

# DOE-ID NEPA CX DETERMINATION

## Idaho National Laboratory

### **SECTION A. Project Title:** Achieving High Operating Reliability for Continuous Feeding of Biomass into a High Pressure Reactor

### **SECTION B. Project Description and Purpose:**

The U.S. Department of Energy (DOE) has selected Idaho National Laboratory (INL) to receive funding through the Feedstock-Conversion Interface Consortium (FCIC) Directed Funding Opportunity to address technical risks and understand how biomass properties influence preprocessing and conversion technologies in collaboration with Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), Red Rock Biofuels Holdings, Inc. (RRBH), Forest Concepts, LLC (FC), and Frontline Bioenergy (FB).

This project will improve operational reliability of high pressure, high-temperature conversion systems using woody feedstocks. This will be accomplished by characterizing feedstock properties and variance thereof to elucidate the relationship between these properties and performance in comminution, feeding, and high-temperature conversion reactors. This will improve day-to-day operational reliability for RRBH while furthering the understanding of how feedstock conditions impact the technologies of FC and FB. Finally, this work will provide a significant amount of information that will contribute to improved operational reliability in the broader industry.

The purpose of this work is to improve operational reliability of continuously fed reactors and will result in valuable data that can be used to develop cost-benefit analyses to inform equipment selection and operation for given feedstock types and variability and process parameters for high-temperature conversion plants. This type of information is currently lacking in the bioenergy economy.

#### Reasons for Cooperation:

INL is the nation's leading laboratory for bioenergy feedstock research and is focused on identifying and addressing barriers associated with efficiently, economically, and sustainably supplying large quantities of quality feedstock to future biorefineries. This effort includes improving feedstock preprocessing technologies, understanding feedstock variability and its implications on conversion processes, feedstock supply system design and analysis, and bench-pilot-scale equipment design and testing. In addition, INL has worked with more than a dozen biofuel, biopower, and waste-to-energy technology developers and has produced more than 5,000 tons of feedstock in support of biofuel research, development, and demonstration. INL's onsite biomass characterization laboratory quantifies chemical, physical, and macro feedstock properties. This project will advance INL's goals for the Biomass National User Facility (BFNUF) and PDU, strengthen industry relationships, and enhance the chemical preprocessing unit in the PDU.

RRBH is developing refineries in the United States to convert woody and herbaceous residues to drop-in fuels via thermochemical conversion. RRBH will provide feedstock specifications and act as an endpoint conversion partner. This work will inform equipment selection and operating practices at a new biorefinery operated by RRBH and subsequent biorefineries developed, engineered, constructed and/or operated by RRBH and its affiliates.

ORNL has the leading materials expertise and state-of-the-art facilities in alloying and surface engineering, wear and corrosion testing, and materials characterization. Specifically, the well-equipped tribological testing and analysis labs allow investigating and addressing of various wear and erosion issues including 2-body and 3-body abrasion, rolling-sliding, fretting, and impact wear in dry, wet, and lubricated conditions in controlled temperatures and gas environments. In addition, the rich experience in corrosion allows dealing with the combined wear and corrosion issues and alloying and surface engineering capabilities provide potential solutions to solve the wear and corrosion problems. This project will strengthen ORNL's role and contributions to FCIC and the biomass energy economy.

NREL's Integrated BioRefinery Facility (IBRF) is a state-of-the-art partnering facility for researching and piloting advanced concepts for biochemical cellulose-to-fuels-and-chemicals conversion. It comprises over 30,000 ft<sup>2</sup> of high bay area, including space for industry partners to bring in and test specific equipment in integrated biorefining operations, as well as world class supporting analytical and bench-scale research laboratories. This project will advance NREL's goals for understanding biomass behavior in conversion systems and strengthen industry relationships.

FC is a biomaterials producer and technology development company with unique expertise in feedstocks preprocessing and reactor-ready feedstocks. The core competencies of the company include plant structural biology, biosystems engineering, and industrial process development. FC will use its existing rotary shear, screening technologies and equipment where possible. Initially they will utilize existing Crumbler® rotary shear machines to process feedstocks at their facility to determine optimum feedstock properties with conversion team members. This project will serve to further FC's understanding of the performance of their Crumbler® technology as a formatting and preprocessing option for feedstocks in the bioenergy economy.

FB has continued to develop its gasification, gas cleaning, and gas conditioning technologies to offer solutions that are practical, cost-effective, efficient and reliable. FB gasification solutions are appropriate for producing renewable fuels via catalytic or fermentation processes, making renewable energy with combustion turbines, or re-powering existing utility boilers with biomass or waste fuels. FB's engineering and support staff combine expert-level knowledge with firsthand field experience. The result is a practical approach to robust engineering design and development.

