the Energy to Lead

Synergistic Combination of Natural Gas and Biomass in Gasification-based Systems for Chemicals and Fuels Production

> **Ron Snedic**
Vice President, Corporate Development,
Gas Technology Institute

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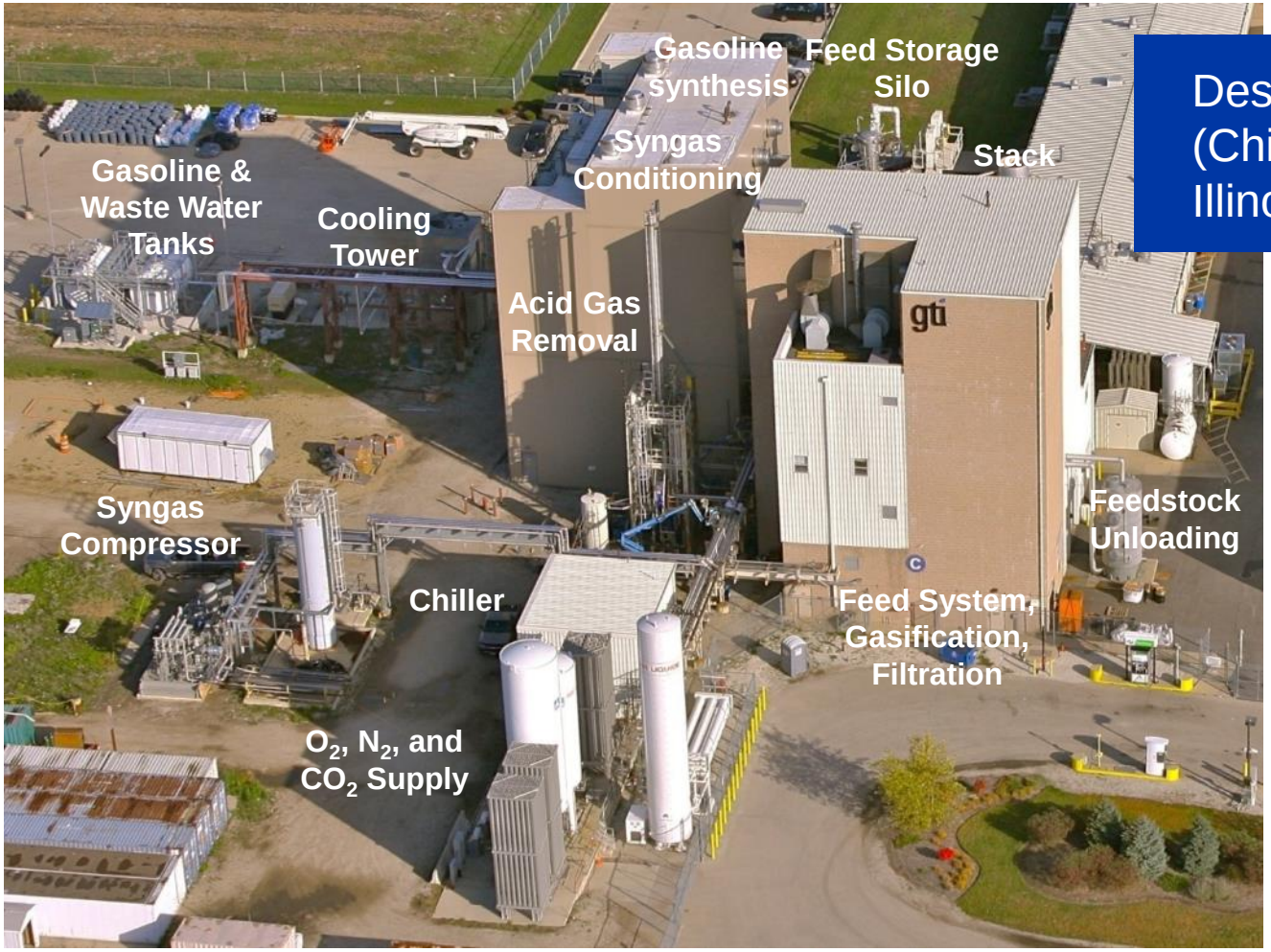
gti

