Biomass Gasification in the U.S.

Vann Bush
Gas Technology Institute

vann.bush@gastechnology.org
(o) +1-847-768-0973 (m) 1-205-862-0688

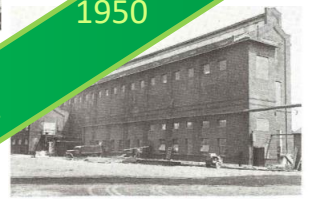
GTI Gasification Development History

Development Focus

Supply Security – **Substitute Natural Gas (SNG)** → Industrial Fuel Gas **Biomass, Renewables** Syngas to Power - IGCC → Syngas to Products Fuels, Chemicals, **SNG**

1941

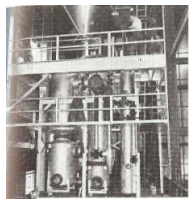
IGT



Lab Facility - 1947

1950

1960

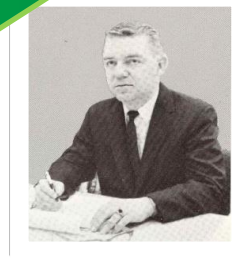


Early PDU

HYGAS Pilot Plant

1970

gri



Dr. James L. Johnson

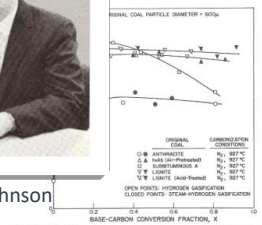


Figure 25 Effect of carbon conversion level on carbon dioxide surface areas of different coal chars gasified in a thermobalance apparatus at 927°C, 35 atm, in hydrogen and steam-hydrogen mixtures. Data from Johnson [121].

1980

RENUGAS Pilot Plant

Tampere - 1992

1990

gti

2000

Shanghai Plant - 1995

FFTF

2016

AGTF

Skive - 2007

Zaozhuang - 2007

Yima - 2012

HALDOR TOPSOE
CATALYSING YOUR BUSINESS

AEROJET ROCKETDYNE

ANDRITZ

e·on

UPM

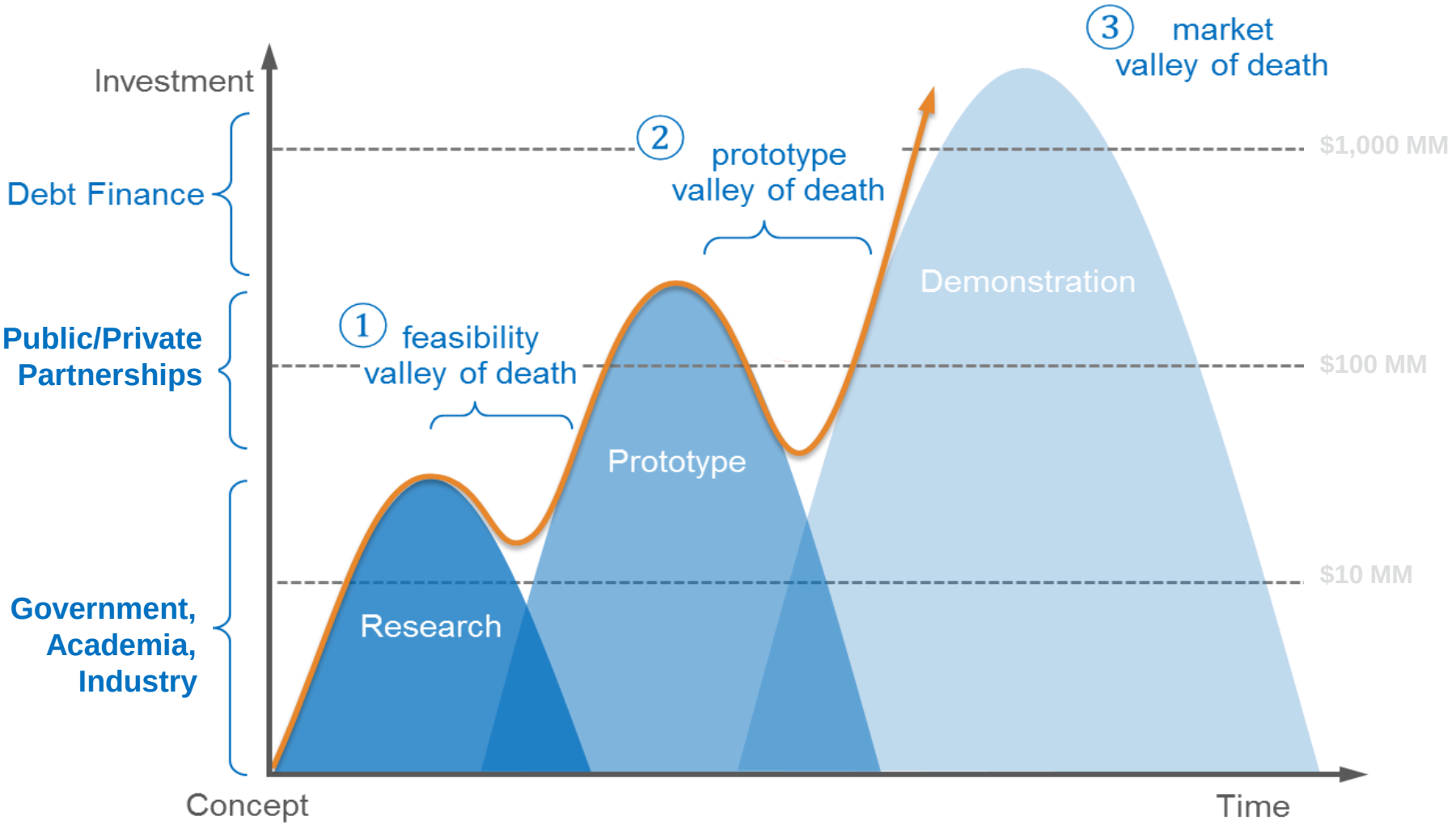
GreatPoint ENERGY

SES SYNTHESIS ENERGY SYSTEMS

SIEMENS Westinghouse

gti

Technical Innovation – Necessary, But Not Sufficient



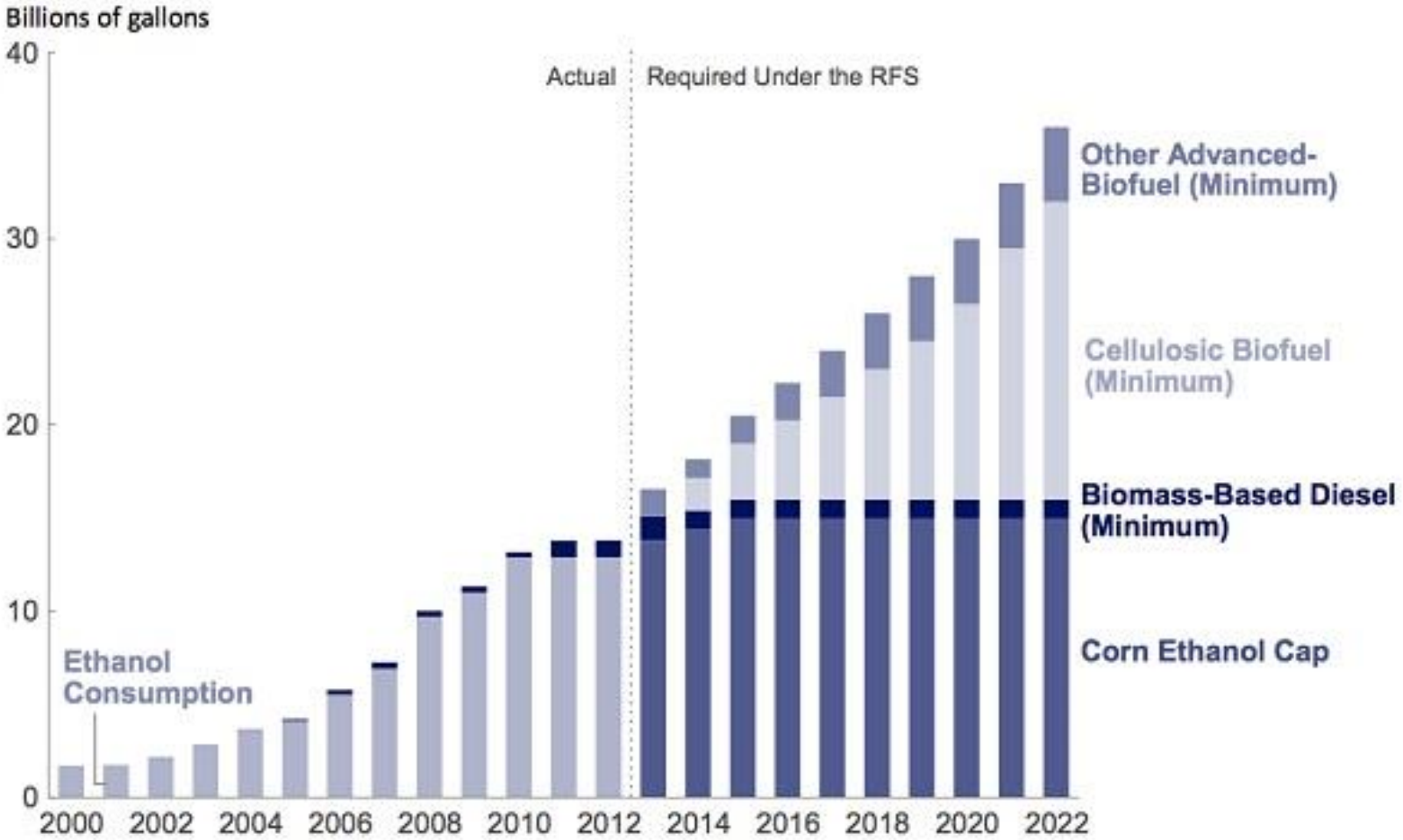
Some very good technical concepts never get developed.