#### Objective

This project will improve operational reliability of high pressure, high-temperature conversion systems using woody feedstocks. This will be accomplished by characterizing feedstock properties and variance thereof to elucidate the relationship between these properties and performance in comminution, feeding, and high-temperature conversion reactors. This will improve day-to-day operational reliability for RRBH while furthering the understanding of how feedstock conditions impact the technologies of FC and FB. Finally, this work will provide a significant amount of information that will contribute to improved operational reliability in the broader industry.

In addition, long term operational reliability will be addressed by understanding how feedstock properties relate to abrasion and wear, thus informing the optimal feedstock critical quality attributes (CQAs), as well as the development of potentially beneficial equipment coatings.

It is also recognized that feedstocks cannot be selected and preprocessed only for the purpose of improving handling and feeding with respect to operational reliability without considering impacts on conversion performance and product yields. For this reason, parallel studies will be performed that evaluate the effect of feedstock selection, variability, and preprocessing on conversion.

This approach will result in valuable data that can be used to develop cost-benefit analyses to inform equipment selection and operation for given feedstock types and variability and process parameters for high-temperature conversion plants. This type of information is currently lacking in the bioenergy economy.

#### Task Descriptions and Deliverables

##### Task 1 – Feedstock Fundamentals and Variability (INL, RRBH, FC)

###### Subtask 1.1 – Characterization of Feedstock Properties and Variability (INL, RRBH, FC)

RRBH will supply chipped forest residues (2-inch to 3-inch nominal) to INL and FC for the duration of the project. These feedstocks will fall into one of two categories; A) feedstocks for parametric comminution and conversion testing and B) feedstocks for a series of isolated, non-parametric tests that will serve to test the findings of the parametric studies, and provide RRBH with specific information on unique feedstock conditions that may occur in their operations. For the parametric studies, RRBH will provide at least six tons of material each to INL and an additional 2 tons of material to FC. For the non-parametric tests, RRBH will provide at least 300 pounds of material each to INL and per condition tested, and at least 100 pounds of material to FC per condition tested. The amount of materials described here will satisfy the requirements for the tests performed in the comminution testing, feed testing in INL's CPS, and the conversion testing. However, additional material will be required for feed testing in RRBH's commercial system and any additional systems that RRBH and INL select for testing. These amounts will be determined at the conclusion of Task 2.1.

The feedstock for the parametric testing will be representative of the biomass available to RRBH for their operations. This will consist of chipped whole trees. These trees will be softwood pines of indiscriminate species (likely lodgepole pine, ponderosa pine, or douglas fir) from RRBH contracted suppliers. The primary feedstock variable will be moisture content, and each of 1) low-moisture, 2) high-moisture, and 3) mid-moisture material will be supplied to INL and FC in parallel. Approximately two tons of each will be supplied to both INL and FC. The mid-moisture material will be approximately 30 – 35 wt% moisture, which is near the saturation content for moisture in softwoods. The low- and high- moisture materials will be below and above the saturation point, respectively. The low-moisture material will be approximately 10 wt%, which is near or below the point where feeding through a plug pipe becomes difficult to impossible, but is still relevant to the likely lower-end moisture feedstocks that may be provided by forest feedstock suppliers to RRBH. The high-moisture material will be approximately 50 wt% moisture, which is typically feedable through plug pipe systems, but is likely to size reduce to a different extent than the low- and mid-moisture material.

In addition, RRBH may provide more unique feedstock types/conditions for additional studies outside of the parametric tests. These exact conditions will be identified later but will be limited to 10 conditions. Examples may include material that is frozen, heated through storage, degraded, blends of dry and wet material, material that has been manually re-wetted, and mill residues (saw dust). The amount of these feedstocks to be supplied will not exceed one ton each. Each material supplied in this task will be characterized at INL with respect to moisture content, particle size distribution, bulk density, total ash, ash composition, and anatomical composition. The material will be stored by INL and FC under dry, stable conditions.

##### Task 2 – Influences and Control of Comminution (INL, FC, RRBH)

###### Subtask 2.1 – Parametric Study to Identify Effects of Feedstock Properties and Operating Conditions during Comminution (INL, FC, RRBH)

Parametric studies will be performed in parallel at INL and FC. INL will utilize a hammer mill and FC will utilize their rotary shear Crambler®. With each piece of size reduction equipment, parametric studies will be performed with the three feedstock conditions described in Task 1.1. A 33 matrix of operating conditions will be tested with respect to moisture content, throughput, and screen size, resulting in 27 test conditions. The exact tip speed and throughputs to be tested will be decided by INL, RRBH, and FC at the beginning of the project. Further, at a moisture content considered to be median by RRBH, a 32 matrix will be performed with respect to tip speed and throughput, resulting in an additional 9 tests conditions, resulting in a total of 36 test conditions. Each of these tests will be performed with at least 100 pounds of material. Using their industrial hogmill, RRBH will perform comminution tests on select conditions that span the matrix tested by INL and FC. The number of conditions tested by RRBH must be sufficient to gather comparative data between the hogmill, hammermill, and Crambler®. This will likely require at least 18 tests using material delivered by their contractors. The specific design of these experiments will be informed by the application of Plackett-Burman and Box-Behnken experimental design.

