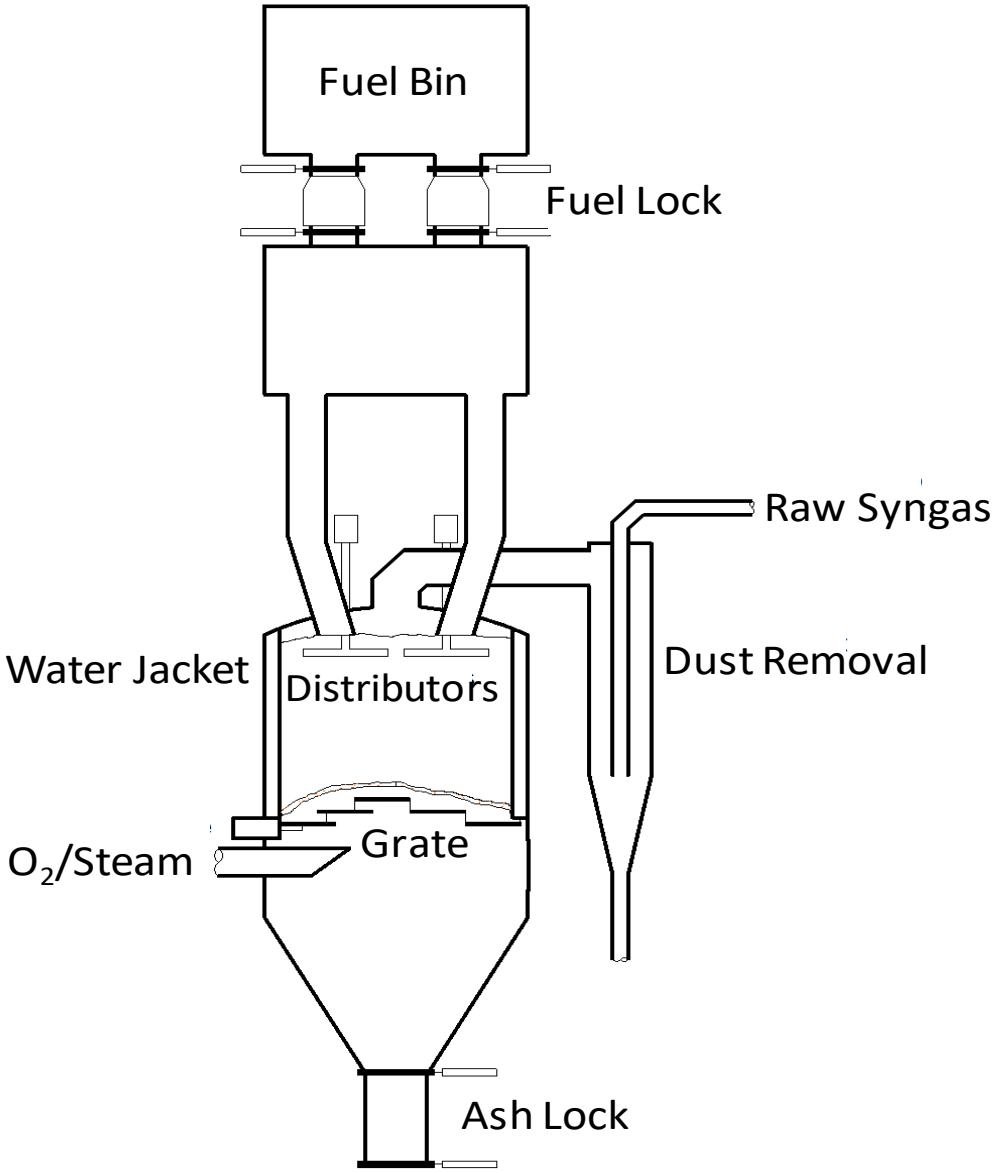
- Enable clean hydrogen production for decarbonization (can be carbon net-negative with biomass)
- Advance flexible modular (5–50 MWe equivalent) gasifier technology using a blended feedstock of biomass mixed with variable loadings of legacy waste coal, waste plastics, refuse derived fuel, and/or other wastes to produce pure H_2
- Improve performance of gasification unit operations with mixed waste feedstocks, including addressing feedstock preparation and feeding, syngas cleanup, and corrosion
- Demonstrate beneficial use of waste normally sent to landfills