Some developed technologies never get to market.

U.S. Renewable Fuel Standard

EPACT 2005, Energy Independence and Security Act 2007

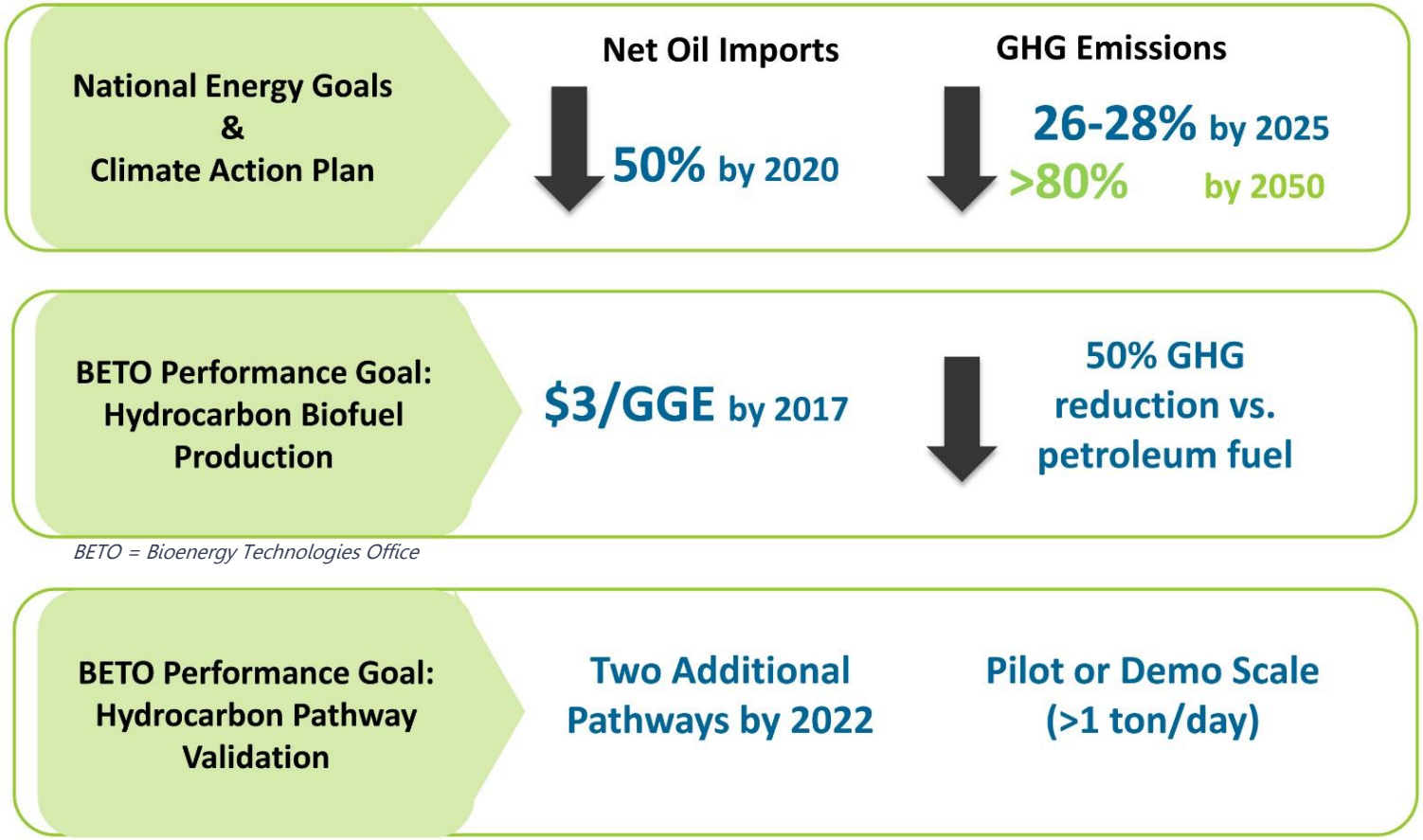
"addicted to oil"



The U.S. mandate for renewable fuels has aggressive targets, "Renewable Volume Obligations", and is subject to ongoing scrutiny for required production volumes and costs.

1st Generation biofuel (ethanol from fermentation of sugars) has reached the consumption and mandate limits.