In addition, tests on the specific, one-off, feedstocks agreed upon by INL, NREL, RRBH, and FC will be performed to compare with the results from the parametric studies. During these tests, the power consumption data will be collected from each piece of equipment, and the moisture content, bulk density, and particle size distribution of the resulting fractions will be measured. Furthermore, a suite of bulk properties will be collected that will leverage the experimental data produced at INL, which includes index characterization, shear tests, compressibility measurements, particle size/shape analysis, and oedometer tests.

Finally, building on previous efforts initiated by FC, the feedstock properties will be compared against the forces of comminution to better understand the relationship between regimes of comminution as a function of applied forces, particle size properties, and energy consumption for a given set of CQAs.

###### Subtask 2.2 – Effect of Feedstock Properties, Variability, and Comminution on Feeding Behavior (INL, RRBH, FB)

At least 18 select samples across the matrix from Task 2.1 will be selected for further testing in INL's 4-inch screw feeder. In addition, up to 18 tests may be performed by an outside vendor using a 5-inch FB system (GranBio, Thomaston, GA), and at RRBH's Lakeview plant on their commercial FB system. This will result in 3 sizes to scale across (4-inch, 5-inch, and RRBH's 19-inch system).

To perform these tests, between 50 (4-inch) and 1,000 (19-inch) pounds will be fed at steady-state, as determined by steady energy consumption and torque measurements. The screw feed rate and hopper feed rate will each be set at a nominal setting and varied up and down to identify effects of operating

condition. RRBH and INL technical staff will observe the operation and failures of each of the plug screw feeders tested to gather analytical and empirical data to better understand how material feeding properties may scale across different systems.

Parameters, including the torque exerted by the screw feed, power consumed by the screw feeder, and weight and volume of the liquid pressed out of the feedstock by the screw feed, will be logged to determine plug formation efficiency or lack thereof. In addition, the liquid pressate will be refrigerated until it is analyzed for inorganic, total dissolved solids, and sugar content.

In addition to the screw feeder tests, a customized and adjustable flow hopper at INL will be used to quantify the flow of feedstock into the feeding system. This pilot scale semi-continuous system (up to roughly 2.5m hopper/bin material height) is instrumented and designed to be flexible to operational geometry by adjustment to the hopper discharge area (length and/or width), hopper/bin liners or inserts, and hopper wall semi-angle. In addition, the system can apply vertical or radial stresses before flow inception to simulate much larger system scales during material charging or discharge. Important verification parameters measured include the critical arching distance (minimum geometric constraint for gravity driven flow), dynamic wall stresses that relate to the stresses in the bulk material, discharge rate (relating to the overall flow performance as well as the maximum void ratio at a free discharge surface), and material profilometry inside the hopper/bins. Capturing these phenomena in the flow simulations will provide significant data relating the impact of feedstock properties, including those impacted by comminution at different conditions, to feed and handling behavior.

#### Subtask 2.3 – Application of Size Separation and Tissue Fractionation to Achieve CQAs for Processing and Conversion (INL, RRBH, FC)

The results of Tasks 2.1, 2.2, 3.2, and 3.3 will inform CQAs for the feedstock downstream of preprocessing. Based on these findings, a more robust set of preprocessing technologies including, size separation, tissue fractionation, and air classification, will be applied to identify a set of preprocessing unit operations and/or operating conditions that can deliver the necessary CQAs from the available initial feedstock conditions. It may also be the case that certain initial feedstock conditions are ruled out due to overly onerous preprocessing requirements to bring the feedstock properties within the desired CQAs.

#### Subtask 2.4 – Deliver Material that Meets CQAs to NREL for Conversion Testing and to ORNL for wear and abrasion testing (INL)

An aliquot from each sample produced in Task 2.1 will be ground to pass a 2-mm screen for microwave pyrolysis testing. In addition, the conditions selected for testing in Task 3.2 will be processed to the necessary CQAs for conversion testing at NREL. This material will be delivered to NREL and ORNL at an agreed upon schedule.