Project Team Organizations

Electric Power Research Institute (EPRI)	• Prime, lead organization, overall Project Management and Administration • Test Plan Development, Market and Industry Review,, and Co-Lead on Cost & Performance Study
Hamilton Mauer International (HMI)	• Gasification technology developer • Lead Fuel Procurement & Prep, Data Analysis & Reporting
NexantECA	• Engineering consulting company • Co-Lead on Cost & Performance Study
Sotacarbo	• Gasifier testing facility • Lead Gasifier Testing and support Test Plan Development and Data Analysis & Reporting

HMI Moving-Bed Gasifier

- This moving-bed gasifier can gasify nearly all coal ranks as well as biomass (peat, wood)
- Testing suggests that gasifier is suited for corn stover
- As the fuel descends, it is dried, devolatilized, and the resulting char is gasified
- Ash is removed through a grate and collected in a lock hopper for removal
- The CO_2 produced by combustion and the steam from the blast react with the char in the gasification zone to produce CO and H2
- Streams leaving the gasifier are ash out the bottom and dry gas/tar/water vapor/dust out the top



Sotacarbo Test Facility

- Pilot-scale gasification at Sotacarbo's research facility in Italy
- Gasifier has experienced over 2000 hours of operation (2008, 2016, & 2023)
- This facility includes 12" (30.5 cm) ID, refractory-lined, moving-bed gasifier
- Gasifier operates with an air/steam blast at flow rates typical of commercial-scale moving-bed gasifiers corrected for fixed carbon content
- Testing uses air as the oxidizing medium diluted with steam to manage ash agglomeration in the combustion zone of the gasifier

Target Fuel Blends for 1st Round of Tests (Completed)

- Biomass is corn stover
- Coal is Powder River Basin (PRB) subbituminous
- Plastic waste is auto-shredder residue (ASR), a.k.a. “Car Fluff” provided by OmniSource
- Pellets were produced by CPM at their test facility in Waterloo, IA

Feed % Based on Heat Input

No.	Biomass	Coal	Plastic
1	0	100	0
2	25	75	0
3	25	56	19
4	25	38	38
5	40	60	0
6	40	45	15
7	40	30	30
8	60	40	0
9	60	30	10
10	60	20	20

Feedstock Supply

- Corn stover supplier was identified in Nebraska
  - Stover was chopped to minus 1” (2.5 cm) before delivery to CPM
- Peabody provided PRB coal from their North Antelope Rochelle mine near Gillette, WY
  - Three supersacks of PRB coal were delivered to CPM
- OmniSource provided 2 tons of ASR from Indianapolis and 2 tons from Toledo
  - As-received ASR had much larger pieces than anticipated, and was shredded to -1/2” (1.3 cm) before delivery to CPM
  - After shredding, ASR still contained small fragments of metals and wire
  - Additional pre-treatment of the ASR was required

Additional Pre-Treatment of ASR

- Ball milling of ASR was used to reduce size of the ASR and metal particles to prevent damage to CPM's pelletizing die
  - Ball mill had 40-gauge mesh screens (0.015" [0.4 mm] opening)
- Ball milling of ASR was required to produce ¼ inch pellets for lab scale gasifier operation. Ball milling would not be required to densify the three fuel components for a commercial scale gasifier

Ball-milled ASR -40 mesh (left), +40 mesh (right)

Tri-Fuel Pelletizing Tests Were Successful

- Pelletizing tests at CPM were conducted from July 18–25, 2022
- Pelletizing 100% PRB was not successful (will use lump coal for baseline)