GTI's Integrated Biorefinery (IBR) Facility

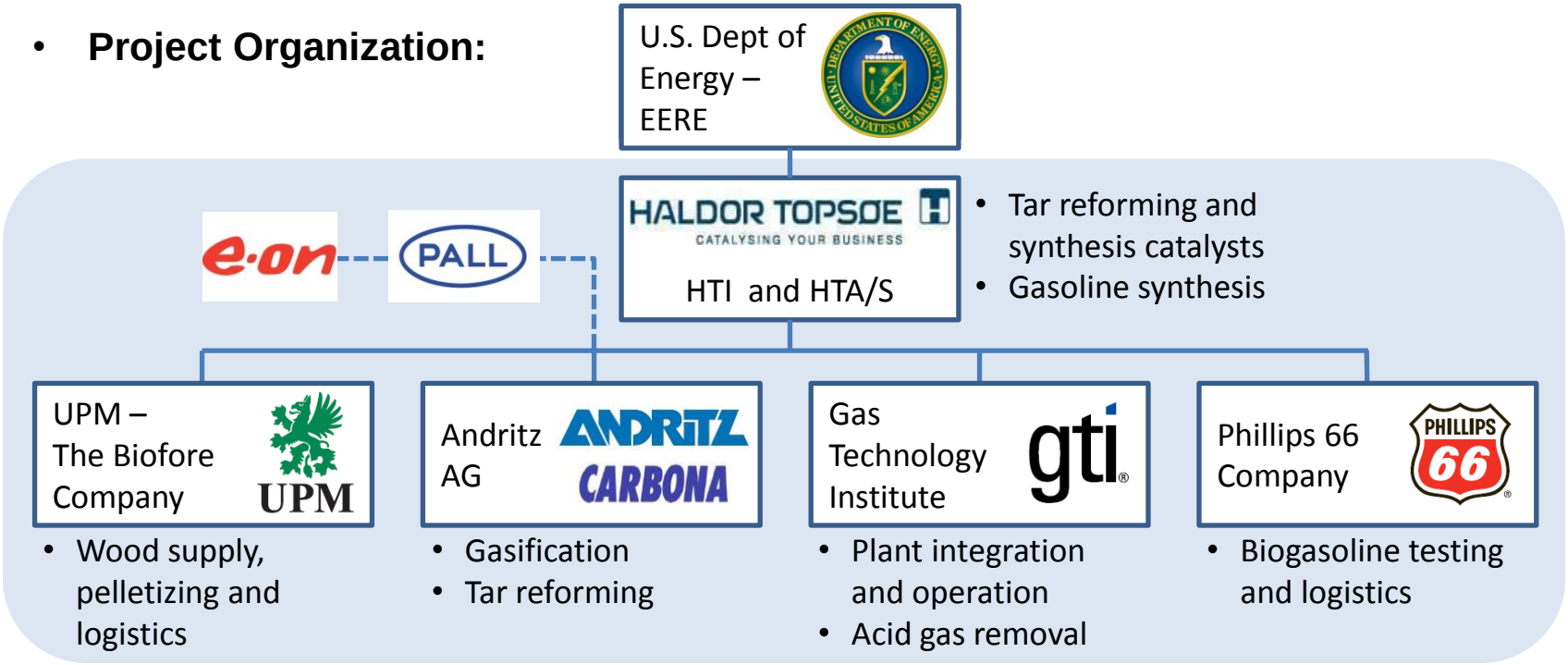


Des Plaines (Chicago), Illinois, USA

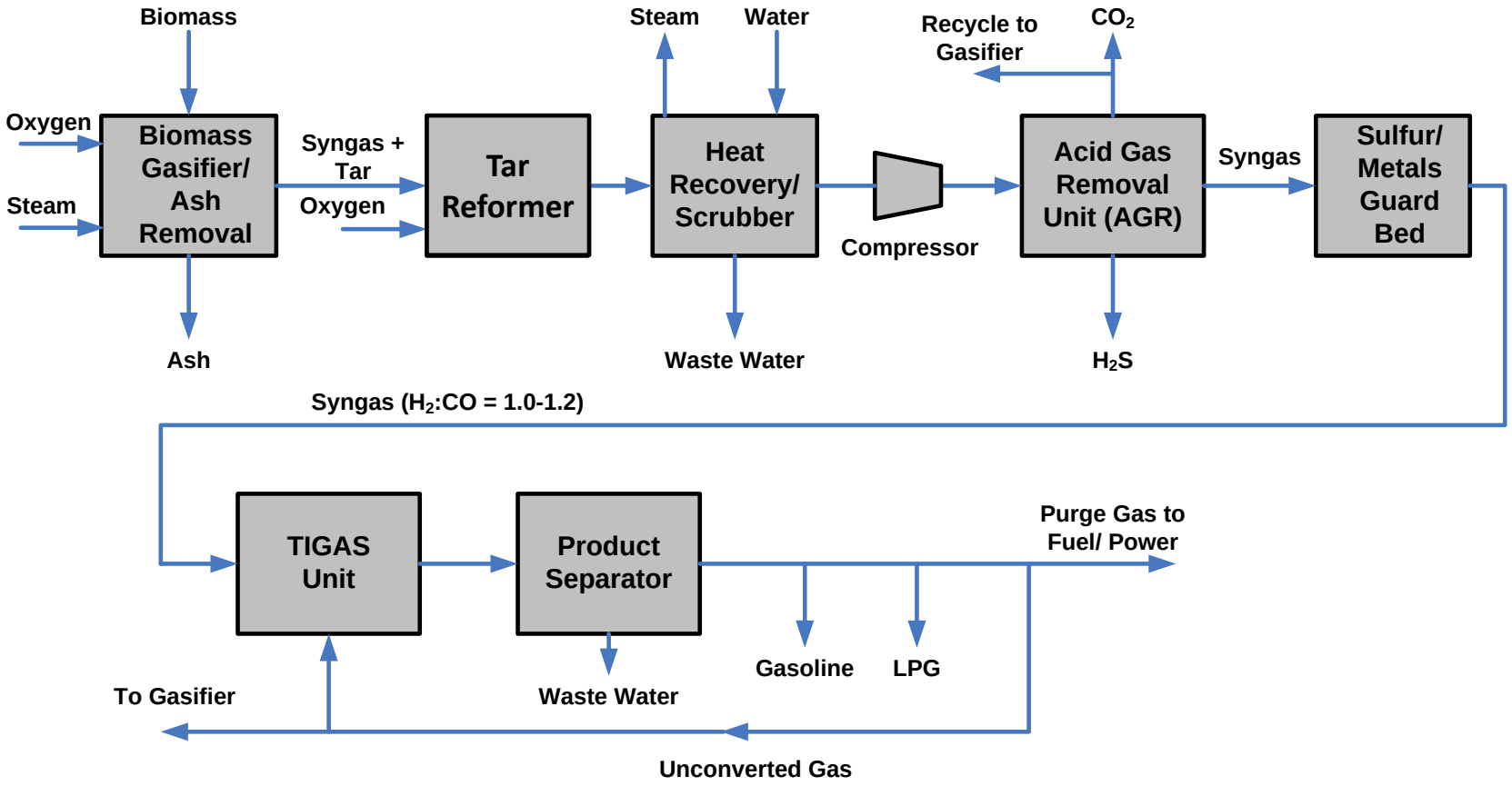
Project Description and Team

- **Project Objectives:** Develop and test an integrated process for thermochemical conversion of woody biomass to drop-in gasoline blendstock
  - Validate performance of the technologies and integration scheme
  - Reduce risk and support deployment of demonstration-scale plants

- **Project Organization:**



Gasoline Production from Biomass Gasification



Pilot Plant Key Results
Conversion and Product Properties

