ALDERFUELS

Field-to-Fuel Production of Carbon-Negative Sustainable Aviation Fuel from Regenerative Agriculture Biomass

Systems Development and Integration WBS 3.4.3.603 – April 4, 2023

Principal Investigator: Derek R. Vardon, PhD

This presentation does not contain any proprietary, confidential, or otherwise restricted information

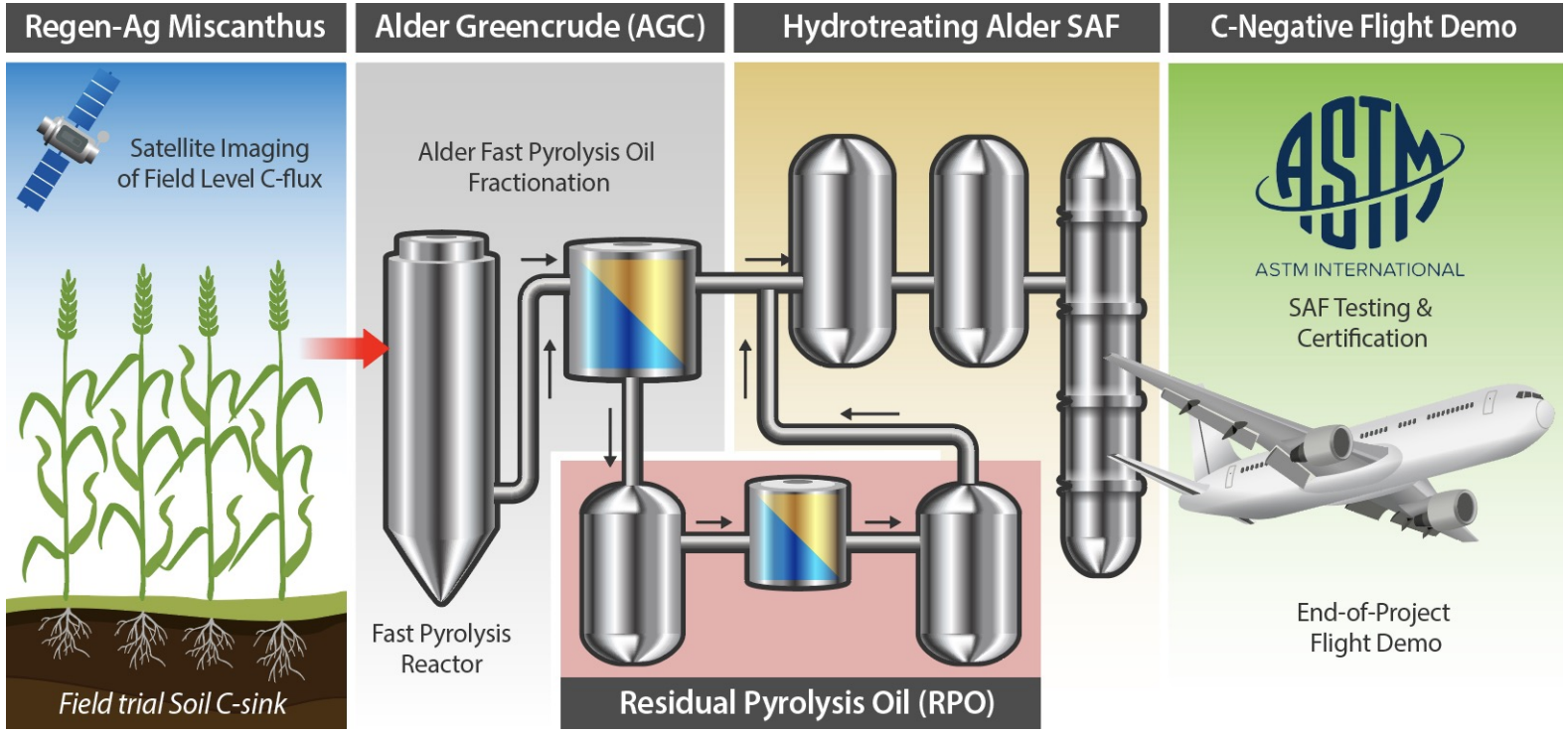
Project Overview

Unlock C-negative sustainable aviation fuel (SAF) with Alder tech using regen-ag Miscanthus

