DOE Bioenergy Technologies Office (BETO)
2015 Project Peer Review

Green Gasoline from Wood Using Carbona Gasification and Topsoe TIGAS Processes

March 24, 2015

Demonstration and Market Transformation

Rick Knight
Gas Technology Institute

HALDOR TOPSOE
ANDRITZ CARBONA
gti
UPM
PHILLIPS 66
PALL
e·on

Acronyms

AGR	Acid Gas Removal
DME	Dimethyl ether
GTI	Gas Technology Institute
HGF	Hot gas filter
HTAS	Haldor Topsoe A/S (Denmark)
HTI	Haldor Topsoe Inc. (Houston TX)
TIGAS	Topsoe Improved Gasoline Synthesis
UHGF	Ultra-hot gas filter

Goal Statement

- To demonstrate and validate an economical integrated technology for thermochemical conversion of woody biomass into renewable drop-in gasoline
- This technology is applicable to many U.S. sites, with the potential to displace 2 billion gallons of petroleum-based transportation fuel annually and create thousands of U.S. jobs.

Quad Chart Overview

Timeline

- Project start: March 31, 2010
- Project end: December 31, 2014
- 100% complete

Budget: $34,388,775

	FY10-FY12	FY13	FY14	FY15	Total
	$1000				
DOE	$11,001	$9,696	$4,204	$99	$25,000
	Project Cost Share				
HTI	$111	$683	$79	$46	$919
HTAS	$2,381	$1,243	$727	$0	$4,351
GTI	$132	$827	$577	$7	$1,543
Andritz	$15	$35	$50	$25	$125
UPM	$0	$488	$241	$0	$729
Phillips	$188	$44	$1,025	$722	$1,979
Cost Share Total	$2,827	$3,320	$2,699	$800	$9,646

Barriers

- Barriers addressed
  - It-A. End-to-end process integration
  - Im-D. High risk of large capital investment
  - It-E. Engineering modeling tools

Partners

- Partners
  - DOE recipients: HTI (3%); GTI (93%); Andritz Carbona (4%).
- Other interactions/ collaborations
  - Pall Corp. and E·ON provided engineering and testing of ultra-hot gas filter (UHGF)
  - State of Illinois supported commissioning of AGR pilot unit