- Engine emissions from 80% biogasoline blend were 'substantially similar' to standard gasoline
- Fleet test with 50% biogasoline blend logging 120,000 km on each of 4 vehicle pairs
- Pilot results reduce technical risk sufficiently for licensors to offer commercial package

Pilot Plant Results	
Biomass* fed, kg	143,900
Gasoline made, kg	14,300
LP gas made, lb	2,900
Energy conversion, biomass to fuels	36 - 40%
Octane (R+M)/2	89 - 92
Aromatics, vol%	29 - 33

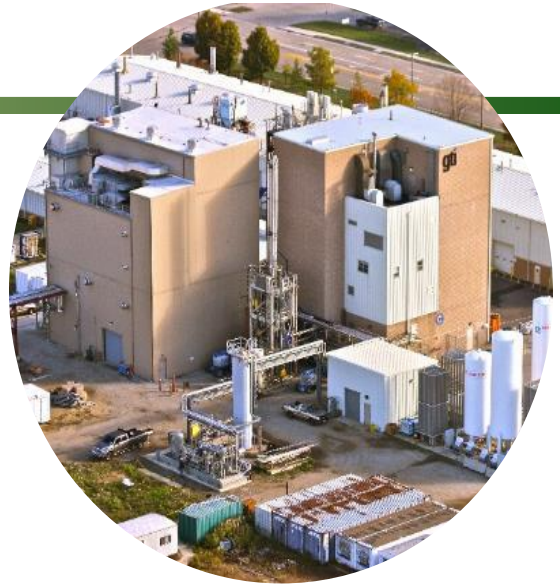
* 6.0 wt% moisture, 0.9 wt% ash
† Dry ash-free basis

Why Incorporate Natural Gas in Biofuels Production?