#### Subtask 2.5 – Risk Analysis of RRBH Equipment with Respect to Operational Reliability (INL, RRBH, ORNL)

INL researchers will work with RRBH management and operators to evaluate the data collected in Tasks 1, 2, and 4. This data will be analyzed in the context of RRBH's existing equipment, and potential future equipment investments. Through this analysis, a summary of risks specific to RRBH's operations will be developed in parallel with potential mitigations through either feedstock contracting, preprocessing, or operating protocols. In addition, this analysis will be expanded to the broader industry where correlations will be identified between feedstock type, conditions, variability, and preprocessing and the performance of these feedstocks in comminution and feeding systems.

### Task 3 - Conversion Testing of Feedstock Conditions Relevant to Red Rock Biofuels Lakeview Biorefinery (NREL, FB, RRBH, INL)

#### Subtask 3.1 - Conversion Screening using Microwave Pyrolysis (INL)

Over the last several years, INL has developed and implemented rapid feedstock screening for thermochemical conversion with NREL under the high-temperature conversion interface using a microwave enhanced fast pyrolysis (MEFP) reactor. These efforts have assisted with QA/QC of relative product quality and yields to down-selecting feedstocks for high-temperature conversion demonstration at NREL. This task will be investigated with the use of the MEFP reactor at INL in coordination with efforts at NREL to assess the relevant conversion systems. The MEFP system at INL will be used to screen relevant preparations of materials being considered for operation at RRBH, specifically, aliquots of the materials produced in Tasks 2.2 and 2.3 will be tested using MEFP. Material attributes of moisture content, tissue type, and particle size metrics will be assessed for criticality with respect to conversion performance. In addition to screening tissue performance, material composition will also be investigated at a few different conditions through size reduction/particle size exclusion at several levels. Conversion quality will be assessed through analytical techniques such as thermal desorption, direct mass spectrometry analysis of vapors, or 2D-nuclear magnetic resonance of the product oil to evaluate distributions between relative product chemical family components. Throughout this process, the data collected using MEFP and INL's micropyrolysis system will be compared to determine the efficacy of microwave pyrolysis as a predictor of larger scale pyrolysis performance.

#### Subtask 3.2 - Conversion Screening to produce biochar and fuel (FB, RRBH)

In connection with the RRBH Lakeview Biorefinery, FB will construct the apparatus illustrated below and produce a biochar representative of the expected biochar produced at the RRBH Lakeview site. These experiments will replicate reactor conditions and the effects of products as a function of feedstock variability. The lab-scale nature of these experiments are intended to have the ability to test an array of feedstock properties and process parameters.

FB will build and operate an lab-scale pyrolysis reactor (Figure 1) to run under conditions specified by RRBH. This lab-scale reactor will be fed feedstocks processed by RRBH, INL and FC to produce fuel and biochar at FB's facility in Nevada, IA. The biomass feedstock to be tested will have similar variability as those anticipated at the RRBH Lakeview biorefinery and operating at pressure (up to 200 pounds per square inch gauge (psig)) and pyrolysis temperature with the apparatus temperature not-to-exceed 815°C. RRBH will guide FB on the various temperature and time conditions that may be applicable at its Lakeview biorefinery, and FB would produce biochar, gas, and liquid samples for composition analyses.

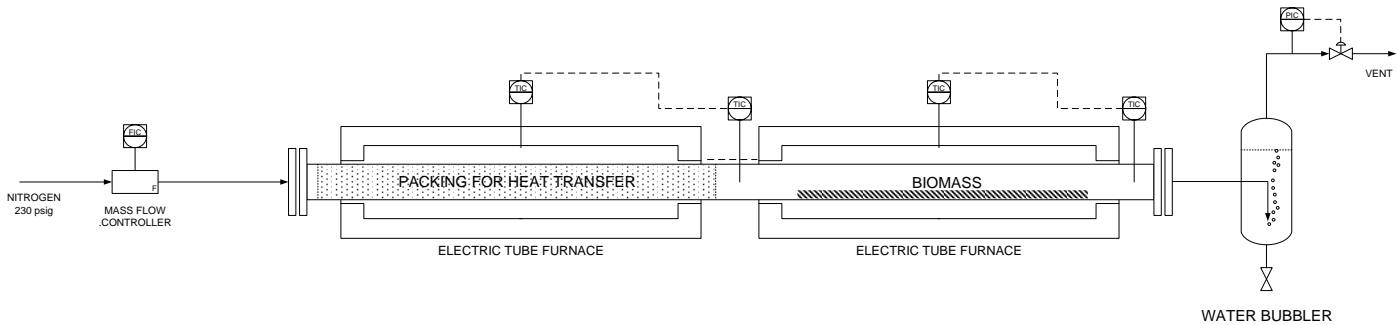


Figure 1. FB's lab-scale pyrolysis reactor system.

With this setup, the system could process approximately 100 – 400 grams of biomass per run, producing approximately 25 – 75 grams of char per run. Up to 16 test runs will be performed varying feedstock and operating conditions. The conditions to be tested will be selected by RRBH, FB, NREL, and INL.