DE EE0009753

Project Goals

- Scale Alder Greencrude (AGC) production to barrel-per-day with Miscanthus pyrolysis oil
- Validate C-negative Miscanthus biomass with field trials and satellite data models
- Generate 100 gallons of Alder SAF from Miscanthus for end-of-project flight demo



Accelerate commercialization of Alder Greencrude (AGC) technology and align with White House SAF Grand Challenge

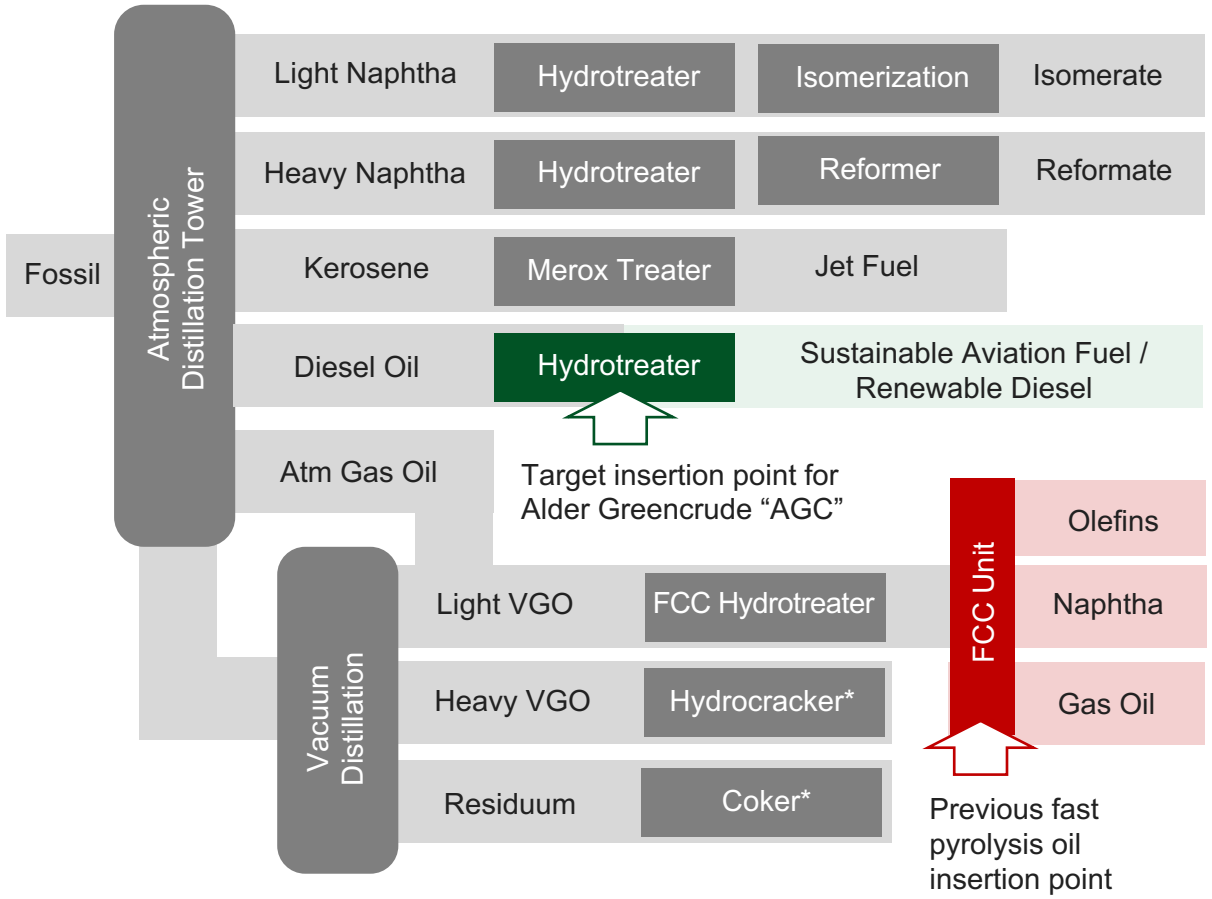
Project Overview

Problem and potential of fast pyrolysis technology for scaling SAF production

DE EE0009753

Limitation of Fast Pyrolysis

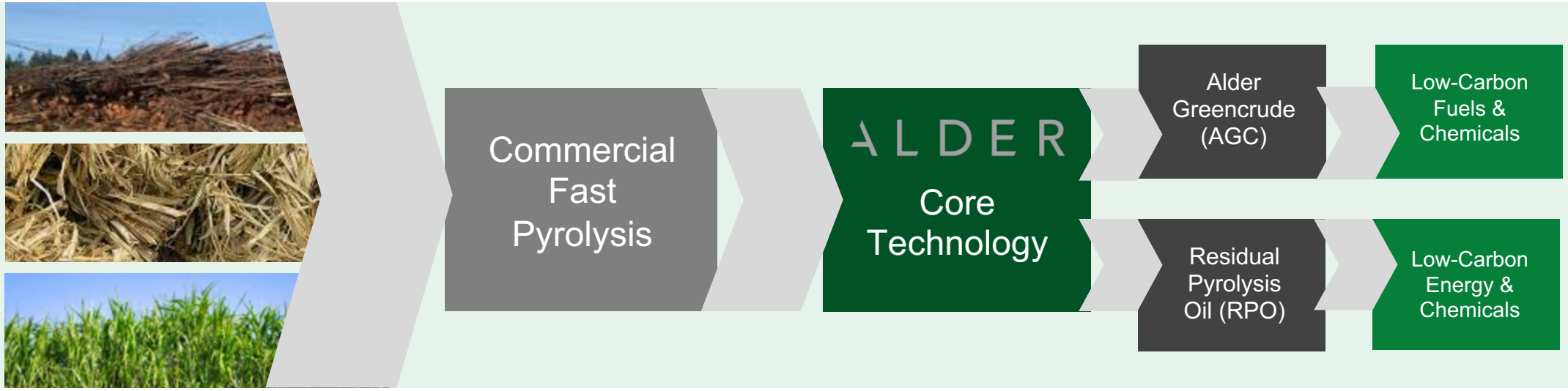
- Fast pyrolysis technology is commercial, but fast pyrolysis oil cannot be refined into jet or diesel
- Fast pyrolysis oil contains “bad actors” (water, aldehydes, ketones, sugars, metals) that clog commercial distillate hydrotreating reactors
- Over 6 billion barrels per day of U.S. hydrotreating capacity if pyrolysis oil can be unlocked as a feedstock



Project Overview

Alder technology integrates existing fast pyrolysis technology with refinery infrastructure

DE EE0009753



Alder Greencrude addresses limitations of fast pyrolysis oil refinery integration for SAF

- *Removes water & increases energy density of fast pyrolysis oil by 1.4x*
- *Reduces organic "bad actors" by 2x that lead to polymerization in catalyst bed*
- *Reduces metals by 4x to 10x that lead to catalyst deactivation*
