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Biomass Gasification Technology Slides

GTI Fluidized Bed Gasifier Development

1975 Bituminous Caking Coal

1978 Lignite Coal

1980 Biomass pilot HP

1983 10 tpd, 35 bar PDU

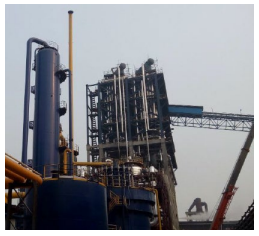
1992 Coal & Biomass demonstration 80 tpd - Finland

1995 DOE awarded 1,250 tpd biomass IGCC Plant, not built

2003 Flex Fuel 30 bar pilot unit, Chicago

2005 High ash Indian Coal tested for IGCC

2008 SES Zao Zhuang 400 tpd oxygen-blown, high-ash coal



2015-2016 SES Chalco 3 sites, 7 gasifiers 350-550 tpd coal

1975 1985 1995 2005 2015 2019

1980 Awarded DOE grant (Memphis) – Scale up technology to 1,000 tpd gasifier, engineering completed

1995 Commercial 150 tpd air-blown, Shanghai, PRC

1998 Biomass demo plant 100 tpd, Maui, Hawaii

2006 Carbona 150 tpd CHP Plant Denmark using wood

2012 SES Yima 2,400 tpd sub-bituminous coal

- **Extensive developmental history**
- **Detailed scale-up, performance & environmental assessments**
- **Supported by US DOE and Industries**

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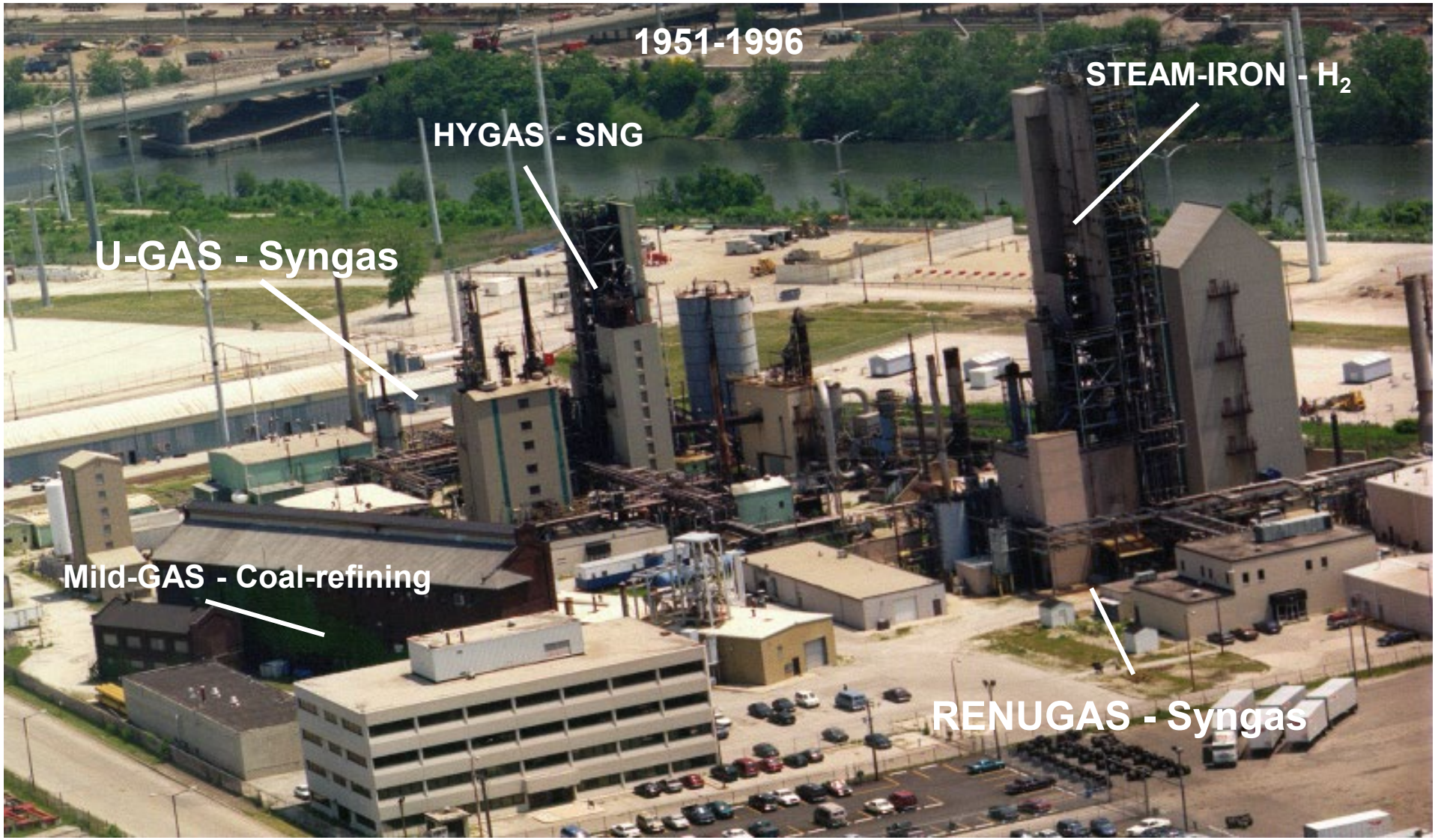
GTI Energy Development Center