**Subtask 3.3 High Pressure TarFreeGas® Pilot Plant to Determine Feedstock Variable Caused Impacts on Conversion (FB, RRBH, NREL)**

For this work, FB proposes to revamp its TarFreeGas® Pilot Plant located at its headquarters located near Nevada, IA ("Facility") and use it to perform the testing outlined herein. The equipment scope of the pilot system is shown in Figure 2. The system will have a biomass feed system that includes a pneumatic transport feeder system that will feed pine biomass feedstocks into a feed lock system located high in the TarFreeGas® reactor support structure. The feed lock system will batch-transfer via gravity drop between an upper pipe section cycling between atmospheric and process pressure, and the lower section (feedstock metering section) operating at process pressure, similar to the existing pilot plant. Feedstock will be metered into the gasifier using a series of two speed-controlled screw augers, which is the same approach as in the existing pilot plant. Two blast points on the gasifier converter will be fed with controlled flows of oxygen and steam to control the reactor temperature and equivalence ratios. The system will not include a bed media management or limestone addition system; rather, the bed will be loaded and unloaded at the start and end of each campaign, and the campaign lengths will be short enough to prevent significant accumulation of tramp material in the gasifier and avoid agglomeration. The TarFreeGas® converter will be constructed of a combination of high alloy steel and 304H stainless steel and be designed at a maximum allowable operating pressure (MAWP) of 200 psig at 815°C. The converter will be heat traced to account for and control heat loss to a commercially relevant extent, thereby providing commercially representative gas yield and compositions possible. The converter riser will be approximately 12.2 m in height and heavily instrumented to monitor the bed density and temperature along the riser length. The feedstock lock metering system and the TarFreeGas® converter will be housed in a new, dedicated steel support structure, which will be enclosed for weather protection and operational accessibility. Syngas produced in the TarFreeGas® converter will be piped via a heat-traced line to a pressurized PMFreeGas® high efficiency particulate filter to remove all solid material as a fine, powdered biochar product. The biochar will be lock-hoppered from process pressure to atmospheric pressure via a lock system similar to the current pilot plant. Samples of biochar will be collected from this point in the plant and analyzed by FB and also sent to NREL for detailed analysis in Subtasks 3.4.

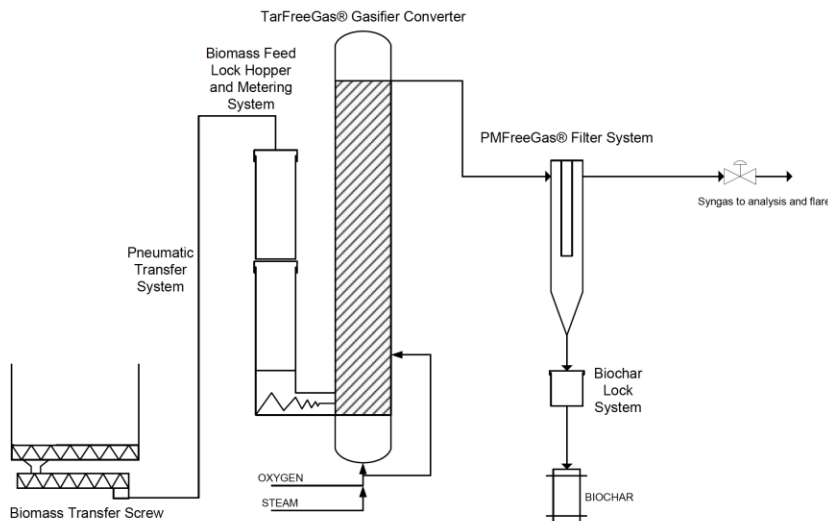


Figure 2. FB's TarFreeGas(R) pressurized pilot gasifier system.