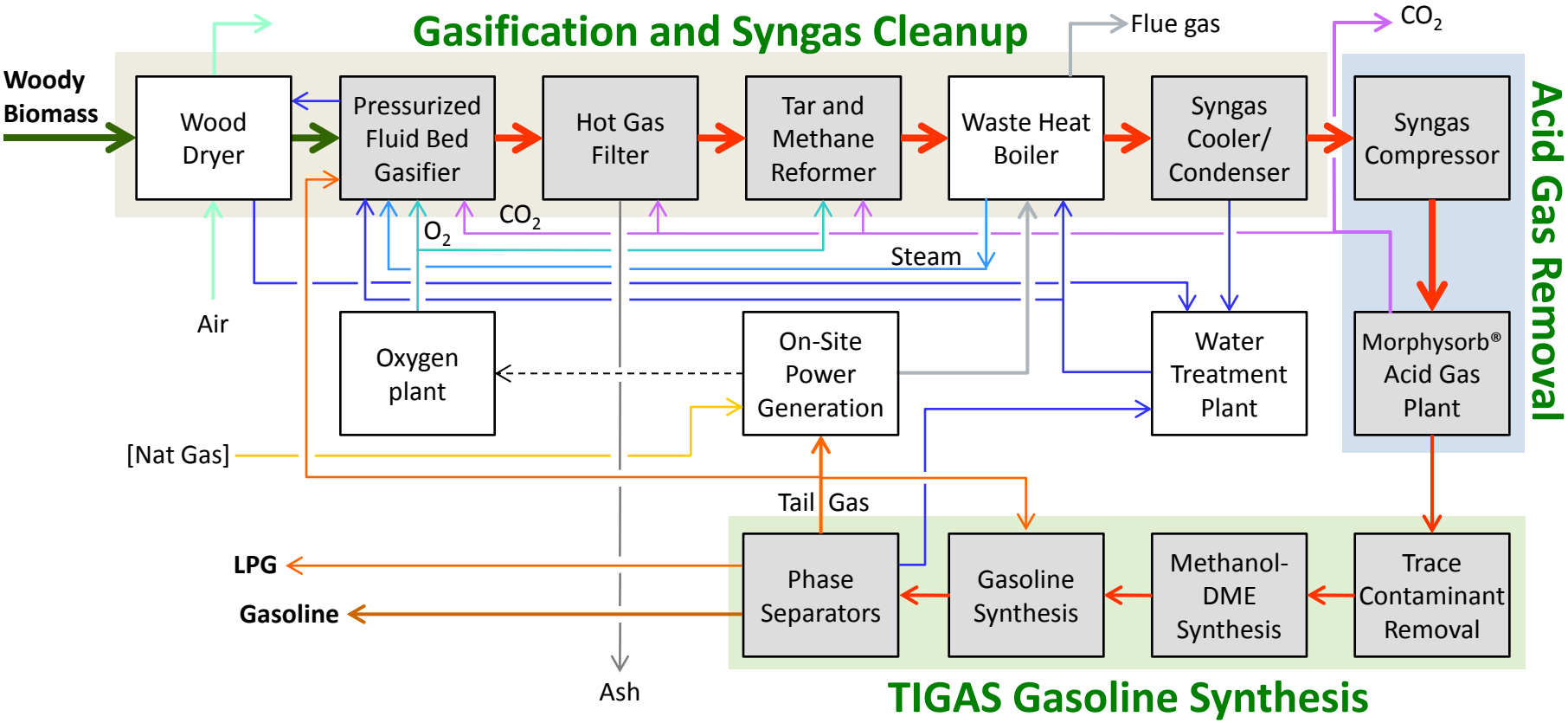
1 - Project Overview

- Haldor Topsoe interested in applying their TIGAS process to biomass-derived syngas for renewable fuel markets
- Prior work by GTI, Andritz Carbona, and UPM developed clean bio-derived syngas for Fischer-Tropsch synthesis
  - Andritz Carbona owns rights to biomass gasification technology
  - GTI owns rights to Morphysorb® acid gas removal
  - GTI owns and operates gasification and gas cleanup pilot plant
- Haldor Topsoe, Andritz, UPM, and GTI teamed up with Phillips 66 to form a project team covering the entire supply chain
- Project team responded to IBR solicitation with ARRA funding

1 - Project Overview

- Pilot plant located at GTI in Des Plaines, IL
- Wood pellet biomass feed is provided by UPM from their Blandin, Minnesota facility
- Biomass is converted into gasoline by the following steps:
  - Andritz-Carbona gasification
  - Hot gas filtration and tar reforming
  - Morphysorb acid gas removal
  - Haldor Topsoe TIGAS gasoline synthesis
- Design capacity of the pilot plant:
  - 21 tons of wood pellet feed per day
  - 23 barrels per day of gasoline product

2 – Approach (Technical)



Green text denotes major biorefinery sections

Gray blocks denote unit operations tested in pilot plant

2 – Approach (Management)

- Critical success factors and challenges
  - Clean syngas for catalytic process steps
  - Stable integrated operation
  - Drop-in gasoline blendstock at competitive price
- Structure of management approach
  - Haldor Topsoe PM coordinates work thru partner PM's
  - WBS extended to level 4 work packages (56 total)
  - Milestones, Deliverables, Go/No-Go decision points
  - Earned Value tracking extended to subcontractors and vendors
  - Risk Mitigation via weekly teleconferences, frequent face-to-face meetings, preliminary & final HAZOP reviews, readiness reviews, post-test evaluation meetings
  - Project Management assistance from Independent Engineer and Executive Steering Committee

3 – Technical Accomplishments/ Progress/Results

- The project team has met and exceeded technical objectives
  - Biorefinery was expanded, commissioned, and operated successfully
  - Completed three test campaigns including internal recycles
  - Syngas cleanup was sufficient for gasoline production with no catalyst deterioration
  - Predicted gasoline yield and quality was met under stable integrated operation
  - Gasoline has been validated for EPA emissions and track-tested for 75,000 miles with no adverse findings