- *Recovers RPO with composition comparable to fast pyrolysis oil for upgrading*

Project Overview

Partnership with Honeywell UOP to commercialize AGC and refinery integration

Refinery Integration

- Honeywell UOP successful track record with Ecofining™ hydroprocessing
- Joint Development Agreement between Alder and UOP for AGC production and refinery hydrotreater integration
- Over 2000 hours of cumulative pilot plant hydroprocessing by UOP with woody biomass AGC

ALDER FUELS

Honeywell UOP

1 – Approach

Partner with leading institutions to advance critical project technical areas

Project Prime and Partners from National Labs, Industry, and Universities

Project Prime & Alder SAF

Alder – Derek Vardon, Allison Ray

Miscanthus Biomass Supply

AGgrow – Travis Hedrick

Biomass Pre-processing & Analysis

INL – Rachel Emerson, Lynn Wendt

Field Trials & Field-to-Gate

UIUC – Kaiyu Guan, Emily Heaton, Jeremy Guest

Fast Pyrolysis Pilot Runs

BTG – Gerhard Muggen

AGC Bench & Pilot, TEA-LCA

NREL – Calvin Mukarakate, Hakan Olcay, Mike Talmadge

Hydrotreating Pilot Runs

UOP – Geoff Fichtl, Lisa Wolschlag

ASTM SAF Fuel Properties

WSU – Josh Heyne

Hydrotreating Demo Runs

RPD – Peter Loezos

Advising ASTM & Flight Demo

Gulfstream, United Airlines, and Boeing

1 – Approach

Advance Alder SAF production with Miscanthus by leveraging work-to-date on woody biomass