Clean syngas leaving the PMFreeGas® filter will be analyzed with FB's online gas, excess will be flared for thermal oxidation. The system will be controlled by FB's programmable logic controller (PLC) with a human-machine interface (HMI) and historical database for collecting operating data. Operating data and sample analysis data from the TarFreeGas® pilot plant operations will be used to increase the fidelity of the FB ASPEN model, which serves as the basis for FB's equipment design for the RRBH project. Therefore, this data will decrease risk for RRBH's plant arising from varying characteristics of feedstock type and moisture content. The system will be operated in continuous mode. Prior to each operational campaign, the system will be prepared by pre-loading the lower section of the gasifier converter with bed media consisting of silica or olivine sand and pre-loading the riser section with activated carbon (priming biochar) containing a heavy tracer metal impregnated on its surface. The system will also be pressure checked and slowly heated using guard heaters installed on the gasifier exterior up to the desired operating temperature for the start of the campaign. Each campaign will consist of an initial induction period operating on the desired feedstock for an amount of time sufficient to naturally replace the priming biochar inventory in the riser with gasifier-produced biochar, until the priming biochar tracer concentration (measured by XRF) falls below a target threshold. This operating period is of unknown duration but anticipated to take 12-24 hours. Each campaign will consist of a series of mass balance periods of 12 hours in duration ("weight checks"), with a six-hour period between weight checks provided when a change in operating conditions (gasifier temperature or pressure or feedstock parameters such as moisture content or particle size) is desired. Operating data from the PLC, along with samples of feedstock and biochar will be collected during each weight check to allow for the creation of test reports (explained in greater detail below). FB will analyze syngas using online gas chromatographs, solid phase adsorption with post-extraction for tar analysis, and Dräger tubes. FB will analyze the feedstock for bulk density, moisture content, and proximate analysis, and the biochar for bulk density, proximate analysis, and particle size distribution. FB will collect additional samples of feedstock and biochar to be sent to NREL for additional analyses, the results of which will be shared with the project team. After the test campaign is over, the system will be shut down, cooled, and the bed media removed and sampled for analysis. Any operational issues identified during the campaign will be investigated as well, at the discretion of FB and the RRBH team.

During Task 3.3, FB will test up to 24 different combinations of feedstock and operating conditions.

This task will generate biochar that will be supplied to Task 3.4 for analysis. In addition, FB will generate a report describing the correlation between operating conditions and biochar formation and syn gas production/composition.

#### 3.4 Biochar Analysis (NREL)

Char samples generated by the gasification experiments performed by FB will be delivered to NREL and subjected to comprehensive bulk characterizations. These will include typical fuel (ultimate, proximate, and heating value), ash (quantification of Cl, S, Al, Ca, Fe, K, Mg, Mn, Na, and P), and ash fusion analyses on biomass feedstocks and biochars. Nitrogen physisorption will be used to quantify the specific surface area and pore volume of the char samples. Samples analyzed will consist of the following: dry woody feedstock, 2) pyrolysis char from high pressure pyrolysis from 3.1, and 3) gasification char from 3.3.

The morphology and microstructure of the char will be characterized by multiscale, multimodal imaging. Scanning electron microscopy (SEM) will be used to assess the general morphology and surface texture of the char. X-ray computed microtomography (XCT) will be used to obtain full 3D reconstructions of the interior microstructure of the char particles. Transmission electron microscopy (TEM) will be used to visualize and measure intra-cell wall porosity. The data obtained from these analyses will be used to parameterize the geometry and transport models constructed in Task 3.5.

#### Subtask 3.5 Simulating impacts of pretreatment-induced CMAs on high pressure pyrolysis and gasification rates and yields (NREL)

The compositional and structural data collected in Task 3.4 will be used to inform computational models of biomass particles undergoing high pressure pyrolysis and gasification under the FB Gasifier operating conditions. These models will build upon and extend the functionality of previous Consortium for Computational Physics and Chemistry (CCPC) models. Characterization data from pre- and post-pyrolysis samples will be used to provide a description of the evolution of microstructure resulting from the conversion process. Year 1 will involve data analysis, translation into model parameters, and initial model construction. Year 2 will entail validation of the model and sensitivity analysis of the input parameters (i.e., CMAs) to determine how feedstock variably impacts char characteristics and gasification yields and conversion times.

#### Task 4 - Investigating and Addressing the Wear Issue of Plug Screw Feeders (ORNL)

##### Subtask 4.1 - Tribosystem Analysis of Plug Screw Feeders (ORNL)

Based on initial discussion with the team and first-hand experience at FB, mechanical wear has been identified as the major challenge for the plug screw feeder. Unlike some other high temperature conversion systems that have screw feeders directly connected to the reaction tank, this proposed system is designed to have a T-pipe in between as a cushion. As a result, the plug screw feeder has no deposit problem due to biomass thermal decomposition or coking. ORNL will closely work with RRBH to understand the wear challenges and materials needs for the plug screw feeder and housing. RRBH will supply material and qualitative information on observed wear. INL will provide material properties from Tasks 1 and 2. Tribosystem analysis will then be conducted to determine the ranges of torques, contact pressures, sliding velocities, and operation temperatures at the contact interfaces for the biomass feedstock (before and after forming plugs) and extrinsic minerals rubbing against the plug screw feeder and housing.

##### Subtask 4.2 - Candidate Alloys and Coatings (ORNL)

Four baseline materials for plug screw feeder and housing have been identified based on the initial discussion with the team:

- Type 316 stainless steel (used by NREL for the 4" plug screw feeder in a low-temperature conversion PDU),
- 17-4PH (Type 630) stainless steel (used by INL for plug screw feeder in a high-temperature conversion PDU),
- high-chromium white iron (used by FB for most their 5" plug screw feeders and housings in most high-temperature conversion systems), and
- SiC-Ni composite weld overlay (used by FB for corrosive environments).