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Biomass Gasifier Projects

80 ton per day Gasification Pilot Plant in Tampere, Finland using biomass & coal

100 ton per day Bioenergy Demo Plant in Maui, Hawaii using bagasse

20 ton per day Flex-Fuel Test Facility in Des Plaines, IL for biomass & coal

150 ton per day CHP Plant in Skive, Denmark using wood

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Tampere, Finland Pilot Plant (1992)

- 26 Tests
- 3850 h operation
- 80 tpd biomass
- 30 tpd coal
- up to 20 bara

- 700+ tons coal, 5300 tons biomass processed
- Multifuel capability; mixed coal and biomass (wood & straw) tested
- Demonstration of clean syngas for IGCC; cogen heat & power

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Biomass Feedstocks Tested

- Hard wood chips
- Soft wood chips
- Hard & soft wood mix
- Forest residue
- Bark
- Paper mill waste
- Wood pellets
- Saw dust
- RDF pellets
- Wheat straw
- Willow
- Alfalfa
- Rice straw
- Oil palm
- Bagasse

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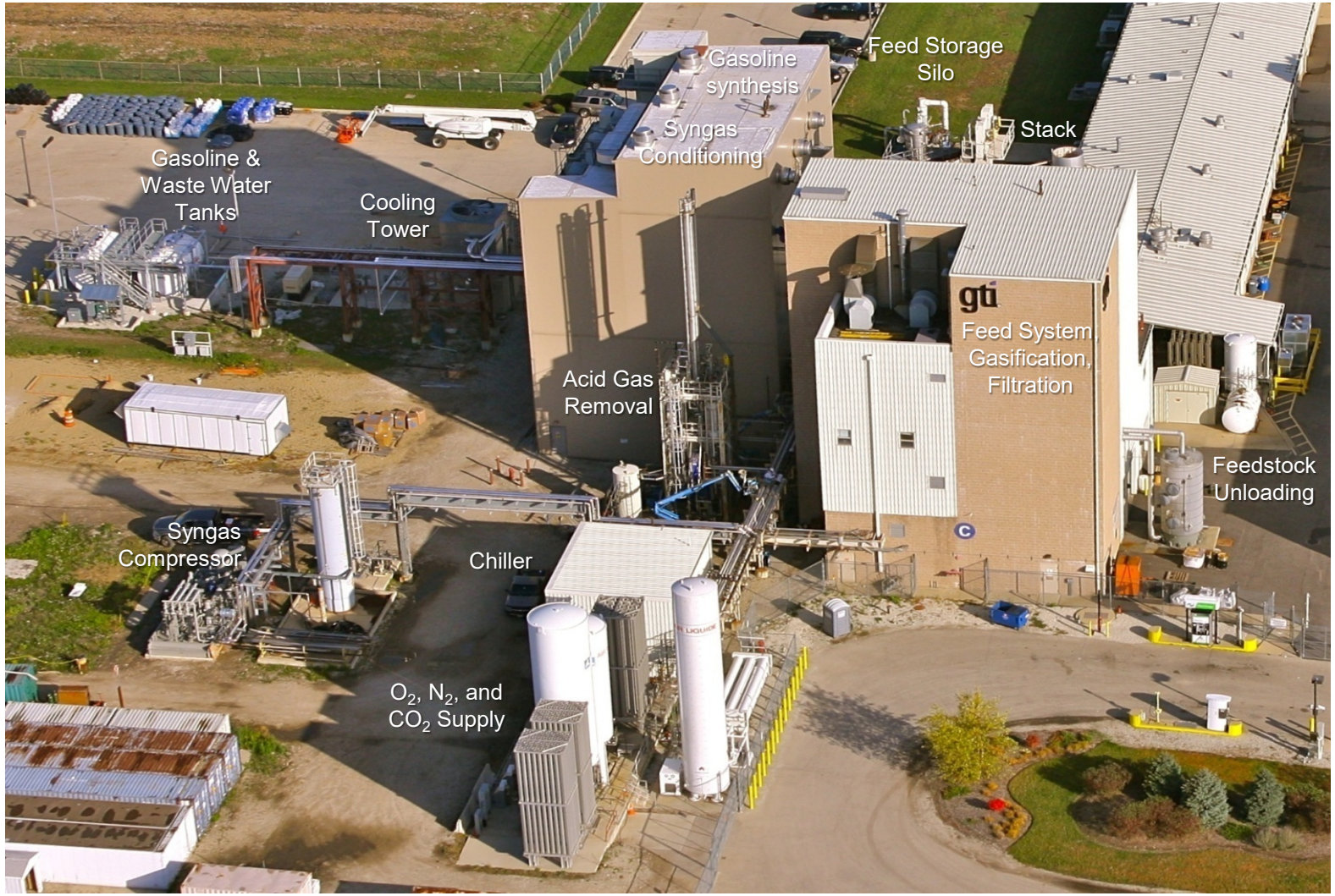
Gasification Technology Development Platform



- 5 MWth fluidized bed and entrained flow gasifiers at 400 psig, air- or O_2-blown
- 20 TPD coal or biomass
- 800 lb/h natural gas POx
- Hot and ultra-hot gas filtration
- Catalytic syngas reforming
- Syngas compression to 1000 psig
- Sorbent and solvent acid gas removal
- Syngas to liquid fuels synthesis

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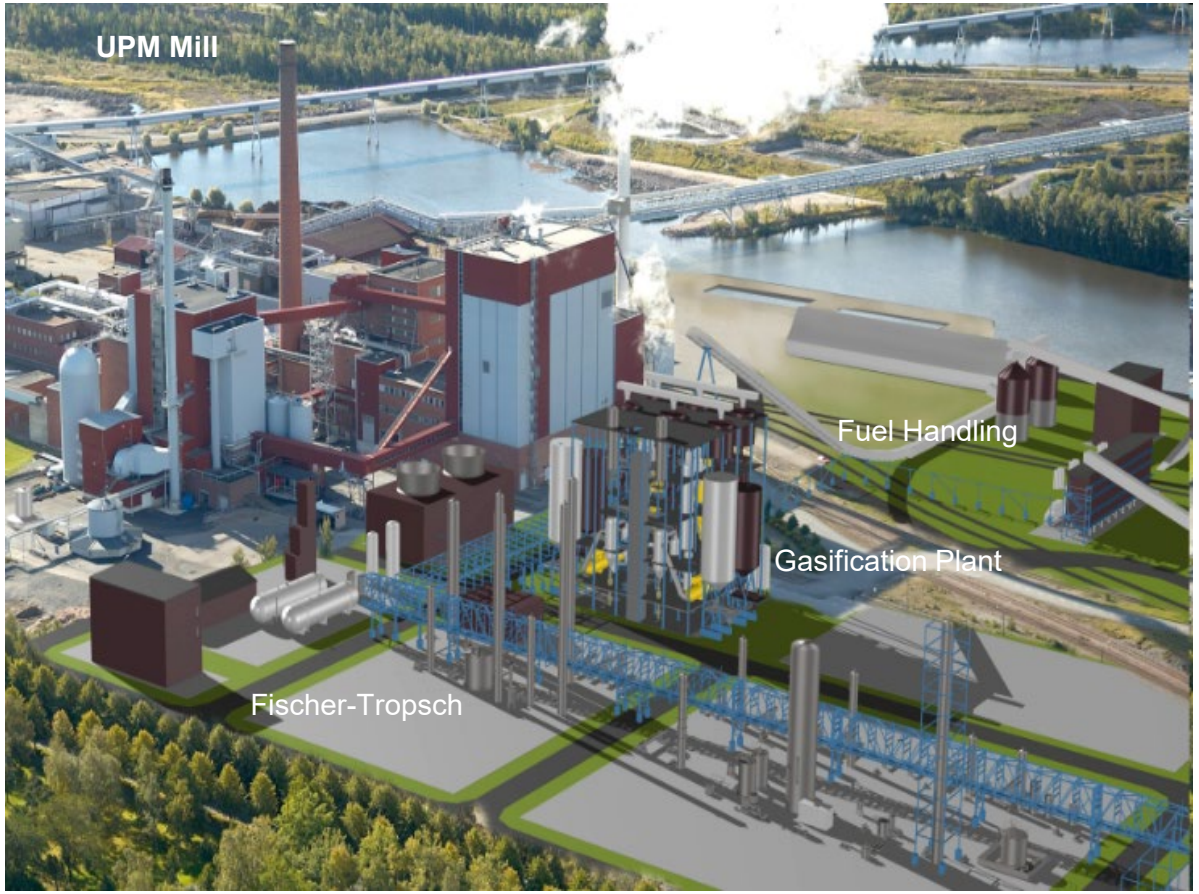
Fischer-Tropsch Products from Gasification of Forest Biomass