Baseline with Woody Biomass

- **Feedstock**: commercial woody fast pyrolysis oil
- **Product**: confirmed Alder SAF meets key ASTM fuel properties for Fast Track
- **AGC Processing**: semi-integrated gallon-per-day scale; tolled 9,000 gal of AGC to date
- **Hydrotreating**: gallon-per-day feed of AGC tested for >2000 h in Honeywell UOP pilot plants
- **GHG Reduction**: >80% reduction with green H_2
- **Fuel Selling Price**: market competitive

Subtopic 1a: Pre-Pilot with Miscanthus

- **Feedstock**: regen-ag Miscanthus fast pyrolysis oil
- **Product**: demonstrate Alder SAF from Miscanthus that meets ASTM properties
- **AGC Processing**: integrated barrel-per-day (BPD) scale for 100 h continuous; 500 h cumulative
- **Hydrotreating**: gallon-per-day of AGC for 1 gal of SAF; Go/No-Go for 100 h continuous at BPD
- **GHG Reduction**: targeting >100% reduction
- **Fuel Selling Price**: $2.75/gal gasoline equivalent

1 – Approach

Budget Period activities scale Miscanthus Alder SAF from bench to pilot

BP1 Verification

- Verification of prior bench data, semi-continuous pilot data, and TEA-LCA
- Prior AGC production and SAF hydrotreating data based on woody biomass pyrolysis oil

BP2 Bench-Pilot

- Harvest, characterize, pre-process 2 tonnes of Miscanthus
- Conduct fast pyrolysis with 2 MT of Miscanthus biomass
- Screen Miscanthus AGC-RPO production at bench scale
- Test barrel-per-day AGC pilot yields and hydrotreat to SAF

BP3 Pilot Runs

- Conduct fast pyrolysis with 20 MT of Miscanthus biomass
- Operate AGC pilot plant for 100 h continuous and 500 h cumulative
- Hydrotreat AGC to produce 1 gal of SAF for ASTM testing
- Demo barrel-per-day hydrotreating

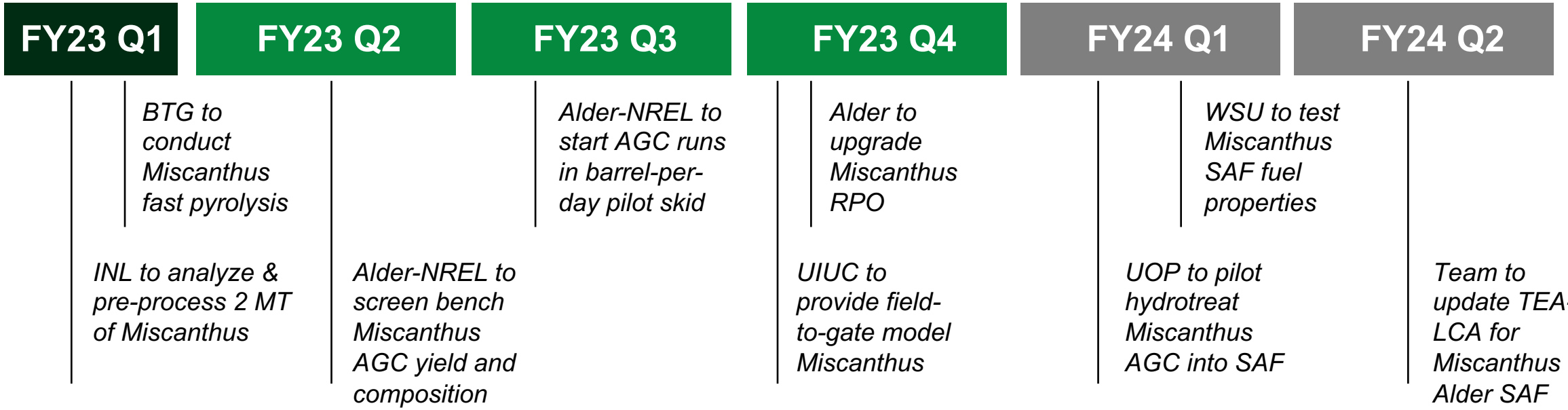
BP4 Flight Demo

- Produce 100 gal of Alder SAF from Miscanthus AGC
- Validate ASTM fuel properties of neat and blended Alder SAF
- Conduct flight demo on C-negative Alder SAF from Miscanthus