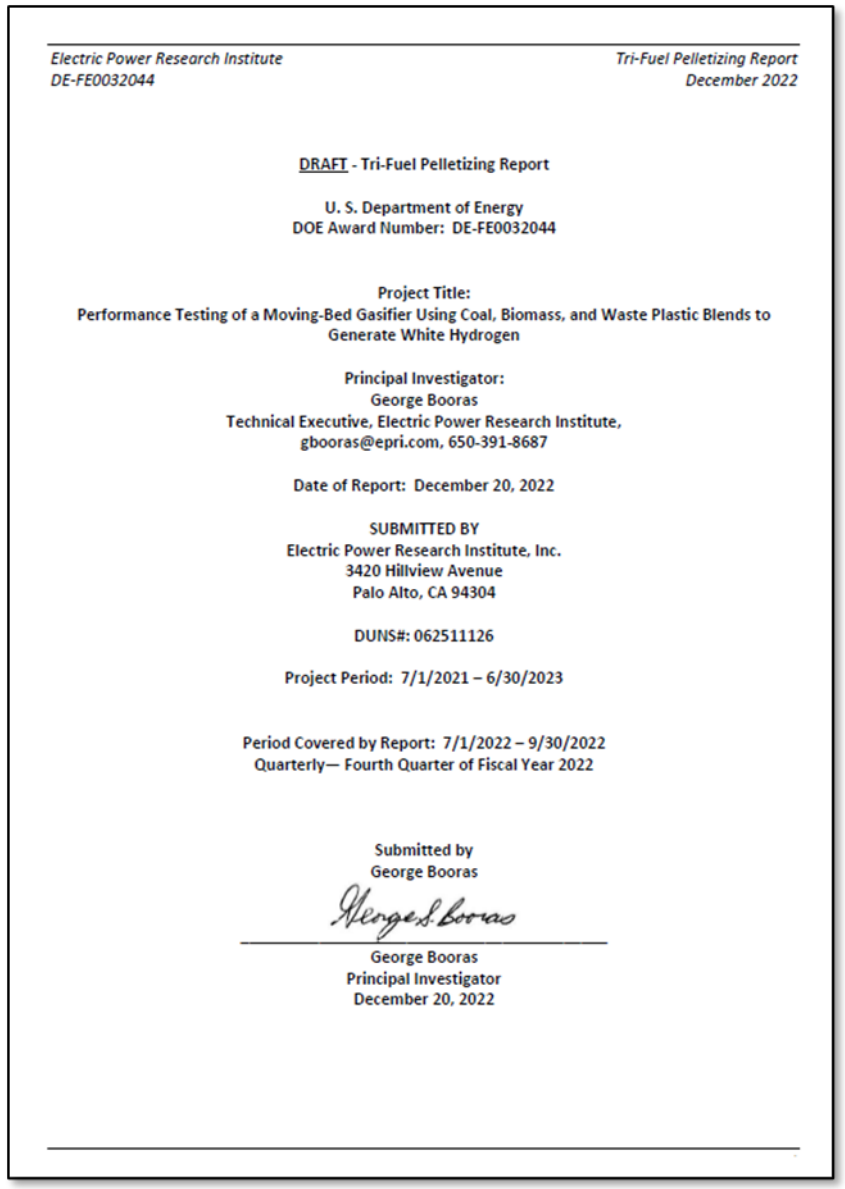
Recipe 3 (left) and Recipe 7 (right)

Close-up of pellets

Pelletizing head open. See the pencils sticking out of the die.

Weighing pellet sample for Pellet Durability Index test

Pelletizing Report: Final Tri-Fuel Pellet Formulations Produced



Electric Power Research Institute
DE-FE0032044

Tri-Fuel Pelletizing Report
December 2022

DRAFT - Tri-Fuel Pelletizing Report

U. S. Department of Energy
DOE Award Number: DE-FE0032044

Project Title:
Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen

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Date of Report: December 20, 2022

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Project Period: 7/1/2021 – 6/30/2023

Period Covered by Report: 7/1/2022 – 9/30/2022
Quarterly— Fourth Quarter of Fiscal Year 2022