> Andritz-Carbona partner

> Sponsored by UPM-Kymmene

- Pilot gasification and gas processing at GTI: 15 tpd biomass gasification, catalytic reforming (1/100 commercial scale)
- Forest residues: tops, bark, hog fuel, stumps
- Commercial site for 300 MWth scale in France selected for NER-300 funds



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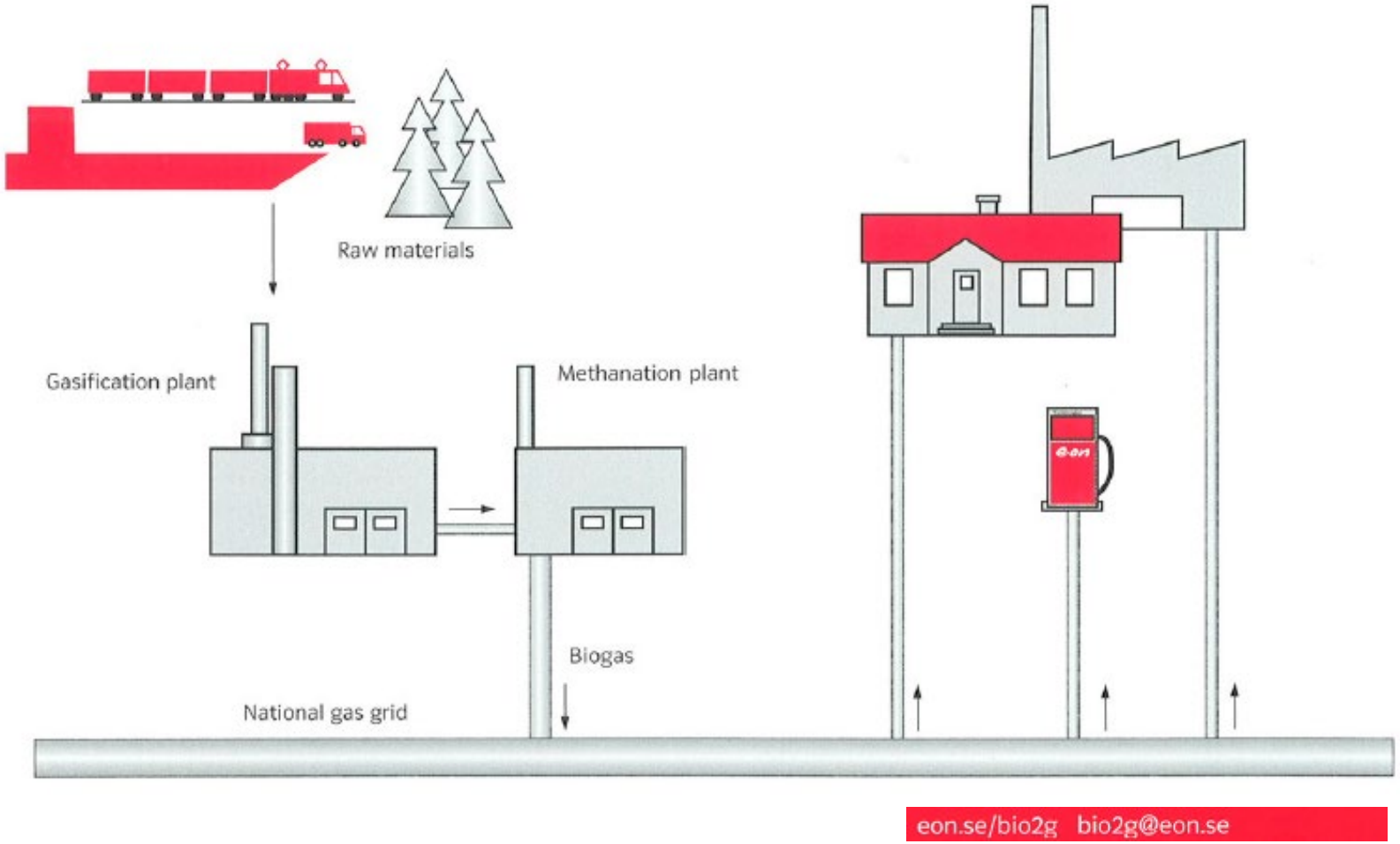
Bio2G: Forest to Renewable Natural Gas