1 – Approach

Timeline for Budget Period 2 with select milestones to measure and ensure progress

***Budget Period 2 started Dec 2022**



Go/No-Go FY23 Q4: Alder-NREL to process Miscanthus and woody fast pyrolysis oil in barrel-per-day skid to evaluate AGC-RPO yield and composition. If metrics are met with Miscanthus, continue with 20 MT fast pyrolysis run at BTG. If metrics are not met, depending on gap, evaluate alternative process conditions or pivot remaining project campaign to woody biomass fast pyrolysis oil.

1 – Approach

Identify major risk factors and proactively define mitigation actions

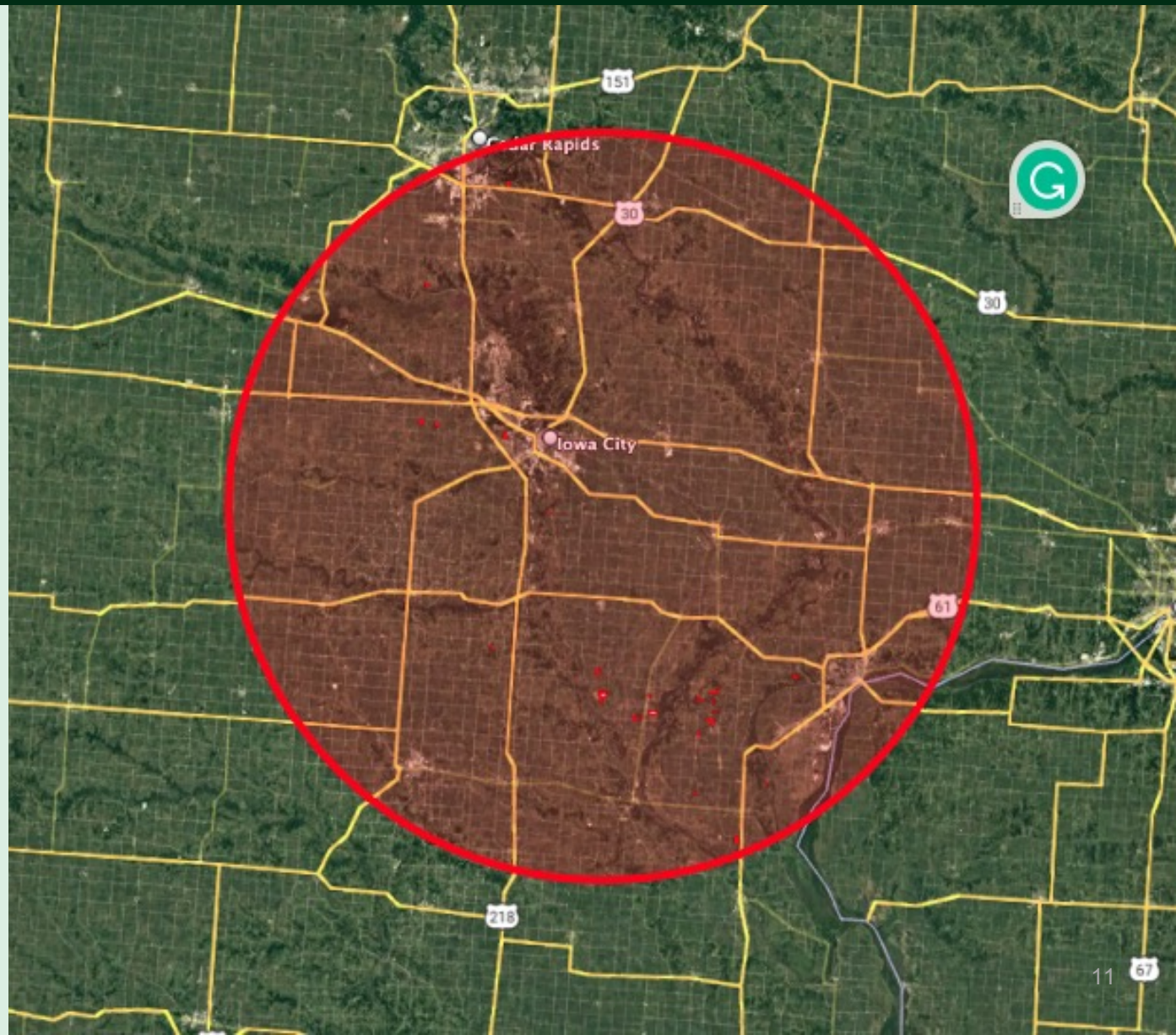
Miscanthus SAF Risk Factors	Risk Mitigation Strategy
Biomass – Miscanthus contains high ash and that results in low fast pyrolysis oil yields and high metal content in AGC and Alder SAF	**Biomass –** Miscanthus harvest avoids gathering leaves and prevent stems from touching ground to minimize metals
AGC Pilot – Barrel-per-day pilot skid fails to meet AGC and RPO yield and composition targets with Miscanthus fast pyrolysis oil	**AGC Pilot –** Leverage conditions established with wood pyrolysis oil; employ Go/No-Go to move forward with wood pyrolysis oil if necessary
Alder SAF – High metals content in Alder SAF do fails to meet ASTM specs; poor low temperature fuel properties	**Alder SAF –** Employ hydrotreating metal guard bed; leverage current UOP catalysts that show exceptional low temp properties for Alder SAF