Submitted by
George Booras

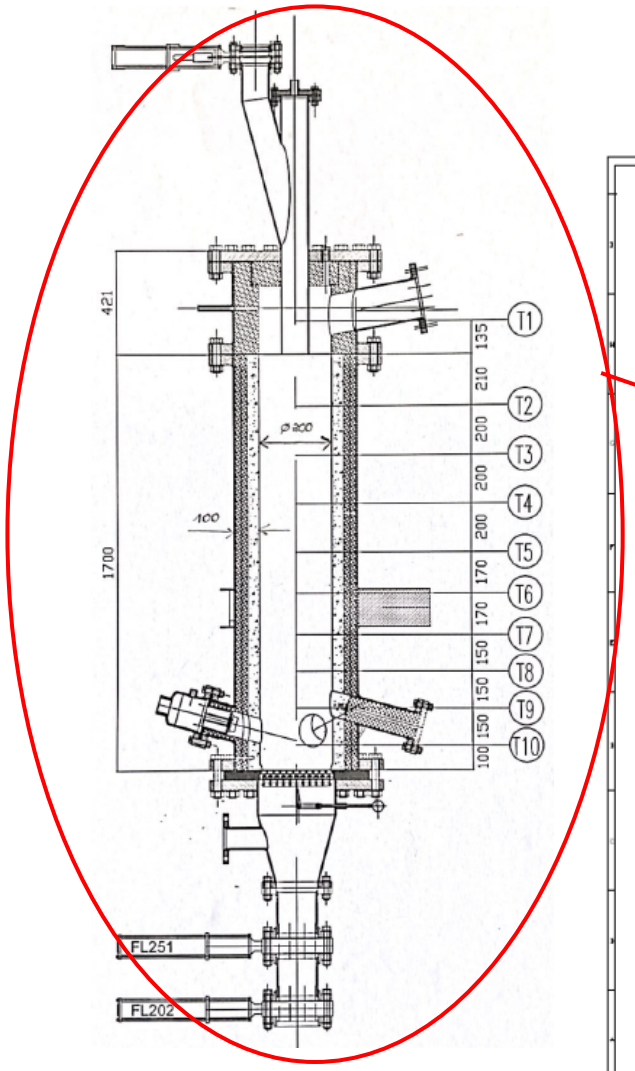
George Booras
Principal Investigator
December 20, 2022