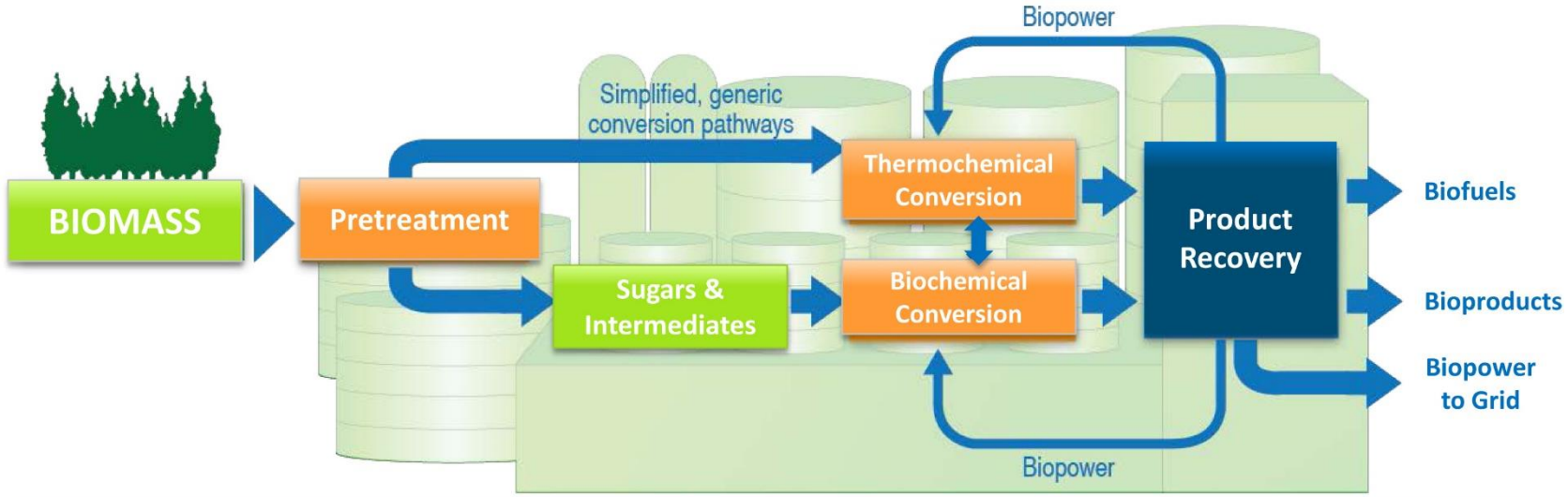
U.S. Administration Goals for Bioenergy



BETO's goals support the Presidential Initiatives on Energy

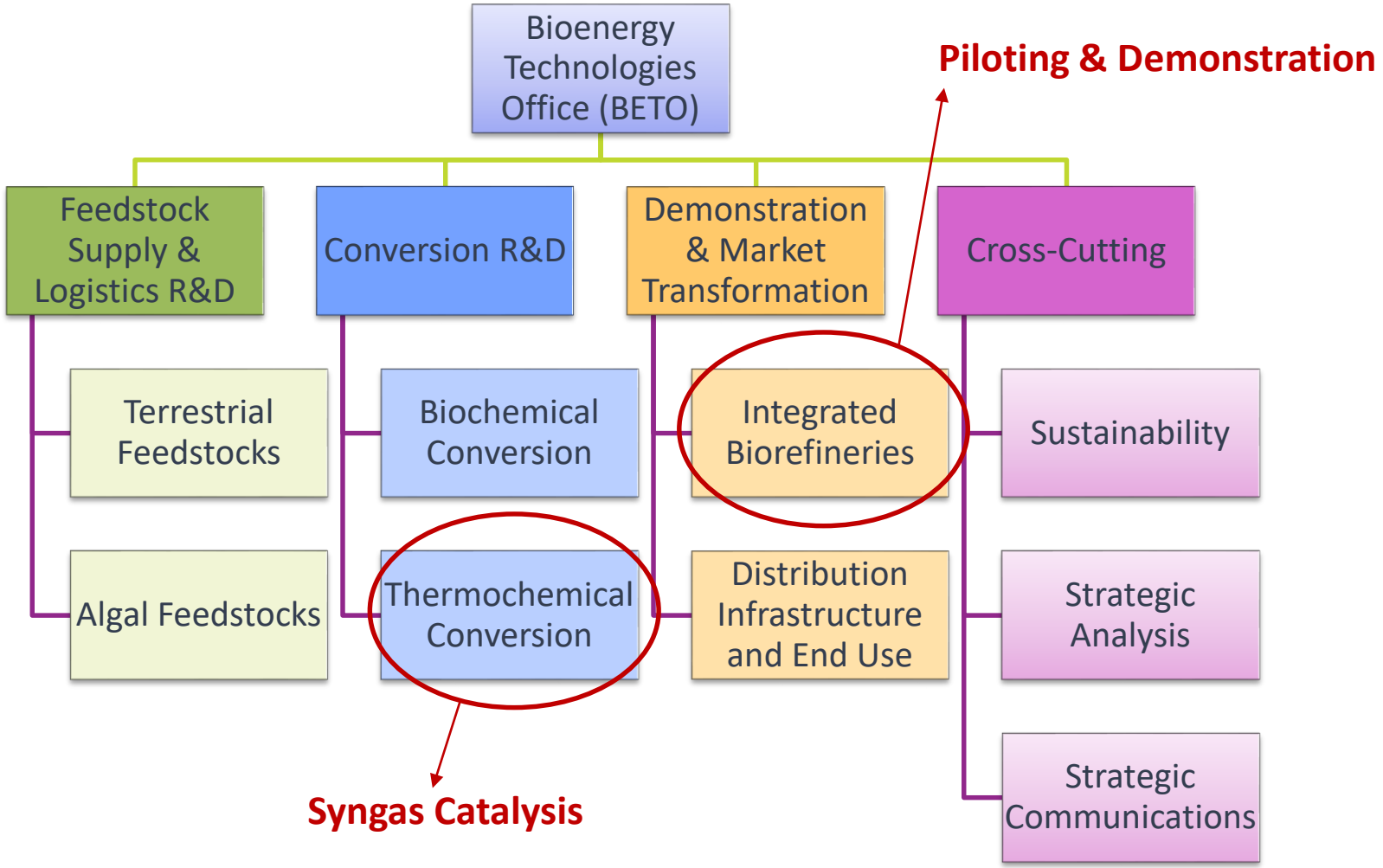
Key Challenges for Biofuels

- Technical, construction, operational and financial/market **risk reduction**
- **Demonstration** through greater process integration and scale



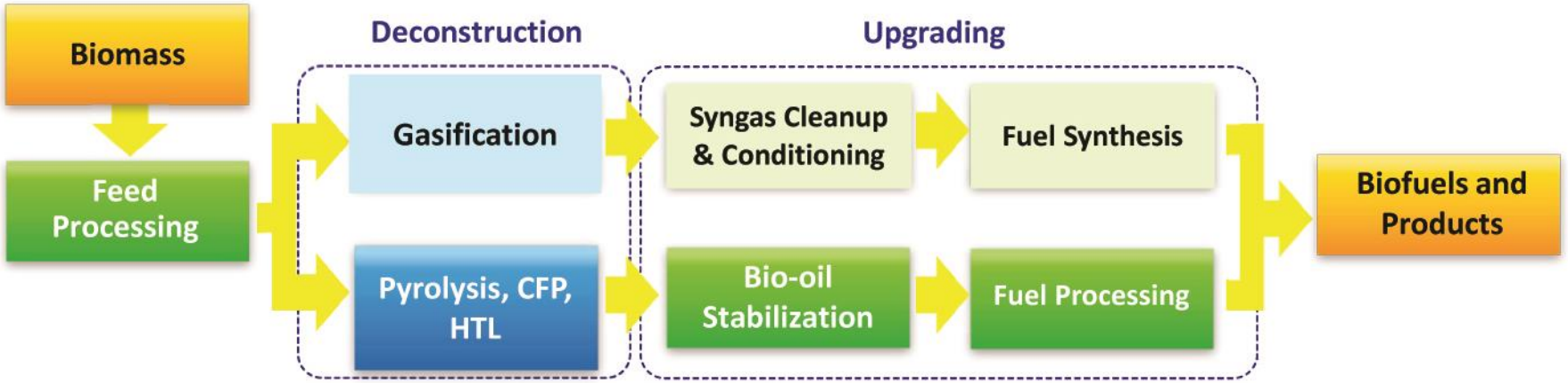
Key Challenges			
Biomass	**Pretreatment**	**Conversion**	**Product**
• Reliable supply • Consistent quality • Affordable delivery	• Biomass feeding, sizing and moisture • Solids handling • Construction materials	• Products Yields • Construction materials • Catalysts • Fermentation organisms	• Separations • Catalytic upgrading • Recycle loops

USDOE Program—Biomass Gasification RD&D



Conversion R&D in BETO

Gasification R&D falls under the BETO Conversion Technology Area



> Conversion activities include continued efforts in both core and competitive R&D

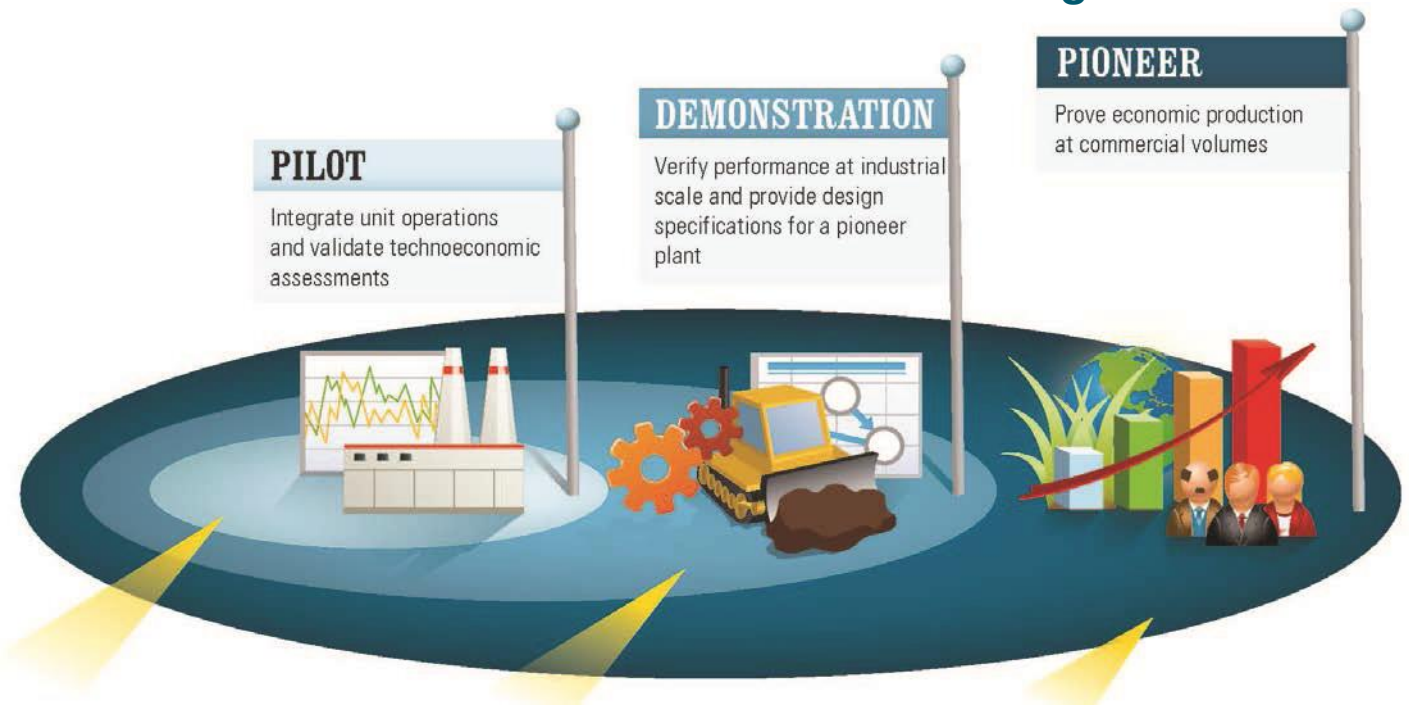
- R&D focuses on gaseous intermediates and mixed oxygenate upgrading to produce gasoline, distillate, and jet range hydrocarbons from biomass in support of the programmatic goal of $3/GGE by 2017

Gasification Demonstration Activities in BETO

There are several IBR projects within BETO's Demonstration Program

- Examples of indirect liquefaction technologies within the D&MT Program include:
  - INEOS: Syngas fermentation to ethanol at 300 tpd
  - Haldor Topsøe: Syngas catalysis to gasoline at 20 tpd
  - REII: Syngas to F-T liquids and diesel at 10 tpd
  - ClearFuels-Rentech: Syngas to F-T liquids and diesel at 20 tpd
  - Frontline: Syngas to F-T liquids to jet fuels at 10 tpd