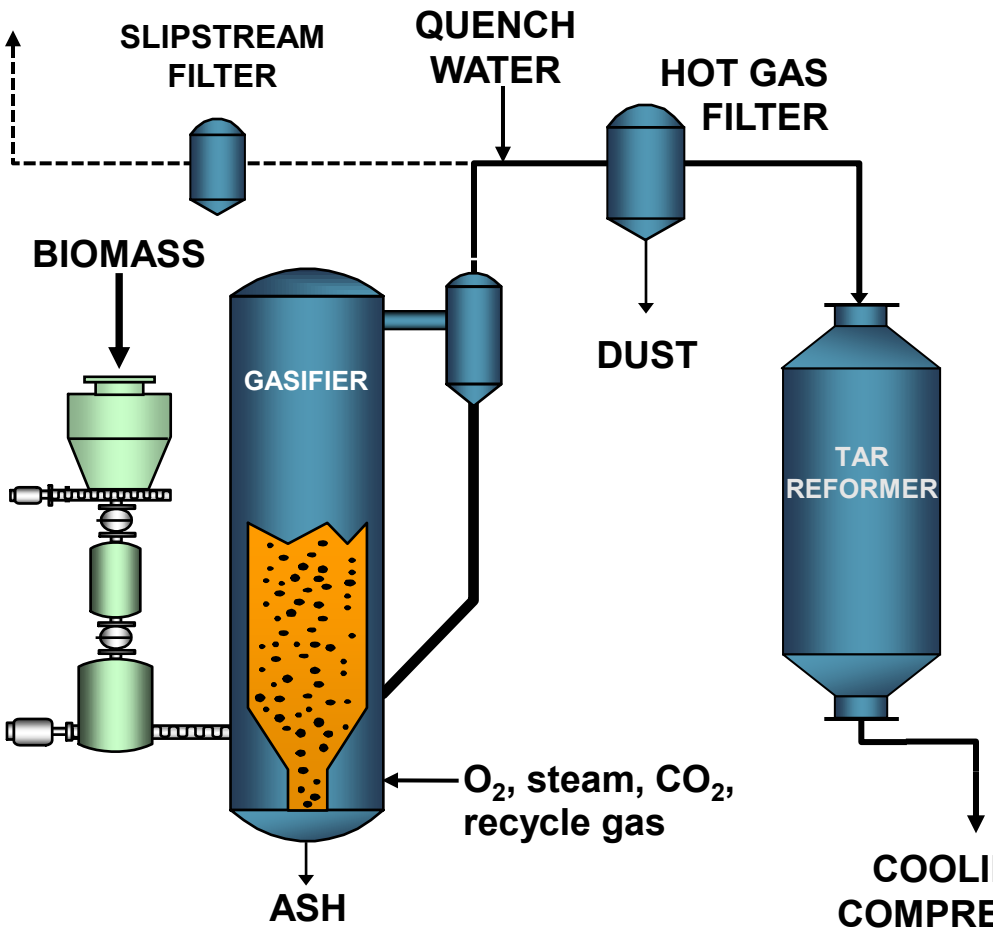
3 – Technical Accomplishments/ Progress/Results (continued)

- 61-65% syngas to motor fuel conversion (LHV energy basis)
- Engine emissions from 80% biogasoline blend were 'substantially similar' to standard gasoline
- Fleet test with 50% biogasoline blend logging 75,000 mi on each of 4 vehicle pairs
- Pilot results reduce technical risk sufficiently for licensors to offer commercial package

	Target	Actual
Biomass* fed, lb		317,230
Gasoline made, lb		31,560
LP gas made, lb		6,360
Gasoline + LPG yield,† lb fuels/ton maf biomass	312	284-320
Energy conversion, Btu fuels/Btu biomass, %	36.2	36-40
Octane (R+M)/2	>83	89-92
Aromatics, vol%	<35	29-33