2 – Progress and Outcomes

Miscanthus biomass grown by AGgrow Tech that leverages ongoing UIUC field trial

Miscanthus Cultivation

- Alder acquired 22 tonnes of Miscanthus from AGgrow Tech from farm locations in central Iowa
- No-till Miscanthus grown on conservation practice-land; converted from row crop to continuous perennial
- Part of ongoing field study with UIUC to measure soil C sequestration potential



2 – Progress and Outcomes

Miscanthus biomass harvested to minimize moisture and ash content

Miscanthus Harvesting

- Harvested in late winter 2022 after leaf fall with 10-15% moisture; single sample for fast pyrolysis campaigns
- Forage chopper (see photo) outfitted with ¾-inch screens to collect Miscanthus biomass from field
- Stems do not contact the ground, limiting soil-derived inorganic contamination

AGgrow TECH

2 – Progress and Outcomes

Miscanthus biomass pre-processed by INL to meet size and moisture specs for fast pyrolysis

DE EE0009753

Miscanthus Pre-Processing

- Processed at INL with hammer mill and oscillating screen to size to 0.5 to 3 mm
- Sample submitted for compositional analysis before and after pre-processing

Idaho National Laboratory

2 – Progress and Outcomes

Miscanthus biomass air-shipped to BTG for pilot processing into fast pyrolysis oil

Fast Pyrolysis Conversion

- Air-shipped 2 tonnes of Miscanthus to BTG Bioliquids for fast pyrolysis pilot plant conversion
- Sample will be processed using BTG's 24 kg-per-day system to measure yields and energy balance
- Fast pyrolysis oil will be characterized and air-shipped back to U.S. for AGC and RPO bench screening

btg bioliquids

2 – Progress and Outcomes

Bench screening capability setup at NREL for AGC-RPO yield and compositional analysis

DE EE0009753

AGC Bench Screening

- Miscanthus AGC will be benchmarked against prior work with woody biomass AGC
- Screening conditions established for batch 0.5-gal fractionation, as well as continuous GPD fractionation
- Detailed analytical includes elemental analysis, water content, volatile organics, carbonyls, solids, ash, metals, and chlorine