Demonstration and Market Transformation Program



BETO Demonstration Portfolio—Gasification

Completed Projects

> Rentech (ClearFuels)
> Haldor-Topsøe (GTI)
> REII (Red Lion)
> INEOS

Project Development

> Frontline

Phase I Only

> Flambeau (TRI)
> New Page (TRI)
> Enerkem

Pioneer

Demonstration

Pilot

For more information visit:

http://www.energy.gov/eere/bioenergy/integrated-biorefineries

INEOS:

Indian River Bioenergy Center
Syngas Fermentation

Location	Vero Beach, FL
Feedstock(s)	Wood, yard, and vegetative waste
Size	300 tons per day
Primary Products	Ethanol, electric power
Capacity	8 million gallons per year of EtOH, 6 MW electricity
Award Date	December 2009
GHG Reduction	105% lower than gasoline (calculated)

- Commercial production was announced in July 2013
- First commercial production of cellulosic ethanol in the U.S. using gasification and syngas fermentation technology
- INEOS Bio supplied cellulosic ethanol to racecars participating in Sebring Green Racing and the TUDOR Championship, which is sponsored by International Motor Sports Association

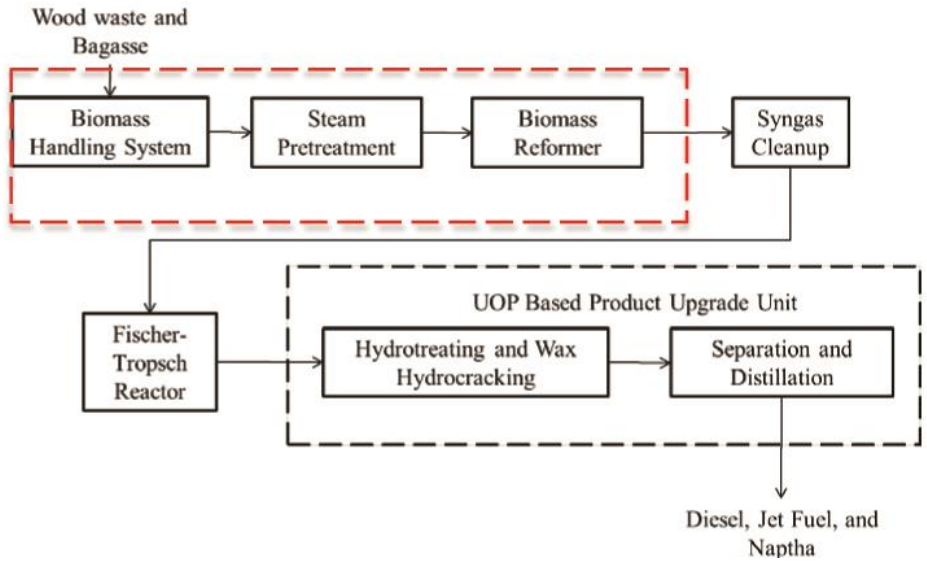
Rentech—ClearFuels

Diesel/Jet Production by Thermochemical Conversion of Wood Waste

Location	Commerce City, Colorado
Feedstock(s)	Wood waste and Bagasse
Size	Up to 16 dry tons per day
Primary Products	Renewable F-T Diesel and F-T Jet Fuel
Capacity	Up to 420 gallons per day
Award Date	January 2010
GHG Reduction	80% reduction versus fossil product

- Project completed Feb 2013
- Achieved 1000 hours of fully integrated operation.
- Many equipment design & scale-up lessons learned.
- Final report available at: http://www.osti.gov/scitech/servlets/purl/1127171
- Equipment added with DOE Grant

Equipment added with DOE Grant



Renewable Energy Institute International (REII):

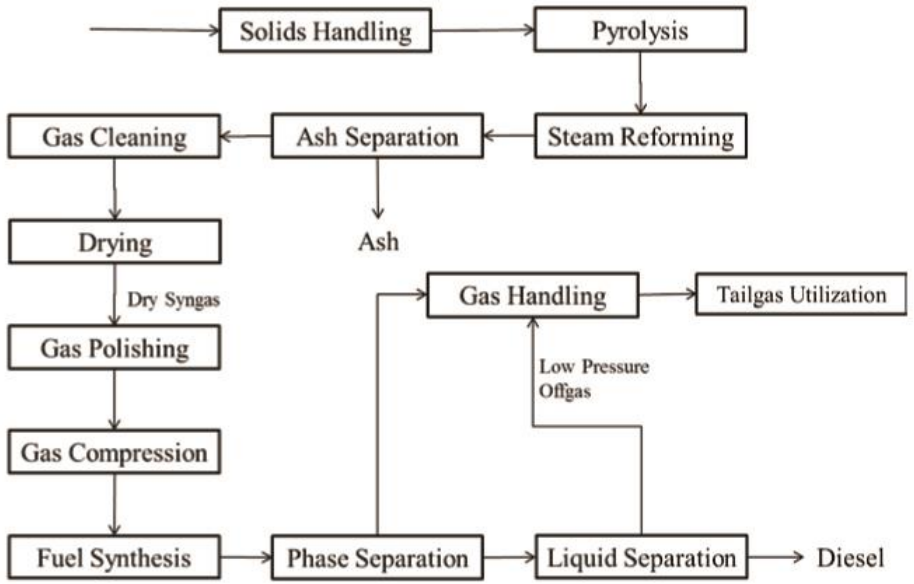
Pilot Integrated Biorefinery for the Economical Conversion of Biomass to Diesel Fuel

Location	Toledo, Ohio (IBR site); Sacramento, California, and Maumee, Ohio (IBR Engineering)
Feedstock(s)	Agriculture and forest residues
Size	25 dry tons per day
Primary Products	Synthetic diesel fuel
Award Date	January 2010
GHG Reduction	89% compared to petroleum-derived fuels

- Project completed in March 2014
- Independent testing on heavy-duty diesel engines showed improved emissions and wear.
- Proprietary Greyrock Energy (formerly Pacific Renewable Fuels) F-T catalyst provides low wax yield.

RED LION BIO-ENERGY

PACIFIC RENEWABLE FUELS



gti

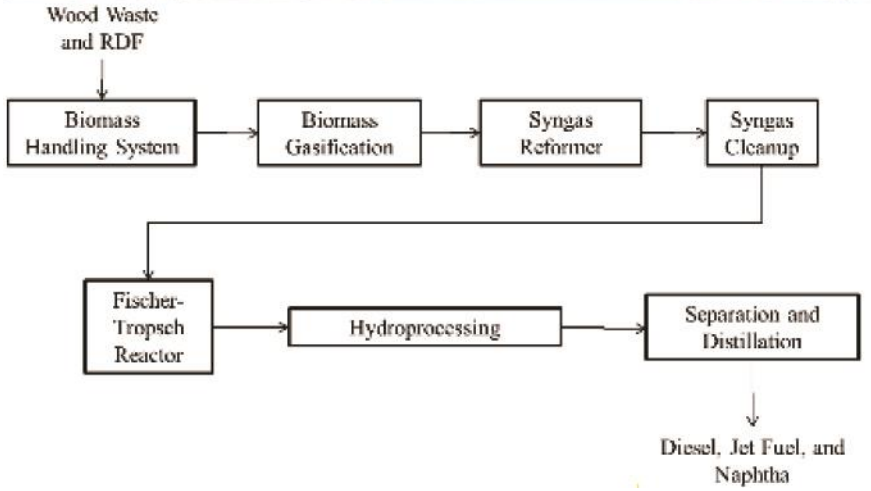
Frontline BioEnergy:

Innovative Gasification to Produce Fischer-Tropsch Jet and Diesel Fuel

Location	Ames, Iowa (HQ Office) Houston, TX (Project Site)
Feedstock(s)	Wood Waste and RDF
Size	10 tons per day (oversized to demonstrate new gasifier technology)
Primary Products	F-T liquids upgraded to JP-5, JP-8 and F-76
Capacity	1 barrel per day
Award Date	10/1/2013 – 3/30/2016

- To be integrated with SGC Energia Fischer-Tropsch pilot plant.
- Project design phase began July 2014

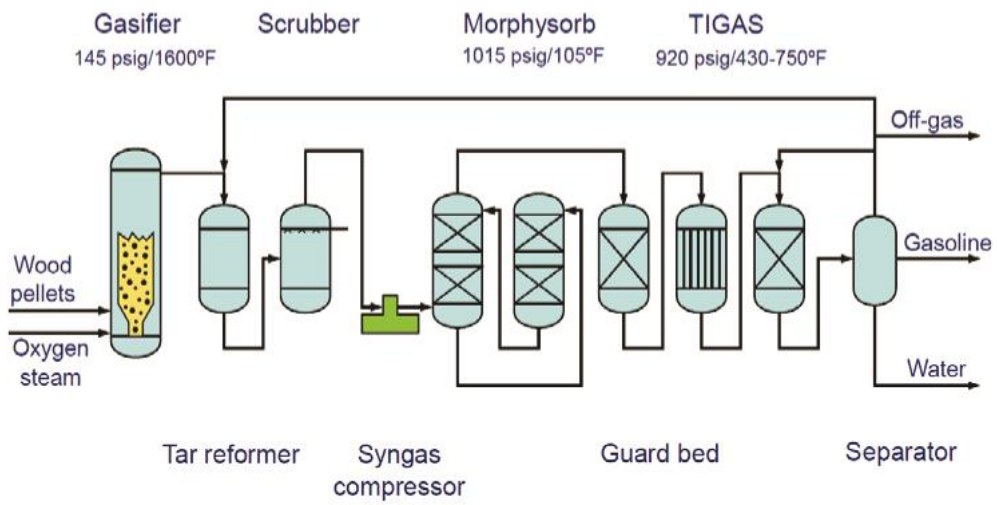
Picture is from Frontline's commercial biomass gasifier project at the CVEC facility in Benson, MN