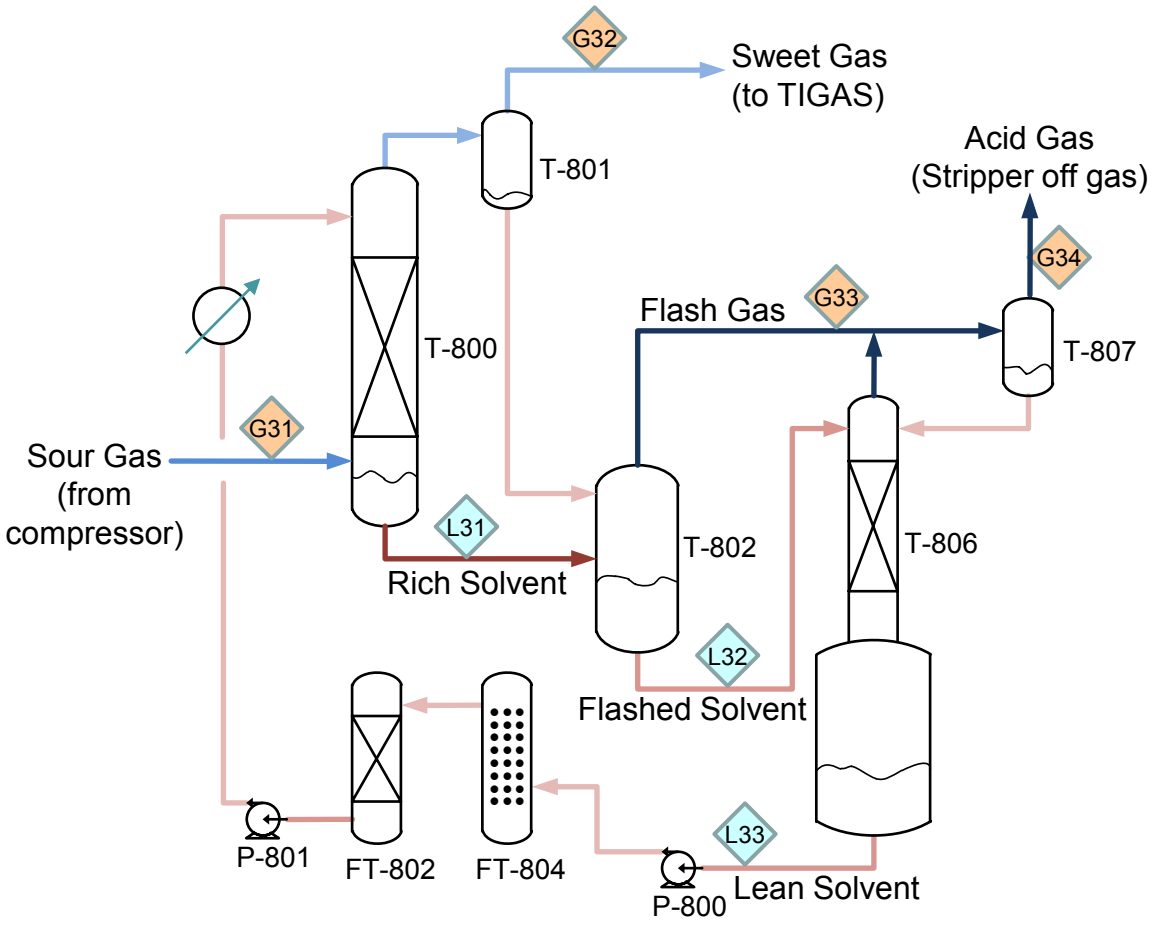
* 6.0 wt% moisture, 0.9 wt% ash
† Corrected for syngas bleed to flare

3 – Technical Accomplishments/ Progress/Results (continued)