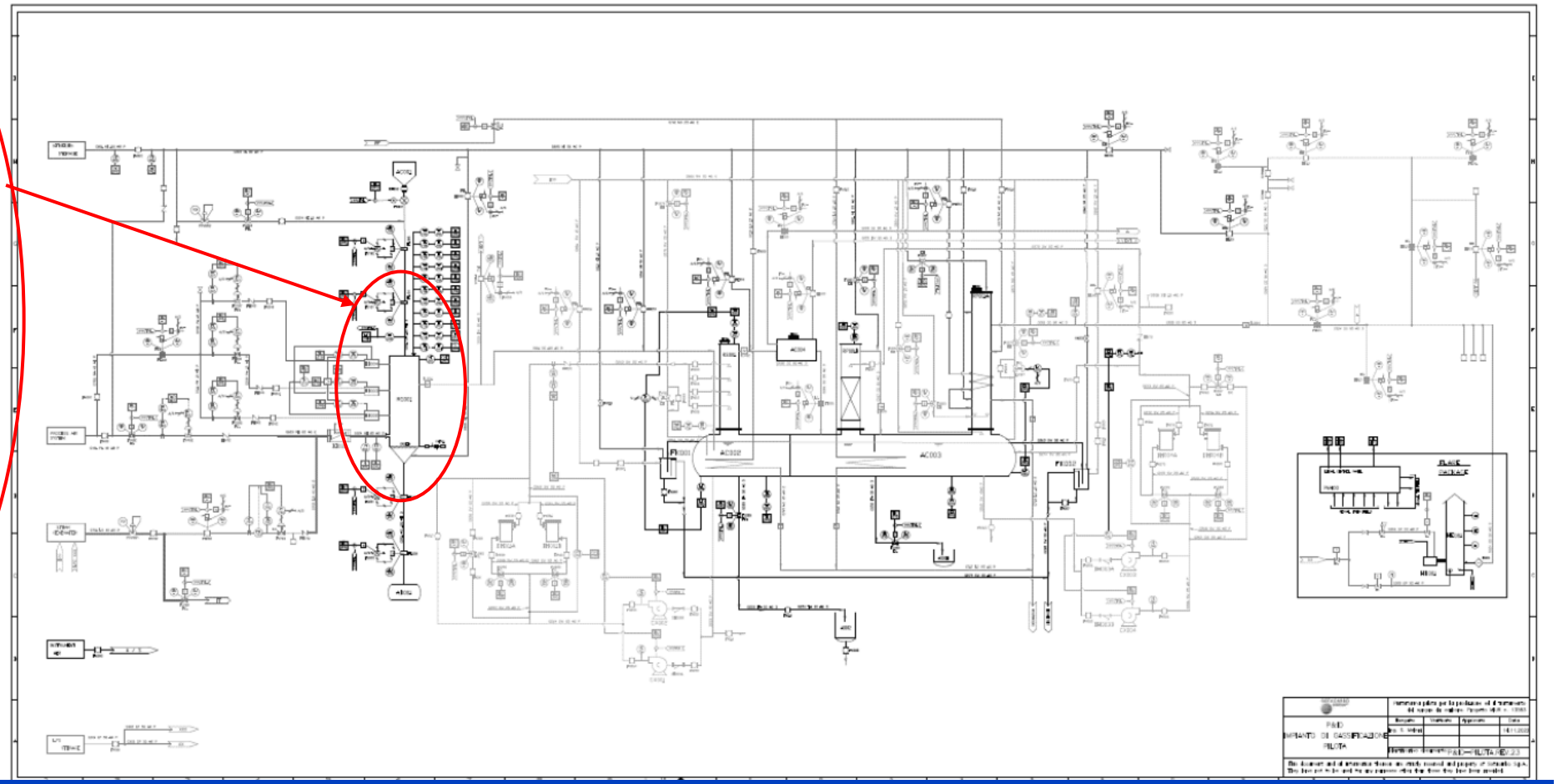
weight %, as-received

Formulation	Corn Stover	Coal	ASR (*)
1		100%	
2		69%	31% (**)
3	31%	53%	15%
4	32%	36%	32%
5	47%		53%
6	48%	40%	12%
7	49%	27%	24%
8		50%	50% (***)
9	67%	25%	7%
10	68%	17%	15%

(*) -40 mesh unless otherwise indicated
(**) ASR component was 28% + 40 mesh, 72% -40 mesh
(***) ASR Component 100% +40 mesh

PFD for Sotacarbo 12” Inner Diameter (ID) Gasifier





One Test Run Per Week – Achieve Steady State Operation

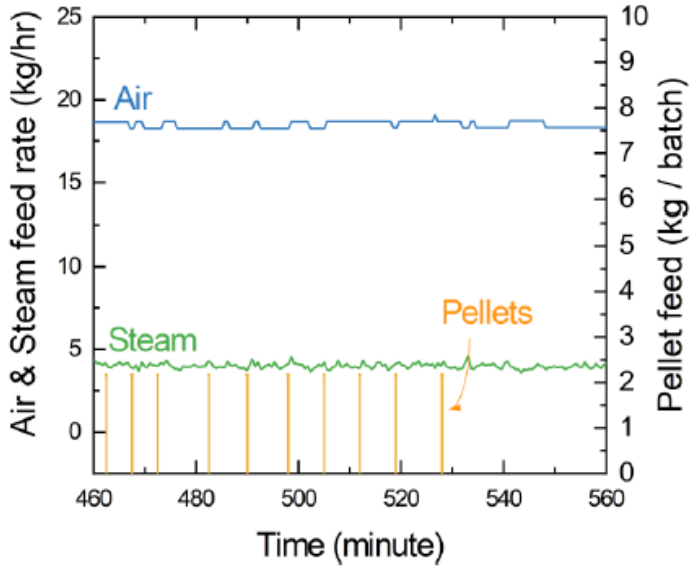
Feeding Hopper and Ceramic IR-radiators of the ignition system