Haldor-Topsøe:
Green Gasoline from Wood

Location	Houston, Texas (US HQ), Des Plaines, Illinois (Project Site)
Feedstock(s)	Wood pellets
Size	20 tons per day (6% moisture content)
Primary Products	Renewable gasoline
Capacity	345,000 gallons per year (approximate)
Award Date	December 29, 2009
GHG Reduction	92% reduction versus fossil product at commercial scale

- Completed 940 hours of operation
- Produced 38.000 L of gasoline
- 61-65% syngas to motor fuel conversion (LHV energy basis)
- Engine emissions testing with 80% blend showed emission levels “substantially similar” to conventional gasoline
- Conducted vehicle testing – 960.000 km on a 50% blend



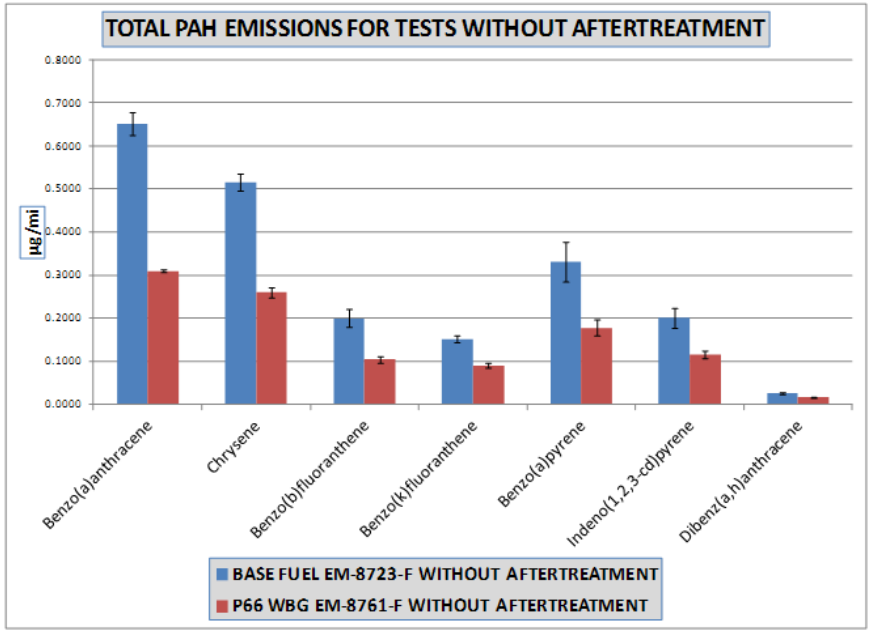
Gasification Technology Development Platform

- 5 MW_{th} fluidized bed and entrained flow gasifiers up to 27 bar operation
- Air- or O_2-blown gasification
- 750 kg/h coal or biomass feed
- 360 kg/h natural gas POx
- Hot and ultra-hot gas filtration
- Catalytic syngas reforming
- Syngas compression to 70 bar
- Sorbent and solvent acid gas removal

Key Results

- 38.000 L of gasoline produced:
  - RON/MON: 95,4/83,6
  - Yield: 367 kg gasoline/ton MeOH
- Engine tests
  - 80/20 blend found to be "substantially similar" to conventional gasoline
- Fleet tests
  - 50/50 blend confirmed no impact on engines
  - 8 vehicles over about 4 months – 75,000 miles each
  - Mileage accumulation with EPA Standard Road Cycle
  - Interim and post mileage engine inspection - borescope valves & cylinders, compression & leak down
- Certified by USEPA for 80% blend

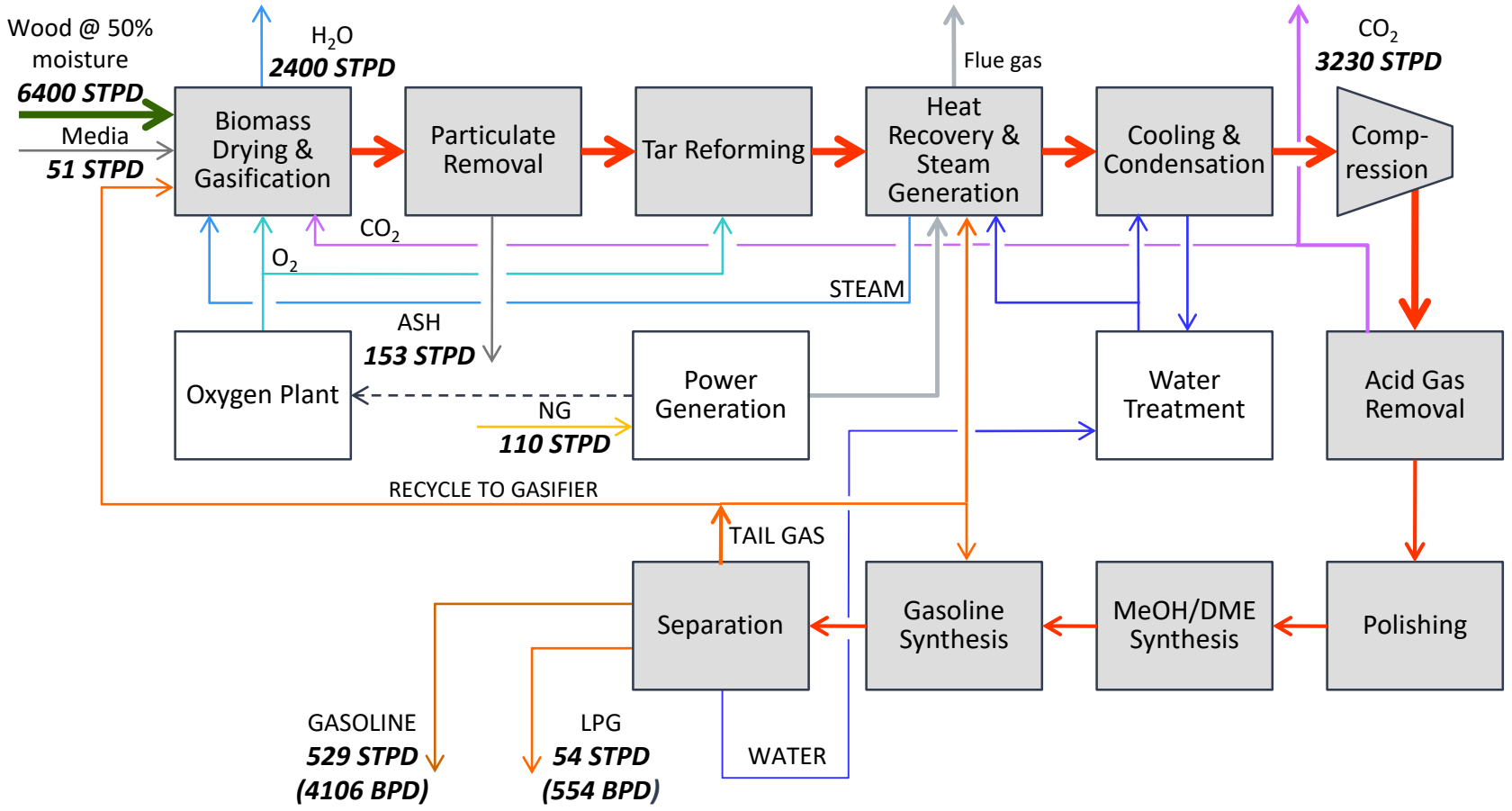
Pilot results reduce technical risk sufficiently for licensors to offer commercial package.