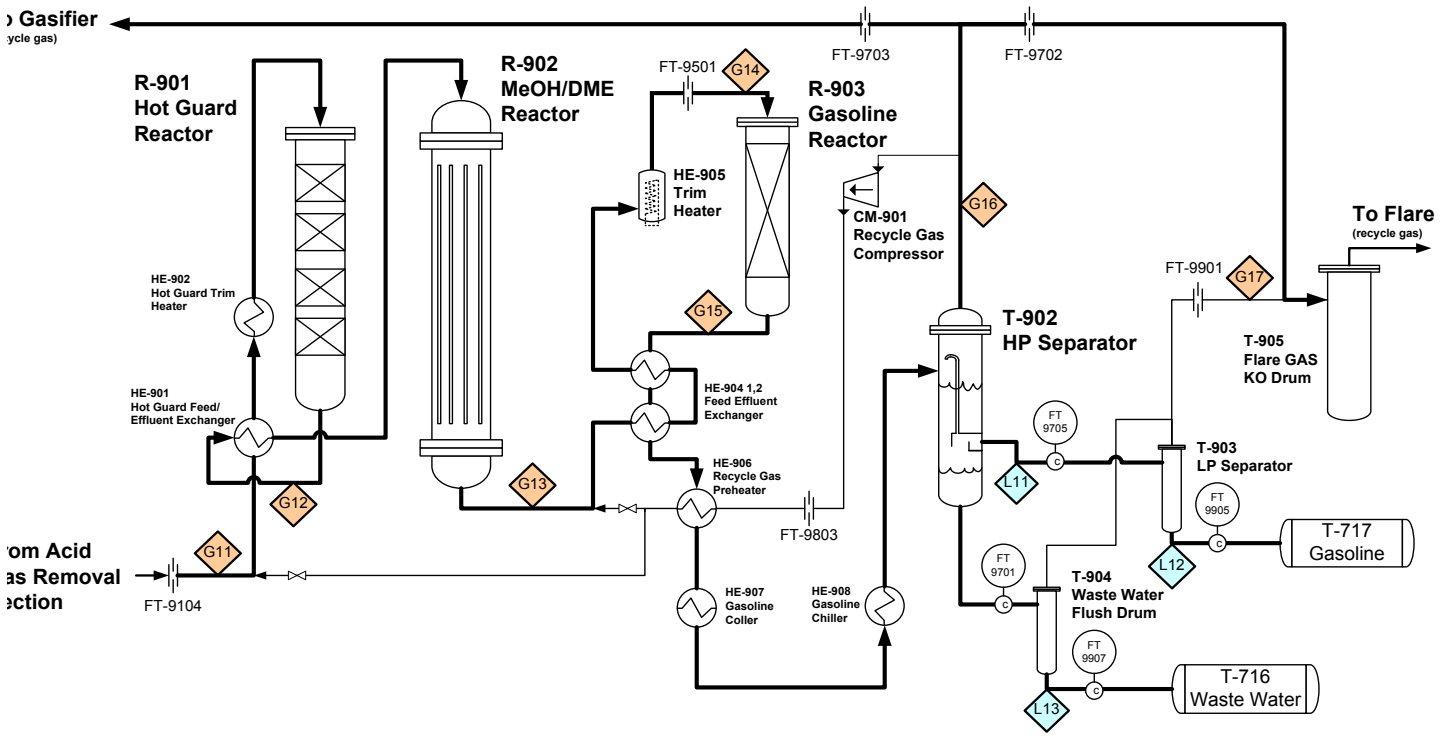
- Essential core of gasification & gas cleanup
- Gasifier ran reliably
- Hot gas filter development advanced through testing
- Pall ceramic filters
- Also validated 1300°F version for higher efficiency
- Tar Reformer converted 85% of CH_4, 99.0% of benzene, 99.5% of naphthalene

3 – Technical Accomplishments/ Progress/Results (continued)