- Sustainably managed forests
- Existing supply infrastructure
- High conversion efficiency
- Existing distribution infrastructure
- Decarbonize all sectors of economy
- Highest potential end use efficiency

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Integrated Biorefinery Pilot Plant

- 1000 hours of pilot-scale testing including demonstration of fully integrated operation – on time and on budget
- Produced more than 10,000 gallons of 89-92 octane gasoline
- 61-65% syngas to motor fuel conversion (LHV energy basis)

HALDOR TOPSØE

gti UPM ANDRITZ PHILLIPS 66 U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

PALL e·on

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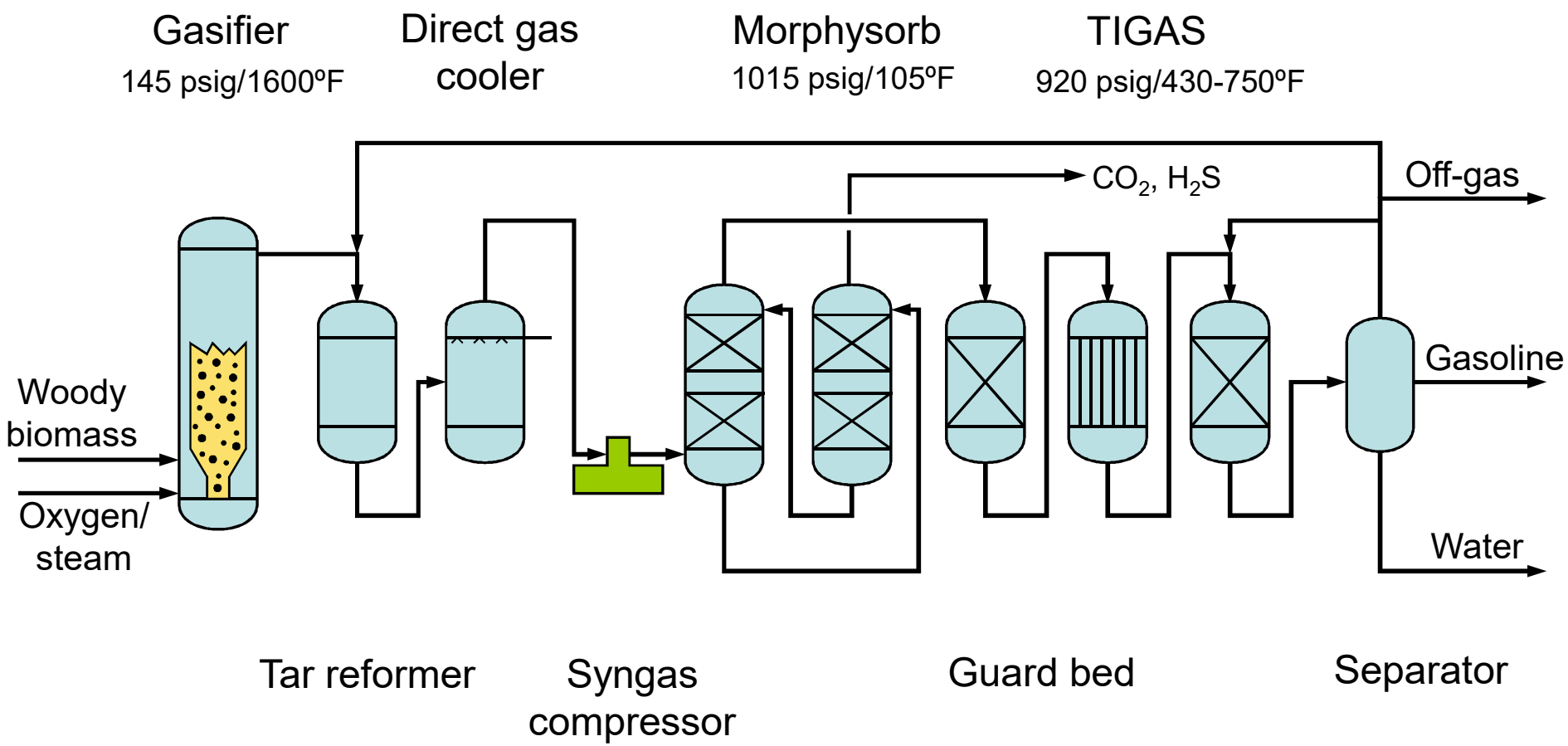
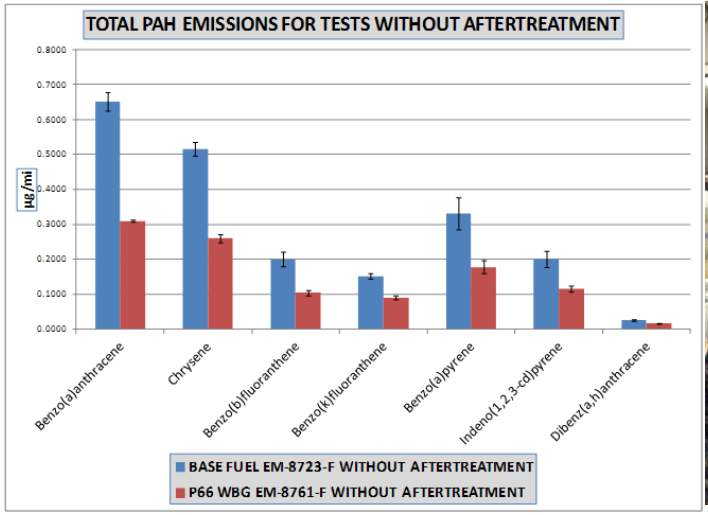
Process Flow Sheet of Pilot Plant



WOOD 2 GASOLINE

Key Results



- Engine emissions from 80% biogasoline blend were ‘substantially similar’ to standard gasoline
- Fleet test with 50% biogasoline blend logging 75,000 miles on each of 4 vehicle pairs
- Fuel certified by USEPA as a renewable gasoline blendstock

Pilot results reduced technical risk sufficiently for licensors to offer commercial package.