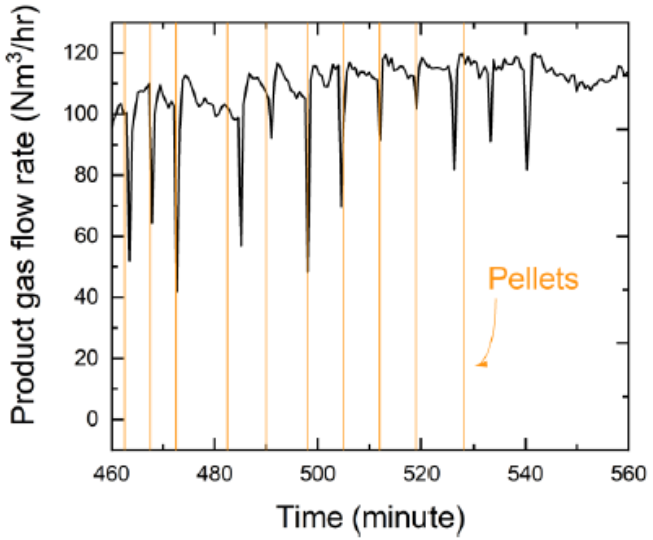
Lessons Learned from Shake Down Testing

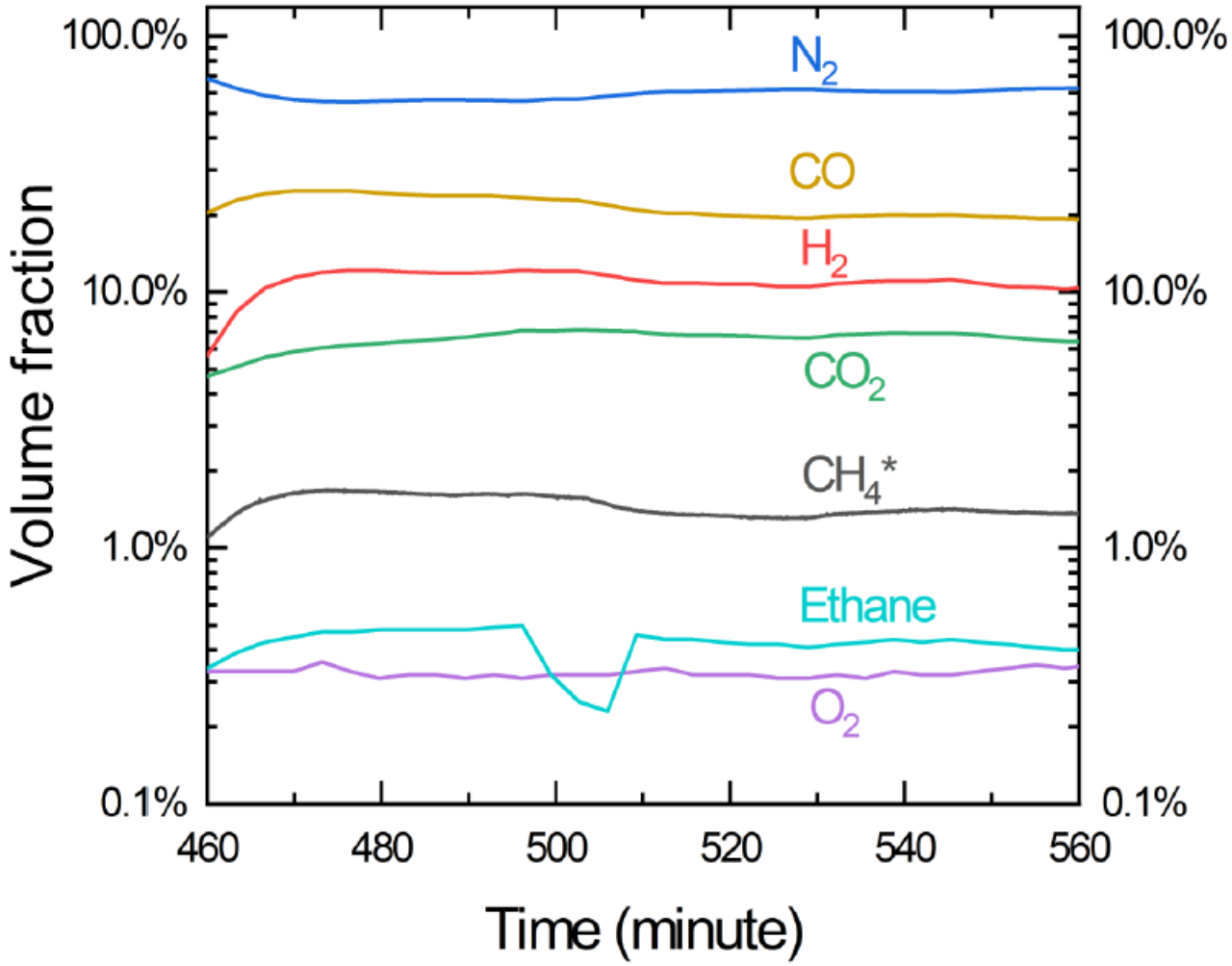
- Nitrogen inerting during pre-startup no longer required
- Pre-heating system (~3 hours) while gasifying charcoal minimizes tar/dust deposition throughout operation
- Frequency of lock-hopper fuel feeding being studied to optimize steady state operation
- Optimizing air/steam flow to maximize steady state operation for up to 5 hours