- Increase process scale to lower CAPEX per unit production
- Increase process efficiency to lower OPEX per unit production
- Stabilize OPEX and production costs with dual feed
- Supply hydrogen to make higher quality products
- Simplify or eliminate process steps to lower CAPEX/OPEX
- Supply heat to permit maximum renewable content in liquids

ENABLES NEXT STEP

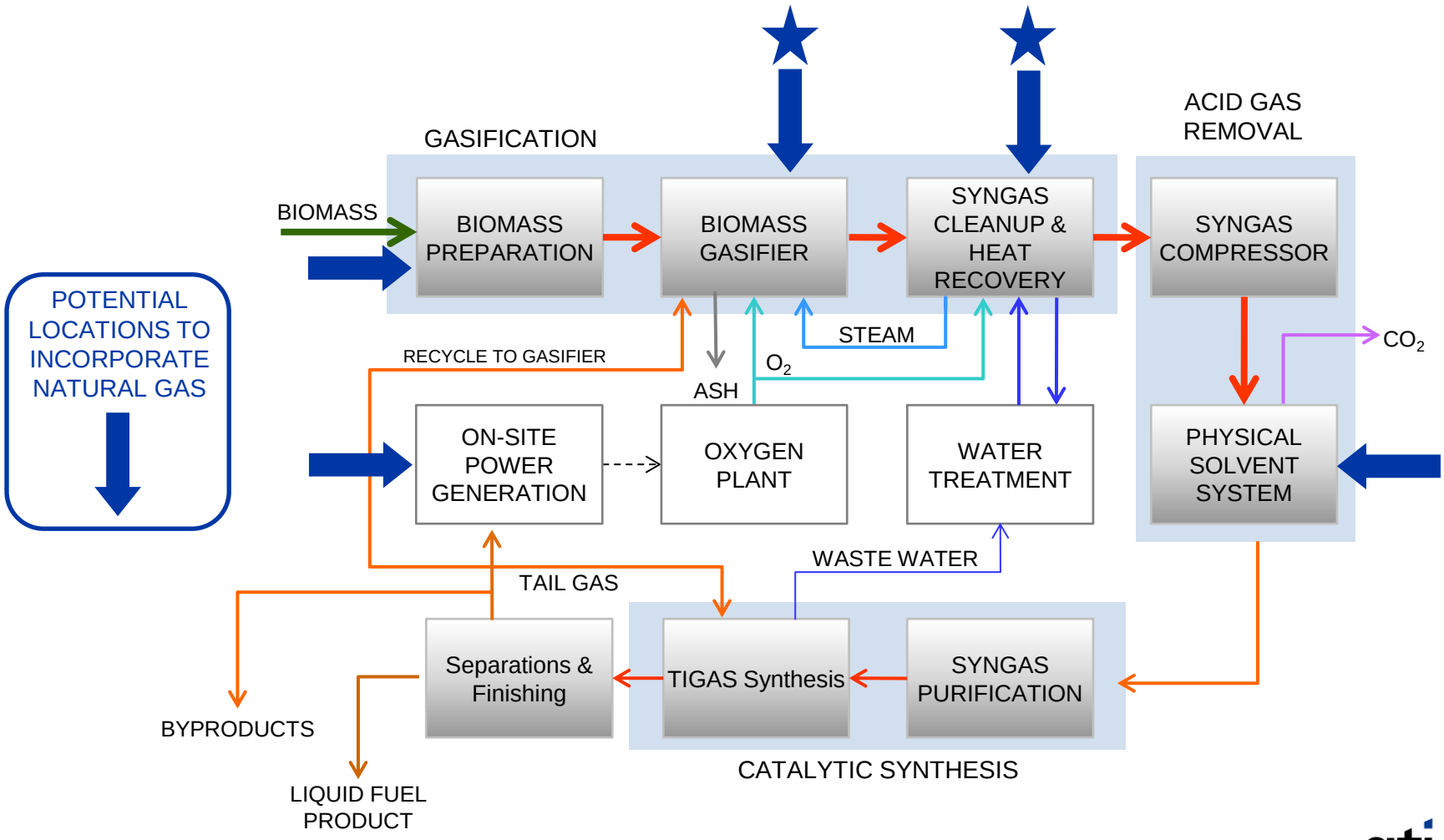
GTI's Technology Platform



The TIGAS Integrated Biorefinery tested at GTI offers a technology platform to combine natural gas and biomass