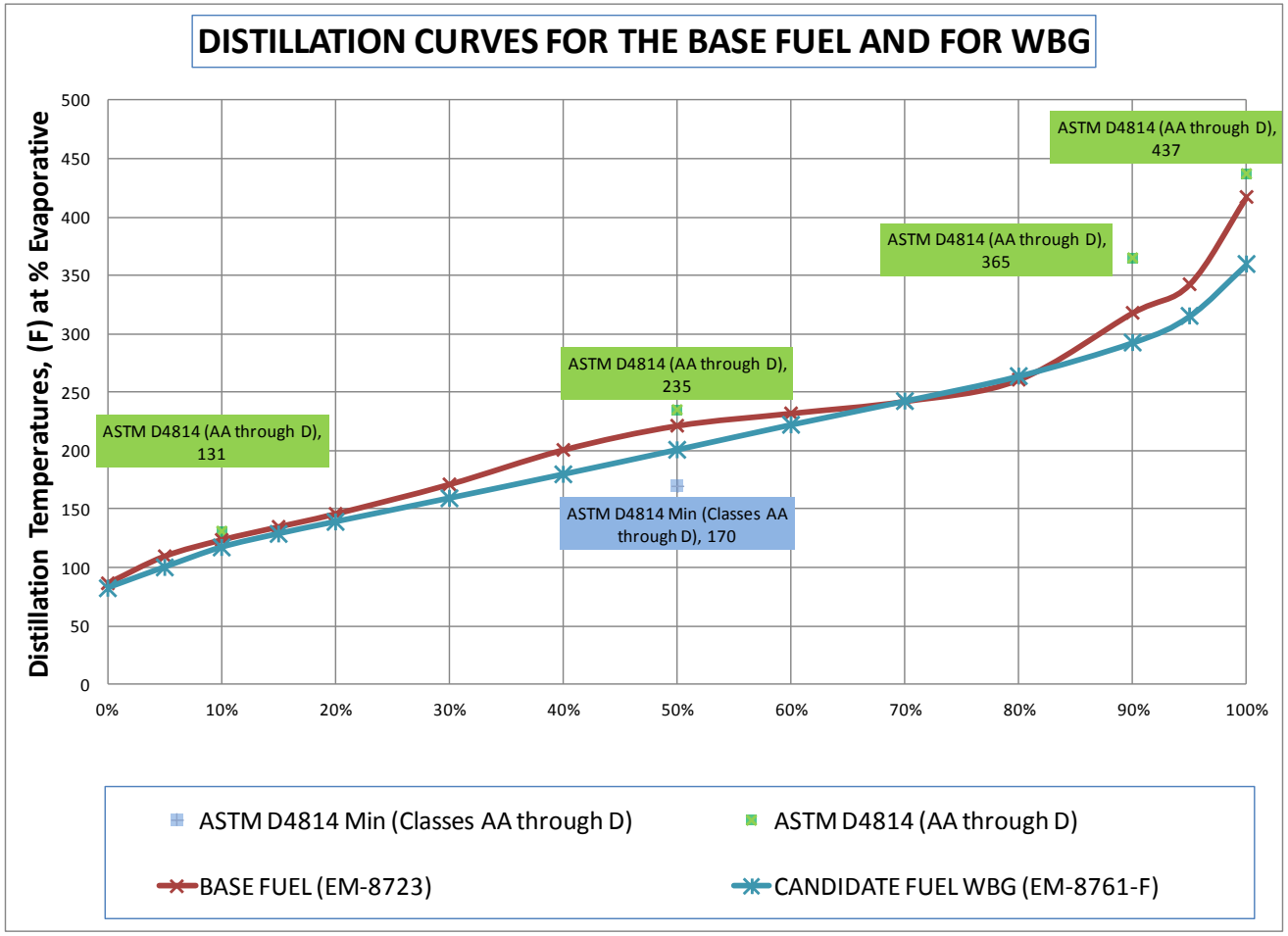
- Reduced syngas CO_2 from 40%+ to 2% for optimal yield
- Reduced H_2S from 15-25 ppmv to 1-3 ppmv
- Acid gas is >90% CO_2
- No significant solvent carryover
- Optimization parameters established

3 – Technical Accomplishments/ Progress/Results (continued)