White Smoke From Vent Confirmed Ignition of the Gasifier

Preliminary Results from May 10 Testing of Pellet #6*







Syngas Composition

H_2	~10%
CO	~20%
CO_2	~6%
CH_4	~1.5%
Ethane	~0.5%
N_2	~60%

* Pellet Formulation #6 = 48% corn stover, 40% PRB coal, and 12% ASR

Key Accomplishments of Completed Testing

- Successfully produced durable tri-fuel pellets containing various mixtures of PRB coal, corn stover biomass, and ASR waste plastic
- Ocean shipped nine barrels of pellets and one barrel of PRB to Sotacarbo
  - Durability of pellets was not adversely impacted by shipment and storage
- Completed gasifier shake-down testing, PRB run, and all pellet runs
- Demonstrated basic gasification process for a wide range of pellet compositions
  - The gasification process is robust and will gasify the tri-fuel pellets
  - There was no agglomeration due to plastics in pellets
  - Stable char was produced in devolatilization zone, with sufficient compressive strength to support an overhead fuel column of 1 meter without crushing to powder

Made continuous improvements to gasification process and procedures

Recommendations from Completed Testing

- Some Sotacarbo equipment modifications may be required to improve the test operation and reliability of results.
  - Additional instrumentation would allow better quantification of tar loading in the product gas.
  - Continuous analysis of trace components such as H_2S, CH_3SH, C_2H_3Cl, and COS would improve understanding the impacts of increasing ASR content of the feed pellets
- Commercial-scale gasification of tri-fuel mixtures requires fuel lumps of a nominal 1”-2” size (25-50 mm). A low-cost, effective means of producing durable tri-fuel lumps in this size range needs to be qualified.

Long term goal is production of hydrogen from tri-fuel mixtures

Key Tasks in Follow-up Project - ONGOING

1. **Feed Procurement and Preparation:** Twenty (20) different feedstocks will be prepared from varying compositions of biomass (both woody biomass and corn stover) with a mixture of legacy coal waste, plastic waste, and refuse-derived fuel (RDF).
2. **Test Plan Development:** Creation of a test plan to define the test runs to be performed – with equipment upgrades at Sotacarbo. The test plan will detail the different tests to be run, instrumentation to be used, extractive samples to be taken, and the relevant figures of merit and how they should be calculated.
5. **Gasifier Testing:** Tests will be performed in the laboratory-scale and bench-scale moving-bed gasifier using 20 different biomass mixtures with legacy coal waste, plastic waste, and RDF.
6. **Cost and Performance Study:** Techno-economic study on the commercial-scale moving-bed gasifier with post-combustion capture designed for clean hydrogen generation from blended fuels.
7. **Market and Industry Review:** Review of the potential market and the energy industry's interests for the moving-bed gasifier and its application for generating clean hydrogen from blended fuels.
8. **Data Analysis and Reporting:** Review of the data, determination of figures of merit, and interpretation of the results to be reported. The results will be used to specify the range of feedstock blends that can be successfully gasified as well as quantify gasifier outputs based on specific blends.

Test Fuel Blends for 2nd Round of Tests (Mass Percentages)

Run	Biomass		Legacy Coal Wastes		Wastes	
	Wood Chips	Corn Stover	Raw	Washed	Waste Plastic	RDF
1	100					
2	75				25	
3	75					25
4	50					50
5	50				50	
6	50		25		25	
7	50			25	25	
8	50		25			25
9	50			25		25
10	50		25		12.5	12.5
11	25		25		25	25
12	25			25	25	25
13		100				
14		75			25	
15		75				25
16		50			50	
17		50	25			25
18		50		25		25
19		25	25		25	25
20		25		25	25	25

Key Accomplishments of Follow-up Project

- Completed Technology Maturation Plan (TMP)
- Finalized fuel selection and pellet formulation
- Identified fuel sources for all proposed pellet formulations
- Confirmed change of waste plastic from auto shredder residue (ASR) to wire insulation tailings
- Finalized agreements with pelletization and transport vendors
- Shipped the fuels to holding warehouse
- Incorporated learnings from recently completed gasification testing at Sotacarbo facility (DE-FE0032044)
- Developed plans for key equipment upgrades at Sotacarbo test faculty to improve operations and quality of test results