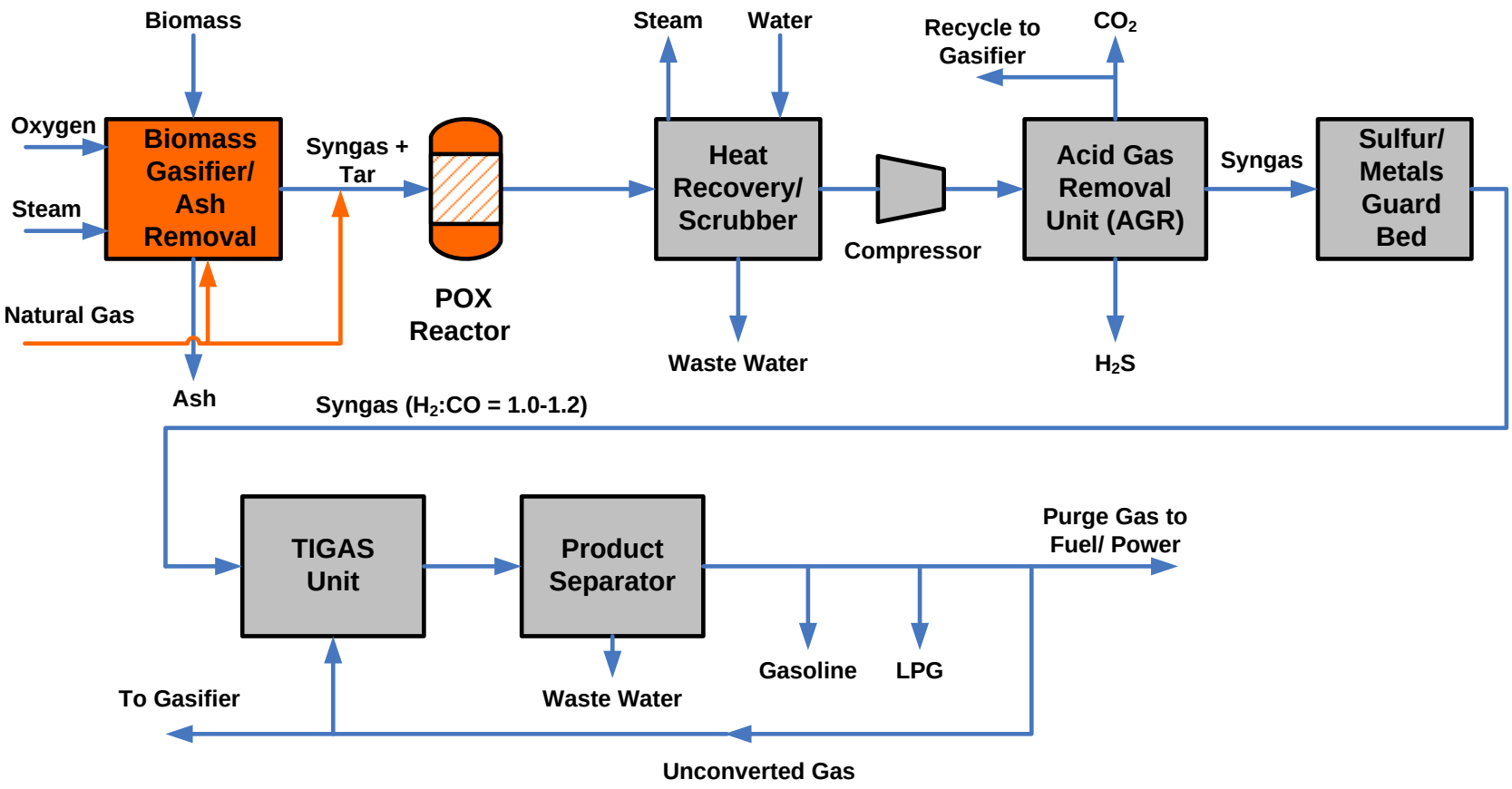
- Base case techno-economics for woody biomass feed had been completed
- Considering use of natural gas as a hydrogen donor, and as a means of partial oxidation of higher hydrocarbons
- Sensitivity analyses on economics were done based on introducing natural gas as a minority feedstock, retaining greenhouse gas reductions in gasoline product above 60%

Natural Gas Options in Natural Gas Plus Biomass to Liquids (G+BTL) Production



INCREASING CAPACITY WITH LOWER CAPEX

Gasoline Production from Biomass Gasification



Technical Options to Incorporate Natural Gas for Biofuels Production

Where is the best place to incorporate natural gas in biofuel processes?