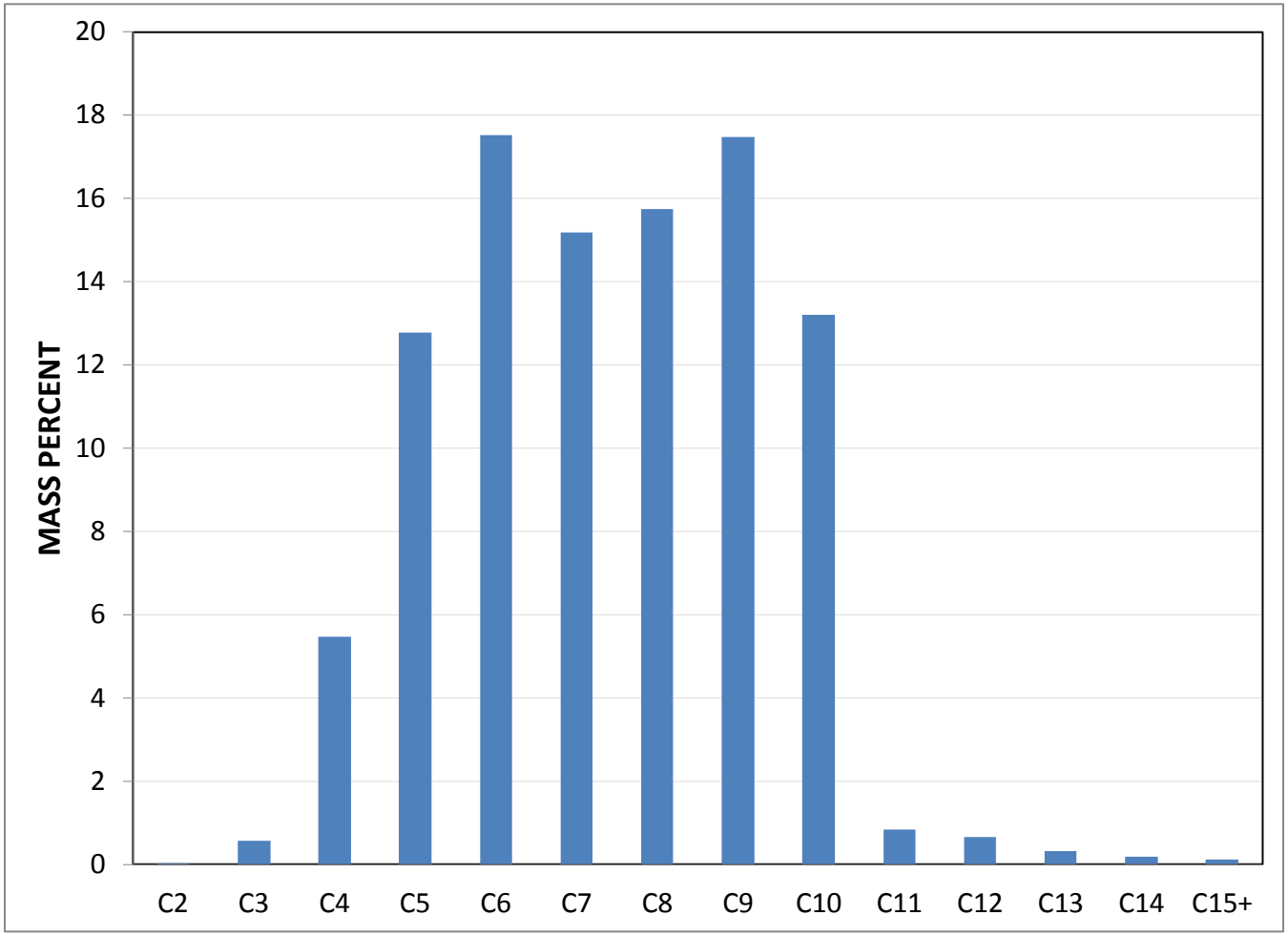


- Pilot testing validated catalyst activity, selectivity, and aging performance with biomass-derived syngas
- Improvements developed for startup and integration with BOP
- Commercial application design basis established

3 – Technical Accomplishments/ Progress/Results (continued)



3 – Technical Accomplishments/ Progress/Results (continued)



4 – Relevance
Biomass Program goals & objectives

- Key Biomass Program goal
  - ***Enable the production of biofuels nationwide and reduce dependence on oil through the creation of a new domestic bioenergy industry supporting the EISA goal of 16 bgy of cellulosic biofuel by 2022***
- This project:
  - Established design basis for a commercial plant to produce 57 million gal/year of **drop-in** renewable gasoline
  - 100 plants of this size would provide 36% of EISA cellulosic biofuel goal for 2022
- Other key points
  - 95% of cars now on the road burn gasoline
  - No new infrastructure or automotive technology required
  - Agricultural wastes and energy crops can expand future resource base