Acknowledgment and Disclaimer

- **Acknowledgment**: This material is based upon work supported by the Department of Energy under Award Number DE-FE0032044.
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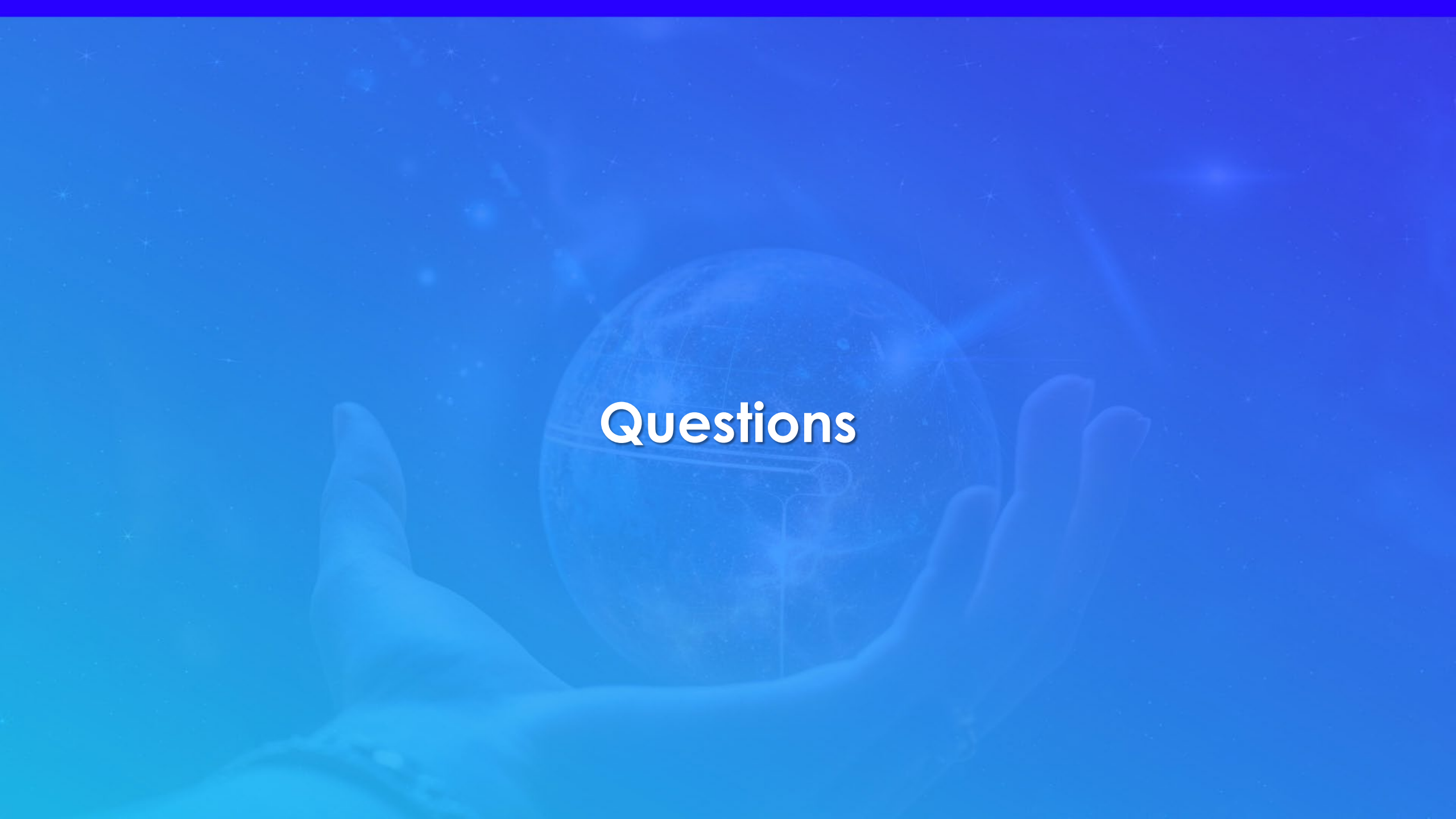
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