Based on ORNL's previous experience and literature survey, several candidate wear-resistant alloys and hardface coatings will be selected to meet the materials needs for the plug screw feeder and housing. Initial selections are listed below and additional candidates may be selected after gaining better understanding of the system during the project.

- Candidate wear-resistant alloys for non-corrosive environments: D2 and M2 tool steels, 52100 bearing steel, and carburized 8620 steel
- Candidate wear-resistant alloys for corrosive environments: 440C and 2205 stainless steels
- Candidate thin ceramic coatings for corrosive environments: diamond-like carbon (DLC, 3-5 µm, by CVD), CrN (3-5 µm, by PVD)
- Candidate thick composite coating for corrosive environments: WC-Co-Ni (1-2 mm, by cold spray)

#### Subtask 4.3 - Bench-Scale Accelerated Wear Testing and Analysis (ORNL)

Microstructural characterization, microindentation hardness measurement, and bench-scale accelerated wear tests will be conducted by ORNL for evaluating and comparing the baseline and candidate materials for the plug screw feeder and housing. Loop abrasion tests (ASTM G 174) will be carried out on small coupons of the baseline and candidate materials for side-by-side comparison of their resistance to 2-body abrasive wear. The worn surface morphology will be examined using optical and electron microscopy and the worn surface composition will be analyzed using energy-dispersive X-ray spectroscopy. RRBH will produce a report on the feasibility of adapting coatings/material suggestions that result from subtasks 4.1, 4.2, and 4.3.

#### Task 5 – Cost Benefit Analysis of Project Outcomes (INL, RRBH)

##### Subtask 5.1 – Cost Benefit Analysis of Project Outcomes (INL, RRBH)

In preprocessing equipment, variability of the feedstock materials can lead to reductions of dynamic throughputs resulting in missing volume requirements. For example, very low or very high moisture levels can lead to unexpected failures of preprocessing equipment due to clogging and plugging, resulting in unplanned downtime. Similarly, high ash contents lead to higher rates of erosive wear of equipment, thus requiring additional unplanned downtime. Traditionally, economic analysis of biomass processing assumes a fixed average feedstock quality and thus utilizes performance measures at the average properties. Understanding of the impact of variability on the economics of the system requires the use of dynamic modeling to capture the impacts. One method of analysis that can be utilized for dynamic systems is discrete event simulation (DES). DES has been commonly used as a method to analyze and solve manufacturing problems and make decisions by simulating and performing "what if" analyses to develop a deeper understanding of an industrial process. The preprocessing of biomass lends itself to the use of DES since each operation has a defined start and end, the flow of material is a defined path and the flow is based on the interactions of the equipment and feedstock characteristics. Additionally, where information exists to correlate unit operations failures with upstream operations, sensitivity analyses will be performed to understand how such conditions may lead to downstream failure. Specifically, this could be classified as a closed-loop queuing model, where the time delay of equipment, number of units waiting, resource utilization and throughput are used to characterize the performance of a system, in which the arrival time of the next unit of biomass is controlled by an infeed system. Ultimately, the economics of the system are determined through calculating the costs on a per unit basis and aggregating the individual units up to determine the system economics.

This approach will be used to evaluate the effect of available feedstock types (contracting) and preprocessing protocols/technologies on feeding performance. In addition, conversion yields characterized in Task 3 and wear and abrasion data collected in Task 4 will be combined with this information to generate an overall cost-benefit analysis of the different feedstock selection, feedstock preprocessing protocols/technologies, conversion conditions, and equipment selection surveyed in this project. Specifically, shutdown events will be documented, along with the feedstock conditions that caused them. These physical shutdowns will be compared against modeled shutdowns using DES for verification. A DES model will then be produced specific to the preprocessing and feeding methods relevant to the RRBH system. RRBH will take this information and contribute to the deliverable with information on how it may impact the design and operation of their existing and future plants.

#### Task 6 - Reporting Project Output and Outcomes (INL, NREL, RRBH, ORNL, FB, FC)

##### Subtask 6.1 – Reporting Project Output and Outcomes (INL, NREL, RRBH, ORNL, FB, FC)

A final report that summarizes project findings, deliverables, and outcomes will be delivered to BETO and all project partners. This report will include recommendations on feedstock processing and screw feeder operation to reduce downtime due to feeding failures. This final report will also include a final cost benefit analysis, as well as a report describing the potential impact on RRBH's demonstration and conversion facility development, as well as the impact on the bioenergy industry as a whole.