Commercial Plant Basis

Type of installation	Co-location with existing paper mill
Prospective plant site	Grand Rapids MN
Feedstock	Waste wood chips
Feedstock moisture (wt%)	50
Feedstock consumption (tons/yr)	2,125,000
Feedstock cost ($/green ton)	$30.88
Gasoline production (gal/yr)	57,288,000
LPG production (gal/yr)	8,492,000
Plant lifetime (years)	30
Term of debt (years)	25
Debt/equity ratio	1.0
Availability (year 3)	91%

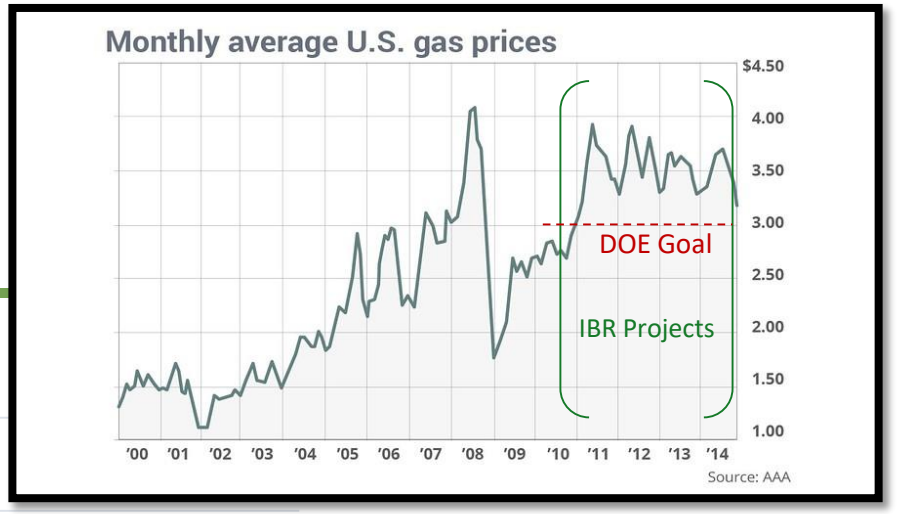
Commercial Integrated Biorefinery

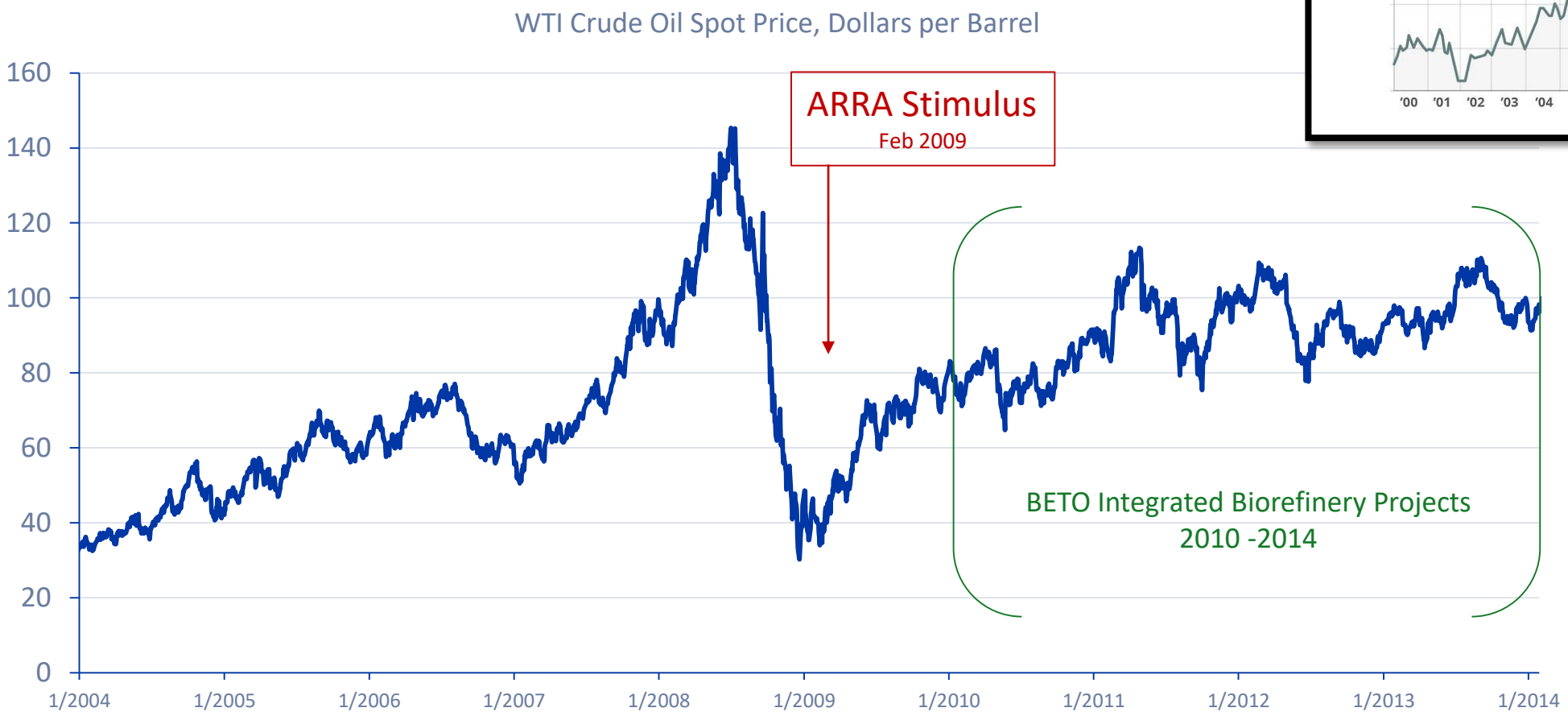


Economics and Sustainability

- Economics
  - Plant capital cost: **$719** million
  - Annual production: **57** million gallons bio-gasoline
  - Production cost: **$2.60** per gallon
  - USEPA registration granted for blends up to **80%** bio-gasoline
- Sustainability
  - **73.7%** reduction of life-cycle GHG emissions
  - **Exceeds** EPA requirement for Cellulosic Biofuel (D3)
  - **100** plants of this size would provide **36%** of EISA Cellulosic Biofuel goal for 2022