- Does combustion for heat provide the best value from natural gas?
- Should natural gas be used as an external hydrogen source?
- Should natural gas be incorporated as a hydrogen carrier to be internally reformed?

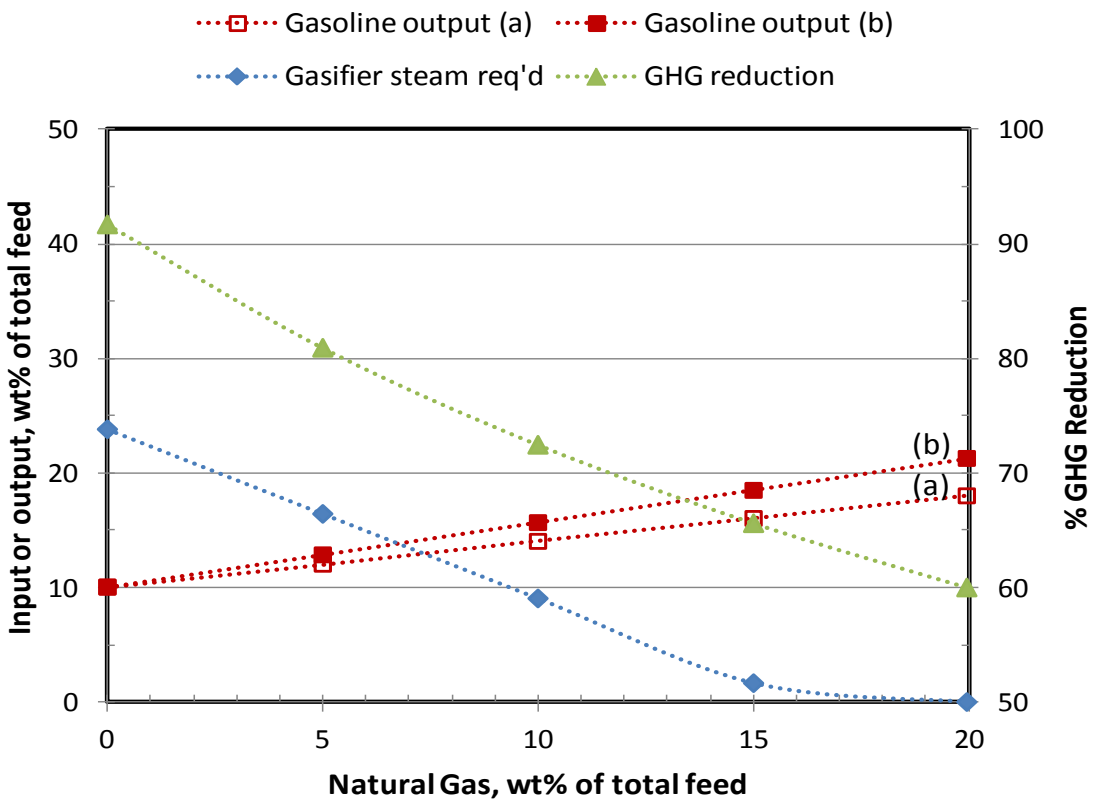
To what extent are these answers sensitive to feedstock prices and location?