4 – Relevance
Sustainability and life cycle emissions

- Sustainability
  - Definition: ***the capacity of forests … to maintain their health, productivity, diversity, and overall integrity, in the long run, in the context of human activity and use***
  - Feedstock will be mill wastes, forest residues, thinnings, brush, etc.
  - At least 60% more energy-efficient than burning in boilers
- Emissions
  - **73.7%** reduction in GHG life-cycle emissions compared to conventional gasoline
  - **1.0 million bbl** of crude oil displaced per year for one plant
  - No hazardous solid or liquid wastes

4 – Relevance
Impact on commercialization strategy

- DOE piloting identified key challenges to a commercial offering
  - Process control in fully integrated mode
  - Startups, shutdowns and emergency trips in different plant sections
  - Sensitivity of product yield and quality to operating conditions in different plant sections
  - Catalyst lifetimes
  - Maintenance expectations
  - Confirmation of projected mass and energy balances
  - Performance of materials of construction
  - Confidence-building

Summary

- I**ntegrated** wood to gasoline pilot plant established design basis for a commercial plant to produce 57 million gal/year of **drop-in** renewable gasoline
  - **100** plants of this size would provide **36%** of EISA cellulosic biofuel goal for 2022
  - Projected gasoline production cost of **$2.56** per gallon
- No new infrastructure or automotive technology required
- GHG life-cycle emissions reduced by **73.7**% compared to conventional gasoline
- Efficient and visible project management procedures with WBS down to level 4 work packages with well defined milestones, deliverables and decision points
- Budget control with Earned Value tracking extended to subcontractors and vendors
- Three test campaigns were completed producing >10,000 gallons of gasoline
- Bio-derived gasoline passed single-engine emission tests for EPA registration
  - Phillips 66 applying for EPA registration of 80% blend
- 75,000-mile track testing validated performance of 50% blend
  - No adverse impacts on mileage or engine condition
  - Provides OEM acceptability of product

Additional Slides

(Not a template slide – for information purposes only)

- *The following slides are to be included in your submission for Peer Evaluation purposes, but will **not** be part of your oral presentation –*
- *You may refer to them during the Q&A period if they are helpful to you in explaining certain points.*

Responses to Previous Reviewers' Comments

- Comment: 96-hr test is not long enough to properly vet the technology. Further testing is required.
  - Response: Final test provided more data at optimized conditions, showing catalyst aging and stability with recycle
- Comment: PIs need to run the facility long enough to actually see longer-term performance, and to allow for the manufacture of sufficient product so as to allow for customer sampling and acceptance testing.
  - Response: Sufficient product was made for single-engine emissions testing, gasoline characterization and evaluation by refiner, and 75,000-mile track testing of 50% blend in four vehicles.

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral presentation. These Additional Slides will be included in the copy of your presentation that will be made available to the Reviewers.

Publications, Patents, Presentations, Awards, and Commercialization

1. IEA Bioenergy Task 42 – Biorefining - 8th Task Meeting, Chicago IL, October 4-6, 2010
2. National Science Foundation workshop on Separation challenges in thermo-catalytical production of biofuels, Washington D.C., April 4-5, 2011
3. tcbiomass2011 Conference, Chicago IL, September 27-30, 2011
4. tcbiomass2013 Conference, Chicago IL, September 3-6, 2013
5. Gasification Technologies 2013 Conference, Colorado Springs CO, October 16-23, 2013
6. Biomass Indirect Liquefaction Strategy Workshop, DOE Bioenergy Technologies Office, Golden CO, March 20 -21, 2014
7. IEA Bioenergy and AMF workshop, Copenhagen Denmark, May 20, 2014
8. 22nd European Biomass Conference and Exhibition, Hamburg Germany, June 23-26, 2014.
9. Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products (TCS2014), Denver CO, September 2-5, 2014.
10. 2014 International Bioenergy and Bioproducts Conference, Tacoma WA, September 17-19, 2014.

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