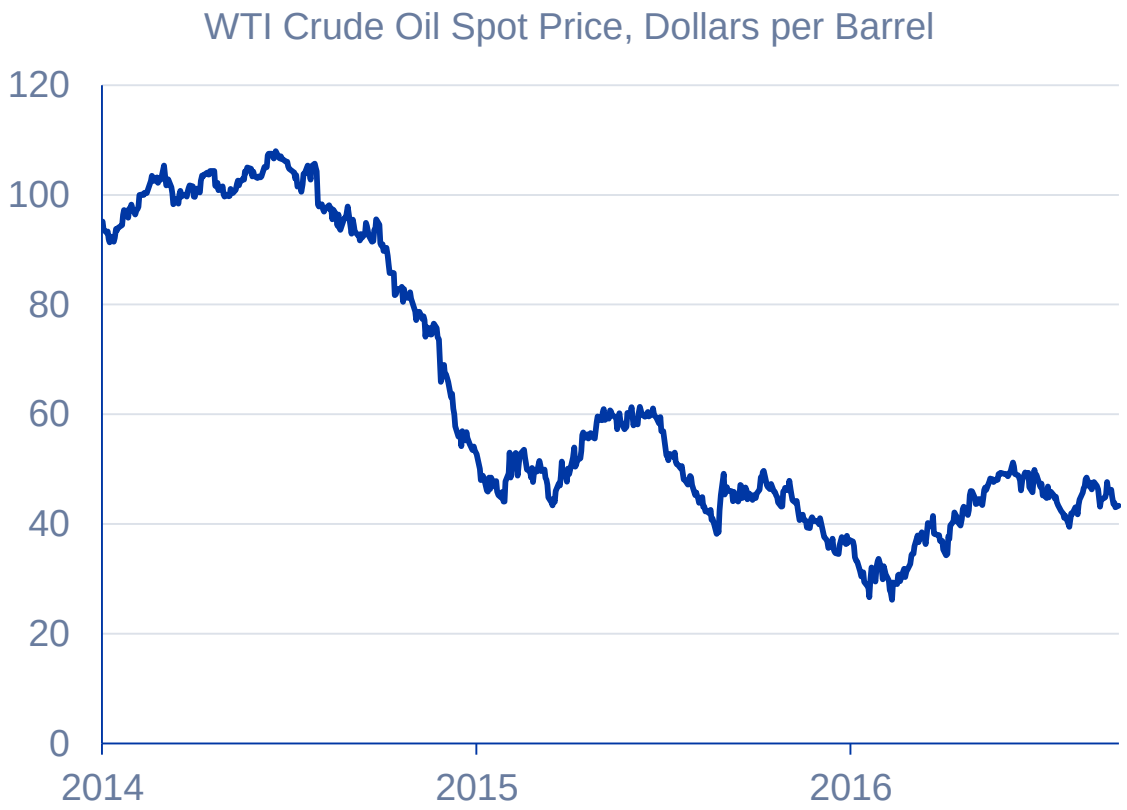
U.S. Hydrocarbon Prices

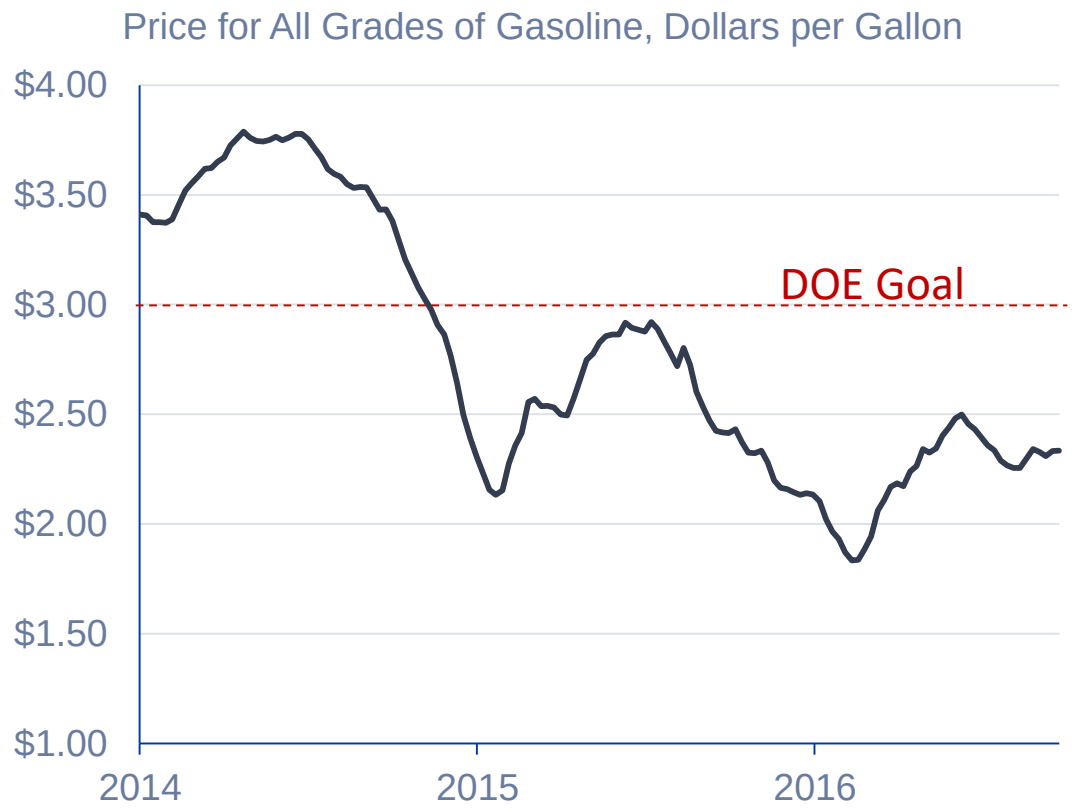




Data source: US Energy Information Administration

What Now?





Data source: US Energy Information Administration

INEOS:

Indian River Bioenergy Center
Syngas Fermentation

Location	Vero Beach, FL
Feedstock(s)	Wood, yard, and vegetative waste
Size	300 tons per day
Primary Products	Ethanol, electric power
Capacity	8 million gallons per year of EtOH, 6 MW electricity
Award Date	December 2009
GHG Reduction	105% lower than gasoline (calculated)

- Commercial production was announced in July 2013
- First commercial production of cellulosic ethanol in the U.S. using gasification and syngas fermentation technology
- INEOS Bio supplied cellulosic ethanol to racecars participating in Sebring Green Racing and the TUDOR Championship, which is sponsored by International Motor Sports Association

Rentech—ClearFuels

Diesel/Jet Production by Thermochemical Conversion of Wood Waste

Location	Commerce City, Colorado
Feedstock(s)	Wood waste and Bagasse
Size	Up to 16 dry tons per day
Primary Products	Renewable F-T Diesel and F-T Jet Fuel
Capacity	Up to 420 gallons per day
Award Date	January 2010
GHG Reduction	80% reduction versus fossil product

- Project completed Feb 2013
- Achieved 1000 hours of fully integrated operation.
- Many equipment design & scale-up lessons learned.
- Final report available at: http://www.osti.gov/scitech/servlets/purl/1127171
- Equipment added with DOE Grant

Renewable Energy Institute International (REII):

Pilot Integrated Biorefinery for the Economical Conversion of Biomass to Diesel Fuel

Location	Toledo, Ohio (IBR site); Sacramento, California, and Maumee, Ohio (IBR Engineering)
Feedstock(s)	Agriculture and forest residues
Size	25 dry tons per day
Primary Products	Synthetic diesel fuel
Award Date	January 2010
GHG Reduction	89% compared to petroleum-derived fuels

- Project completed in March 2014
- Independent testing on heavy-duty diesel engines showed improved emissions and wear.
- Proprietary Greyrock Energy (formerly Pacific Renewable Fuels) F-T catalyst provides low wax yield.

Frontline BioEnergy:

Innovative Gasification to Produce Fischer-Tropsch Jet and Diesel Fuel

Location	Ames, Iowa (HQ Office) Houston, TX (Project Site)
Feedstock(s)	Wood Waste and RDF
Size	10 tons per day (oversized to demonstrate new gasifier technology)
Primary Products	F-T liquids upgraded to JP-5, JP-8 and F-76
Capacity	1 barrel per day
Award Date	10/1/2013 – 3/30/2016

- To be integrated with SGC Energia Fischer-Tropsch pilot plant.
- Project design phase began July 2014

Picture is from Frontline's commercial biomass gasifier project at the CVEC facility in Benson, MN

Responses

Waste feedstocks

Higher-value bio-products

Graphic source: Forest Bio-Products Institute, UBC

Fulcrum BioEnergy

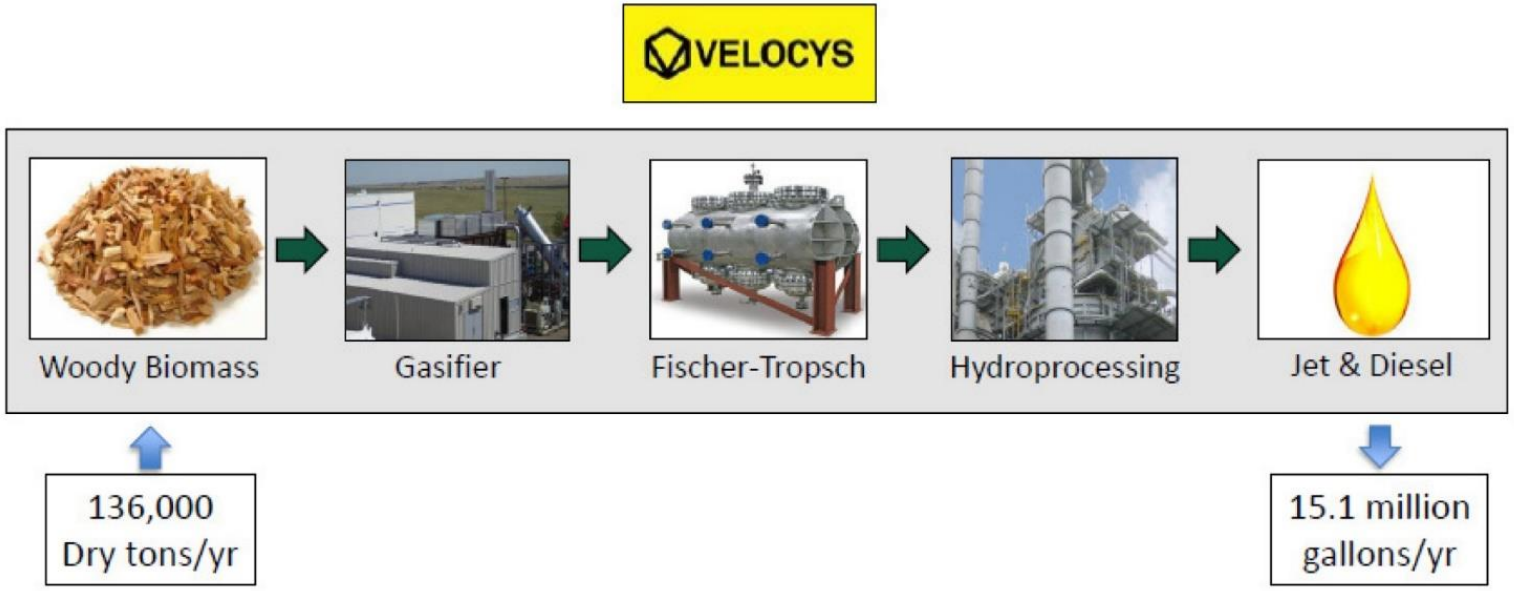
Sierra BioFuels Plant (Storey County, Nevada)

- 200,000 tons per year of prepared municipal solid waste (MSW) feedstock
- ThermoChem Recovery International, Inc. gasifier
- Designed to produce >10 million gallons per year of renewable F-T syncrude
- F-T syncrude will be upgraded and processed into a low-carbon jet fuel product
- Agreements with United Airlines and Cathay Pacific

Red Rock Biofuels, LLC

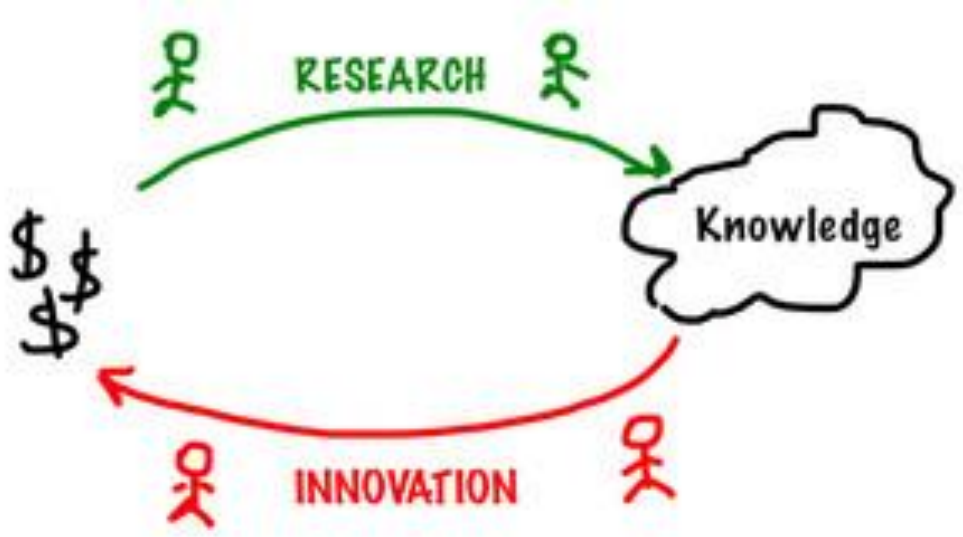
Red Rock Biorefinery (Lakeview, Oregon)