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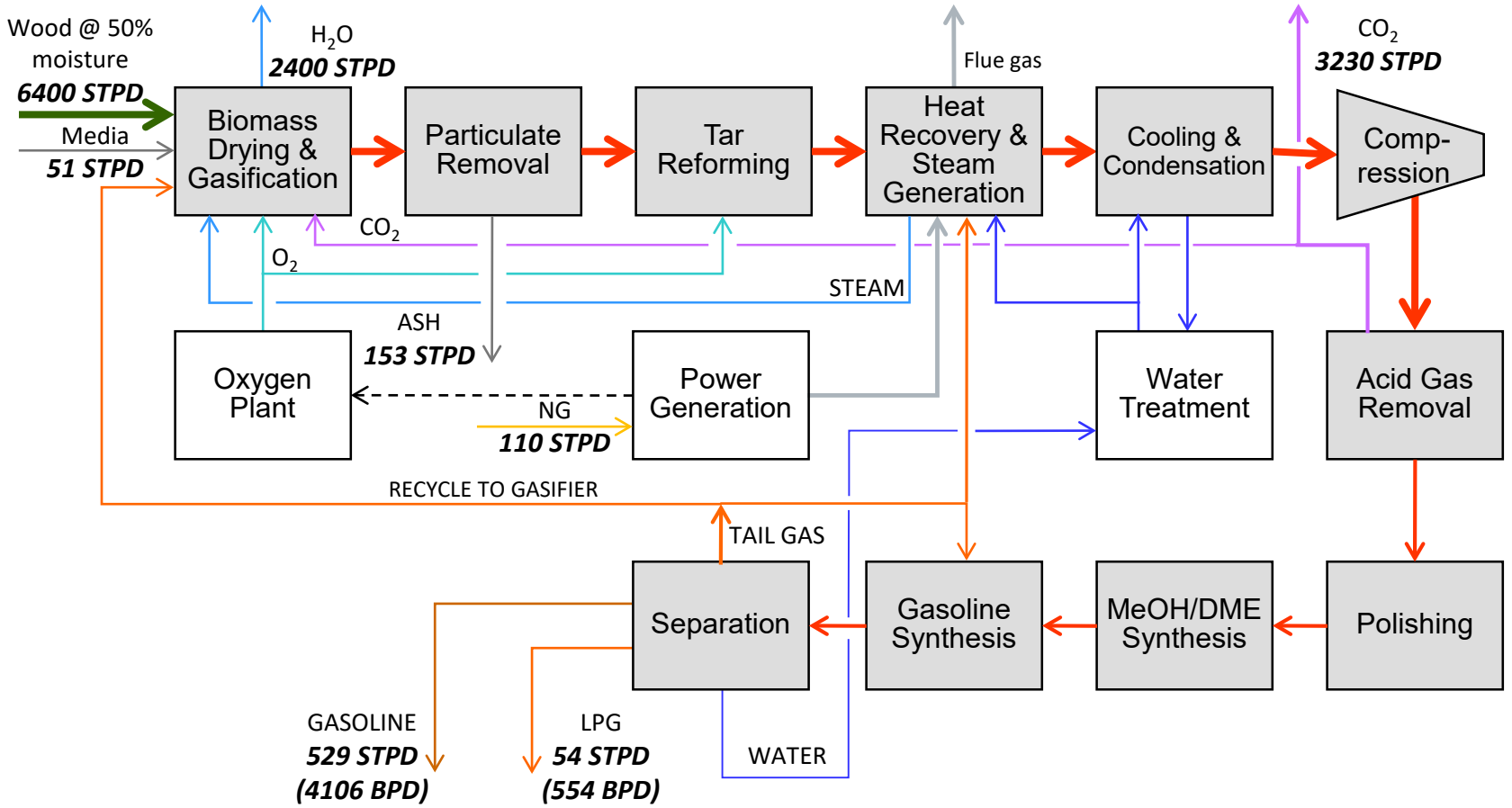
Commercial Integrated Biorefinery PFD



Summary of Biomass Gasification

- Bubbling Fluidized Bed gasifier developed for multiple feedstocks
- Applications for power, chemicals, and fuels have been tested
- Downstream gas conditioning developed to provide high-purity syngas
- Commercial reference in operation since 2006 for combined heat and power with over 90% efficiency
- Integrated biorefinery configuration demonstrated wood to gasoline production over 1000 hours of operation producing 10,000 gallons of gasoline
- Commercial systems have been designed for Fischer-Tropsch diesel and Renewable Natural Gas production

Technology developed over 40 years to handle waste biomass materials from agricultural residues to wood wastes to refuse-derived fuel.

Thousands of hours of testing and over a decade of reference commercial operations provide technical confidence in the GTI-developed direct bubbling fluidized bed gasifier.

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