GTI will address these questions in our next project

U.S. EXAMPLE

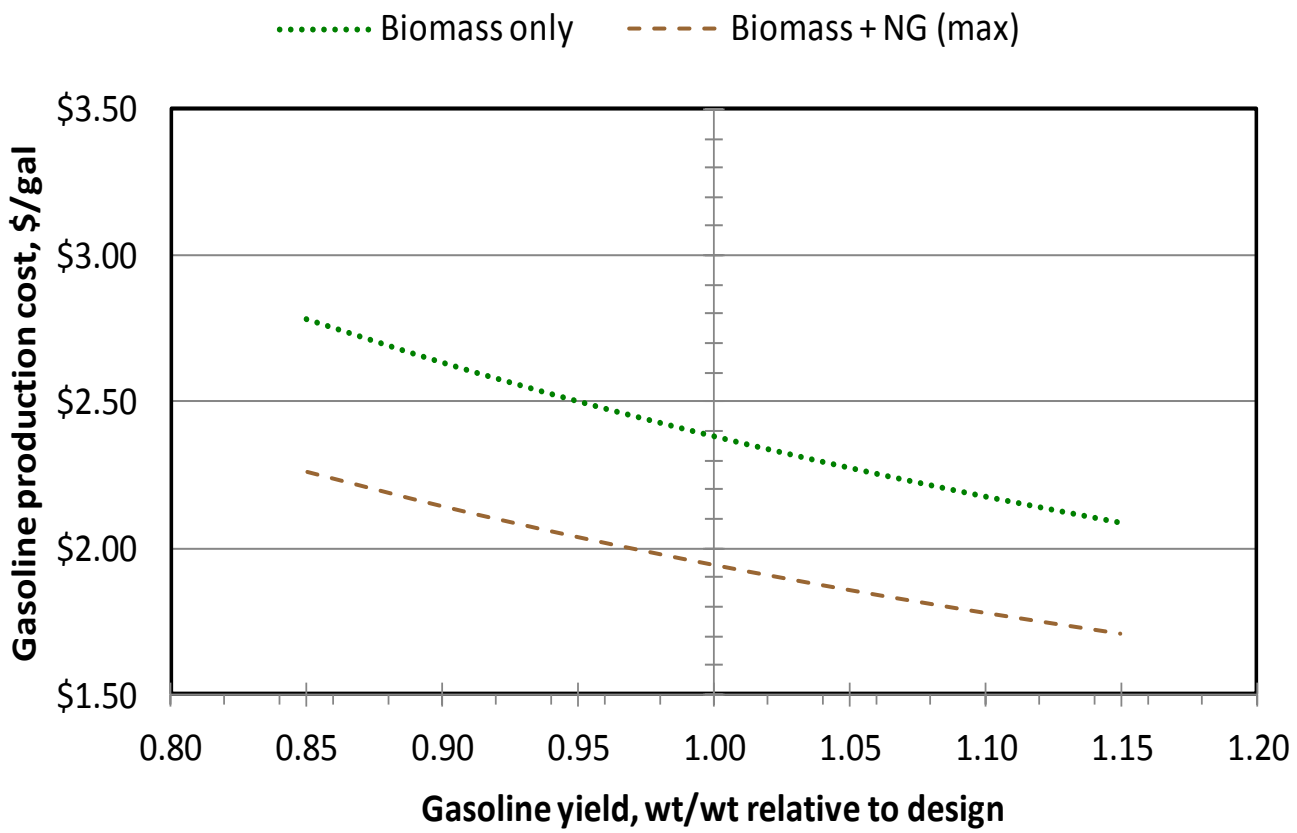
Impact of Natural Gas Addition on Key Biorefinery Metrics

[(a) = 58% methane conversion; (b) = 77% methane conversion]