ALDER FUELS

NREL Transforming ENERGY

2 – Progress and Outcomes

Gallon-per-day pilot plant for AGC hydrotreating

Gallon-per-day Pilot Plant

- Gallon-per-day pilot hydrotreating at RPD with catalysts and conditions supplied by UOP
- System operated extensively in separate privately funded project with woody fast pyrolysis oil
- Scale allows for SAF production and for fuel property screening at Washington State University

RPD Technologies

Honeywell UOP

2 – Progress and Outcomes

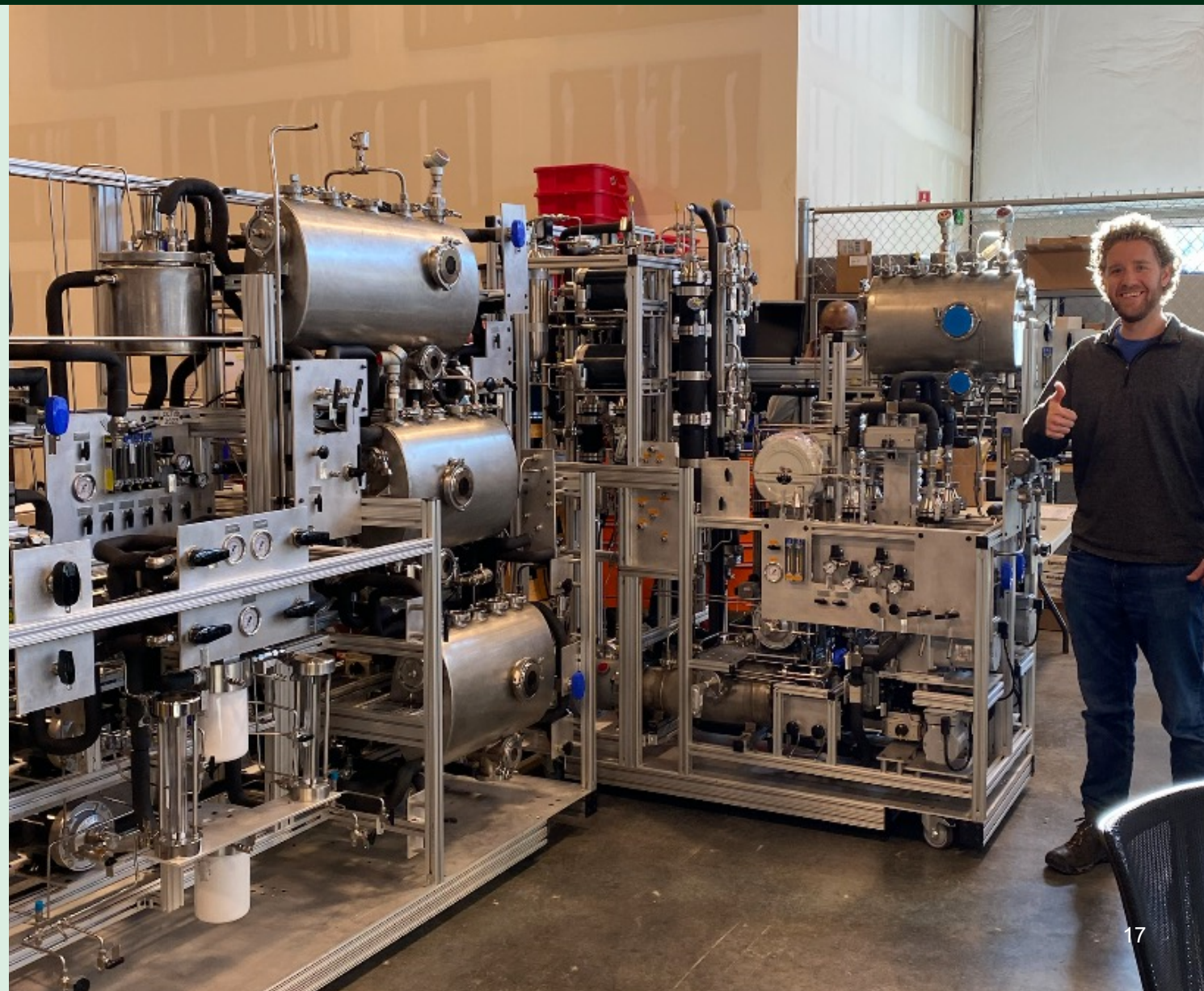
Progress commissioning barrel-per-day pilot skid for AGC-RPO production