The work will be performed at the Energy Storage Laboratory (IF-685). No equipment purchases are anticipated for this project other than incidental laboratory supplies.

### **SECTION C. Environmental Aspects or Potential Sources of Impact:**

#### **Air Emissions**

Air emissions from portable generators, stationary units such as the PDU, thermochemical treatment of biomass, the CPS, fugitive dust from grinding activities, and discharges from laboratory hoods as part of biomass bale permeability studies are anticipated. Emissions from portable generators are exempt since the generators are used only a few days per year. If the generators remain in the same location an Air Permitting Applicability Determination (APAD) is required.

Fine dust created in some processes may be combustible. Dusts can be a product of the processing of multiple feedstocks including biomass, plastics, MSW, and coal. The grinding systems are operated under negative pressure and designed to collect any dust. Explosion detection and suppression

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systems, and an ember detection system with a water deluge are in the facility. Water hoses and hand sprayers are available to cool hot spots on equipment to avoid potential fires. Dust control and mitigation includes adding or modifying ducting, ducting connectors, fabric sleeves, other fixtures and ducted fans, water sprays, other dust control methods, or enhanced cleaning procedures. Controlling fugitive dust under certain conditions is also required under state air regulations.

The Project may involve the discharge of hazardous air pollutants regulated by the state or EPA.

The CPS has an off-gas scrubber drum. The vent scrubber system includes the Scrubber Drum (D-260), the Scrubber Drum Pump (P-261), the Scrubber Cooler (E-262), and the Scrubber Blower (B-263). All fugitive emissions are routed to the scrubber system. The exhaust from the scrubber is connected to the facility exhaust system.

Fugitive emissions from chemical use are exhausted through the facility mechanical ventilation or local exhaust systems.

Emissions from BFNUF activities are covered in APADs INL-10-005 and INL-14-005 R2.

### Discharging to Surface-, Storm-, or Ground Water

N/A

### Disturbing Cultural or Biological Resources

N/A

### Generating and Managing Waste

Excess biomass materials (processed and unprocessed forest products) may be generated. This material will be transported to the Hatch Pit for disposal.

### Releasing Contaminants

Small amounts of chemicals may be discharged to the Idaho Falls sewer system in accordance with sewer regulations.

### Using, Reusing, and Conserving Natural Resources

The primary purpose of this work is to investigate methods by which energy may be recovered from biomass, replacing other sources of energy. Furthermore, this work will focus on the development of processes and chemistries for conversion of other waste materials, such as MSW and plastics, into feedstocks for energy production. Finally, the work will include engineering to develop feedstocks that can be fed efficiently into conversion systems.

**SECTION D. Determine Recommended Level of Environmental Review, Identify Reference(s), and State Justification:** Identify the applicable categorical exclusion from 10 Code of Federal Regulation (CFR) 1021, Appendix B, give the appropriate justification, and the approval date.

For Categorical Exclusions (CXs), the proposed action must not: (1) threaten a violation of applicable statutory, regulatory, or permit requirements for environmental, safety, and health, or similar requirements of Department of Energy (DOE) or Executive Orders; (2) require siting and construction or major expansion of waste storage, disposal, recovery, or treatment or facilities; (3) disturb hazardous substances, pollutants, contaminants, or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)-excluded petroleum and natural gas products that pre-exist in the environment such that there would be uncontrolled or unpermitted releases; (4) have the potential to cause significant impacts on environmentally sensitive resources (see 10 CFR 1021). In addition, no extraordinary circumstances related to the proposal exist that would affect the significance of the action. In addition, the action is not "connected" to other action actions (40 CFR 1508.25(a)(1) and is not related to other actions with individually insignificant but cumulatively significant impacts (40 CFR 1608.27(b)(7)).

**References:** 10 CFR 1021, Appendix B to subpart D, items B3.6, "Small-scale research and development, laboratory operations, and pilot projects."

**Justification:** The proposed R&D activities are consistent with CX B3.6 "Siting, construction, modification, operation, and decommissioning of facilities for small-scale research and development projects; conventional laboratory operations (such as preparation of chemical standards and sample analysis); small scale pilot projects (generally less than 2 years) frequently conducted to verify a concept before demonstration actions, provided that construction or modification would be within or contiguous to a previously disturbed area (where active utilities and currently used roads are readily accessible). Not included in this category are demonstration actions, meaning actions that are undertaken at a scale to show whether a technology would be viable on a larger scale and suitable for commercial deployment."

**DOE-ID NEPA CX DETERMINATION  
Idaho National Laboratory**

Is the project funded by the American Recovery and Reinvestment Act of 2009 (Recovery Act)     Yes     No

Approved by Jason Sturm, DOE-ID NEPA Compliance Officer on: 1/28/2021