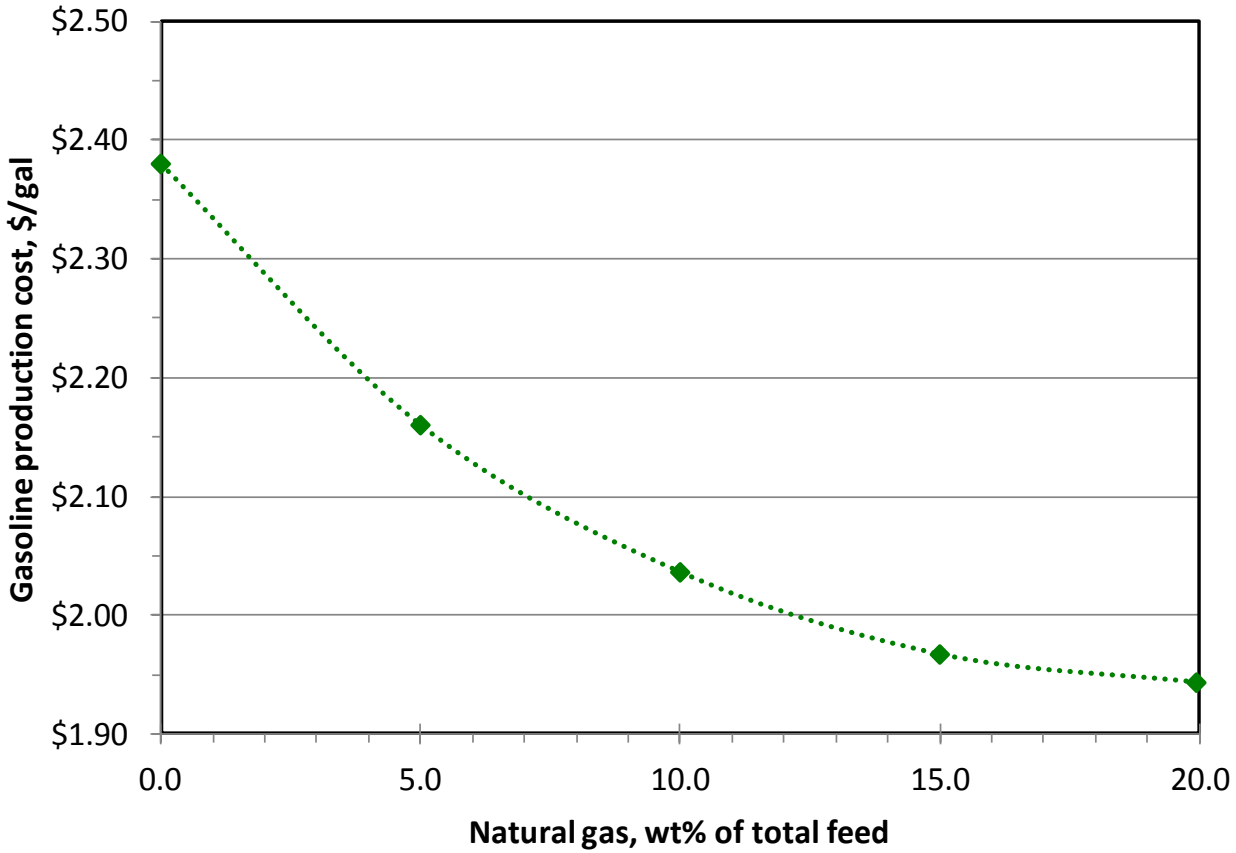


U.S. EXAMPLE

Effect of Gasoline Yield on Gasoline Production Cost

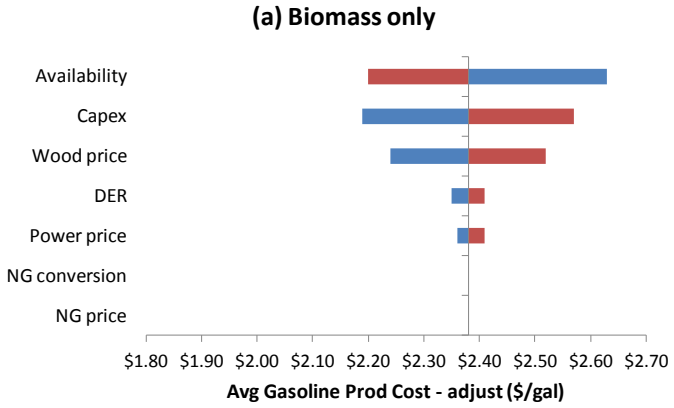


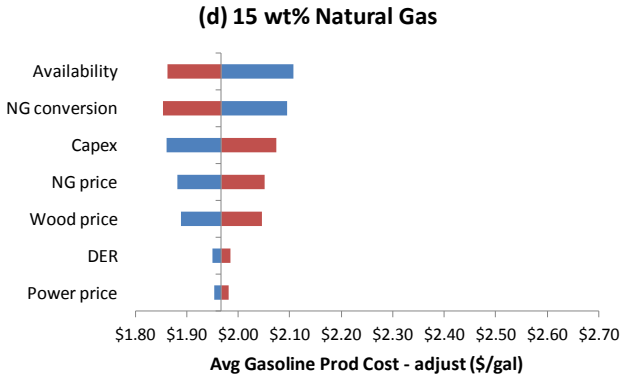
Gasoline Production Cost as a Function of Natural Gas Fraction to the Biorefinery



Natural Gas + Biomass for Gasoline Production

- Analysis carried out for a TIGAS project with up to 15% natural gas input suggests cost of production of gasoline would be reduced nearly 20% to less than $2/gallon
- Natural gas as a supplement to biomass-to-liquids processes could accelerate commercial deployment by increasing capital efficiency, lowering production costs, and also lowering sensitivities to key risk factors





DER is debt/equity ratio

Connect With Us

Contact:
Ron Snedic
Vice President,
Corporate Development

847-768-0572
ron.snedic@gastechnology.org

Gas Technology Institute

1700 S Mount Prospect Rd,
Des Plaines, IL 60018, USA

www.gastechnology.org

@gastechnology

Authors:
Vann Bush, Bruce Bryan,
Richard Knight, Arun Basu,
Andrew Kramer, and
Rachid Slimane, GTI

Economic Model Assumptions

- Biorefinery co-located with existing paper mill in Grand Rapids, Minnesota
- Biomass feedstock = 5800 metric tons/day green waste wood chips at $32/MT
- Plant lifetime = 15 years (startup in 2019)
- Operating days per year = 350
- Plant availability = 90%
- Debt/equity ratio = 1.0
- Interest rate = 8.0%
- Natural gas price (2019) = 15.9 €/MWh