Barrel-per-day Pilot Plant

- Integrated pilot plant actively being commissioned at NREL through separate privately funded project
- System scheduled to be mechanically and electrically complete by March 15, 2023
- If AGC passes bench screening, pilot skid will evaluate continuous yields for wood and Miscanthus pyrolysis

ALDER FUELS

NREL Transforming ENERGY



3 – Impact

Data dissemination, intellectual property, and technology commercialization

Data Sharing & Dissemination	• Data management plan established for data records and data sharing • Present at technical (ACS Fall) and industry meetings for Alder SAF pathway • Project to generate high-impact data suitable for peer-reviewed publications
Intellectual Property	• IP management plan established to control sensitive project data • Non-Disclosure agreement in progress between project partners • Data for Miscanthus AGC will demonstrate Alder's background IP for new feedstock
Technology Commercialization	• AGC-RPO production and SAF hydrotreating findings have potential to accelerate Alder and UOP's partnership to commercially deploy Alder SAF technology • Project results on C-negative SAF have potential to strengthen market demand for Miscanthus and benefit commercialization efforts by AGgrow Tech

3 – Impact

Incorporating diversity, equity, and inclusion (DEI) throughout project

DEI Progress to Date

1) Diverse project team with 6 co-investigators from underrepresented groups in STEM
2) Project supports 2 graduate students from underrepresented groups in STEM
3) Project positioned to advance national SAF goals through positive social, environmental, and economic impacts in rural communities

Upcoming Activities to Advance DEI

1) Leverage programs at Universities and National Labs to identify student interns from underrepresented students in STEM for summer internships
2) Alder and NREL team leads to participate in Dartmouth course, Energy Justice: Fostering More Equitable Energy Futures and share learnings with project team

Summary

Approach, progress, and impact for C-negative Alder-SAF production from Miscanthus

DE EE0009753

Approach	• Address known limitations of fast pyrolysis oil hydrotreating with AGC technology • Bench-screen Miscanthus AGC production and if Go, scale to barrel-per-day pilot • Validate fuel properties for Miscanthus Alder SAF • Determine Miscanthus Alder SAF carbon-intensity versus woody biomass
Progress & Outcomes	• Secured 22 metric tonnes of regen-ag Miscanthus from AGgrow Tech • Characterized, pre-processed, and shipped Miscanthus to BTG for fast pyrolysis • Setup AGC bench-screening capabilities at NREL with established methods • Actively commissioning barrel-per-day pilot skid to scale AGC production
Impact	• Accelerate commercialization of new SAF pathway by Alder and Honeywell UOP • Incentivize carbon-negative Miscanthus for bioenergy applications • Improve DEI STEM outcomes through project staffing and internship recruiting

Acronyms

- **AGC** – Alder Greencrude
- **BPD** – barrel-per-day
- **C-negative** – carbon-negative
- **DEI** – diversity, equity, and inclusion
- **DOE** – Department of Energy
- **FCC unit** – fluid catalytic cracking unit
- **GPD** – gallon-per-day
- **MT –** metric tonnes
- **Regen-ag** – regenerative agriculture
- **RPO** – residual pyrolysis oil
- **SAF** – sustainable aviation fuel
- **STEM** – science, technology, engineering, mathematics
- **TEA / LCA** – techno-economic analysis / life cycle analysis

Quad Chart Overview

Timeline

- Budget Period 2 started Dec 2022
- Project end date May 2025

	FY22 Costed	Total Award
DOE Funding	$28,717	$4,000,000
Project Cost Share	$7,775	$5,147,127

Technology Readiness Level

- TRL at Project Start: 3
- TRL at Project End: 5

Project Goal

- Advance C-negative SAF using Alder green crude derived from Miscanthus

End of Project Milestone

- Conduct flight demo on Alder SAF derived from Miscanthus

Funding Mechanism

- FY21 BETO Scale-up and Conversion FOA DE-FOA-0002396

Project Partners

- NREL, INL, University of Illinois
- Honeywell UOP, Washington State University
- Gulfstream, United Airlines, Boeing