- Funded in part by a $70 million Defense Procurement Act grant from the U.S. Departments of Agriculture, Energy and Navy
- FEED/FEL3 design and engineering by FLUOR
- Convert approximately 136,000 dry tons of woody biomass into 15 million gallons per year of renewable jet, diesel and naphtha fuels
- Offtake agreements with Southwest Airlines and FedEx

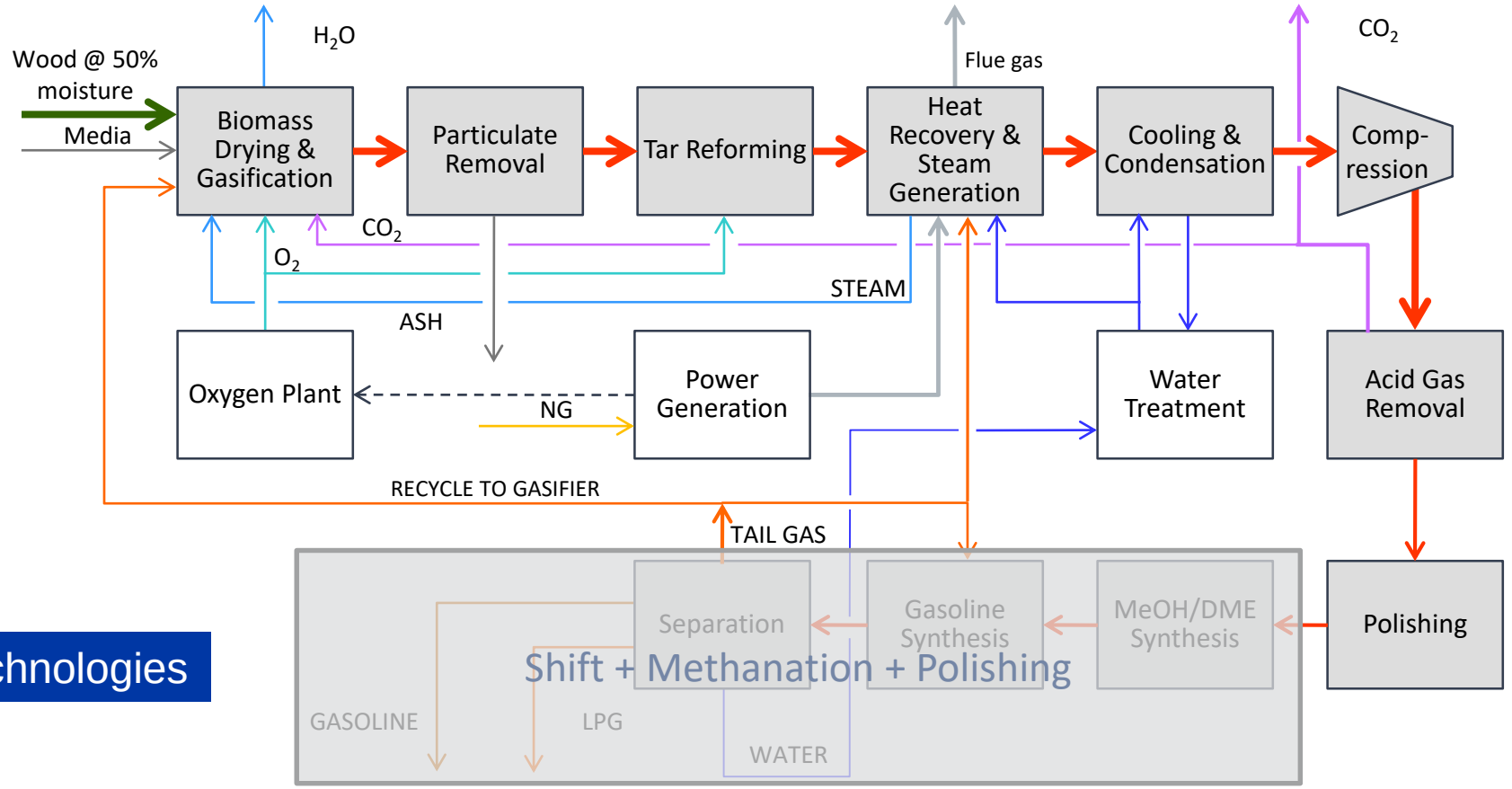


RESEARCH is a lever that provided with money will generate knowledge, whilst INNOVATION is a lever that provided with knowledge will generate money.

Roberto Saracco



Integrated Biorefinery



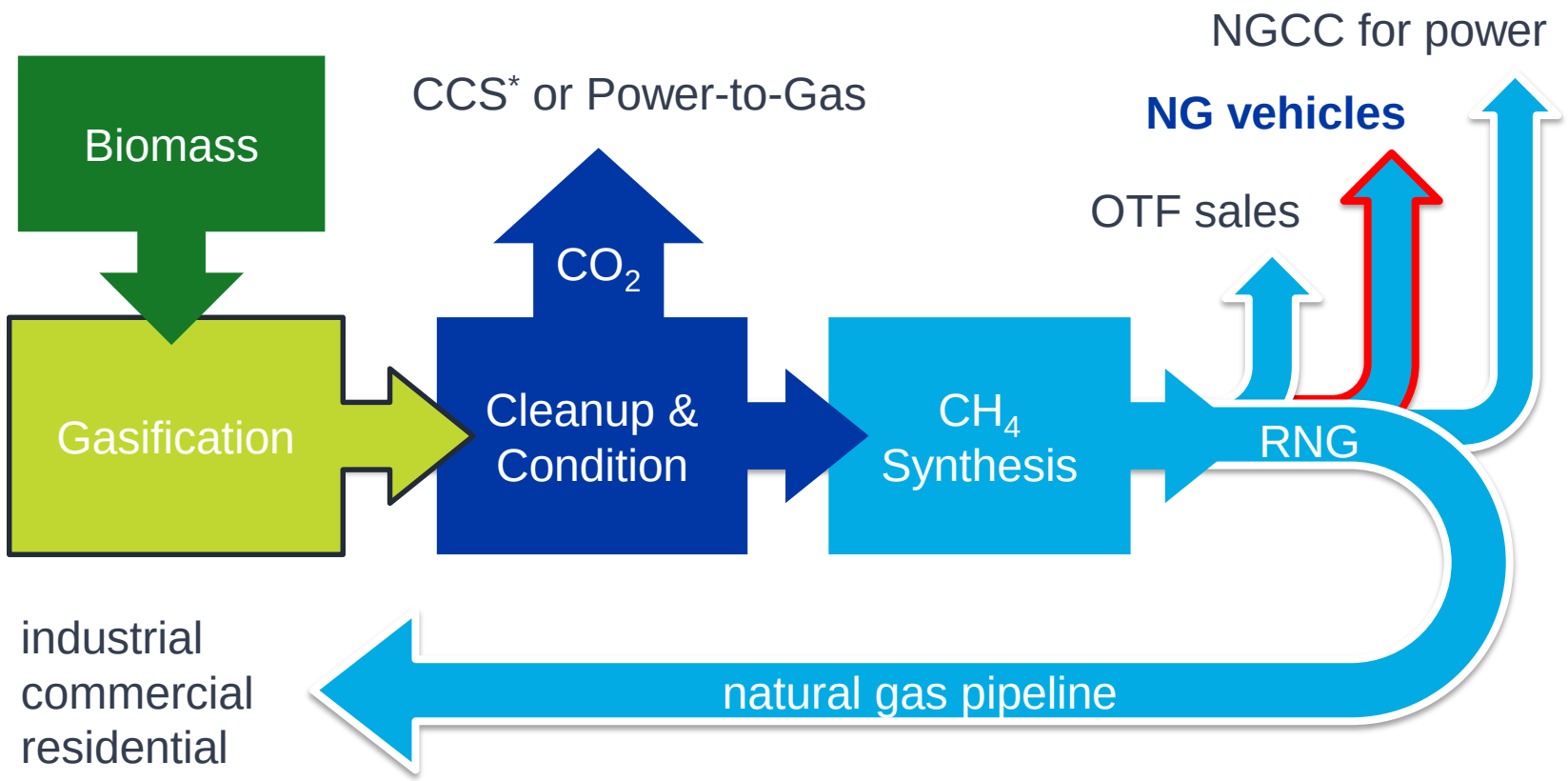
Commercial Technologies

Renewable Natural Gas Opportunity for California

To meet renewable energy and carbon reduction mandates

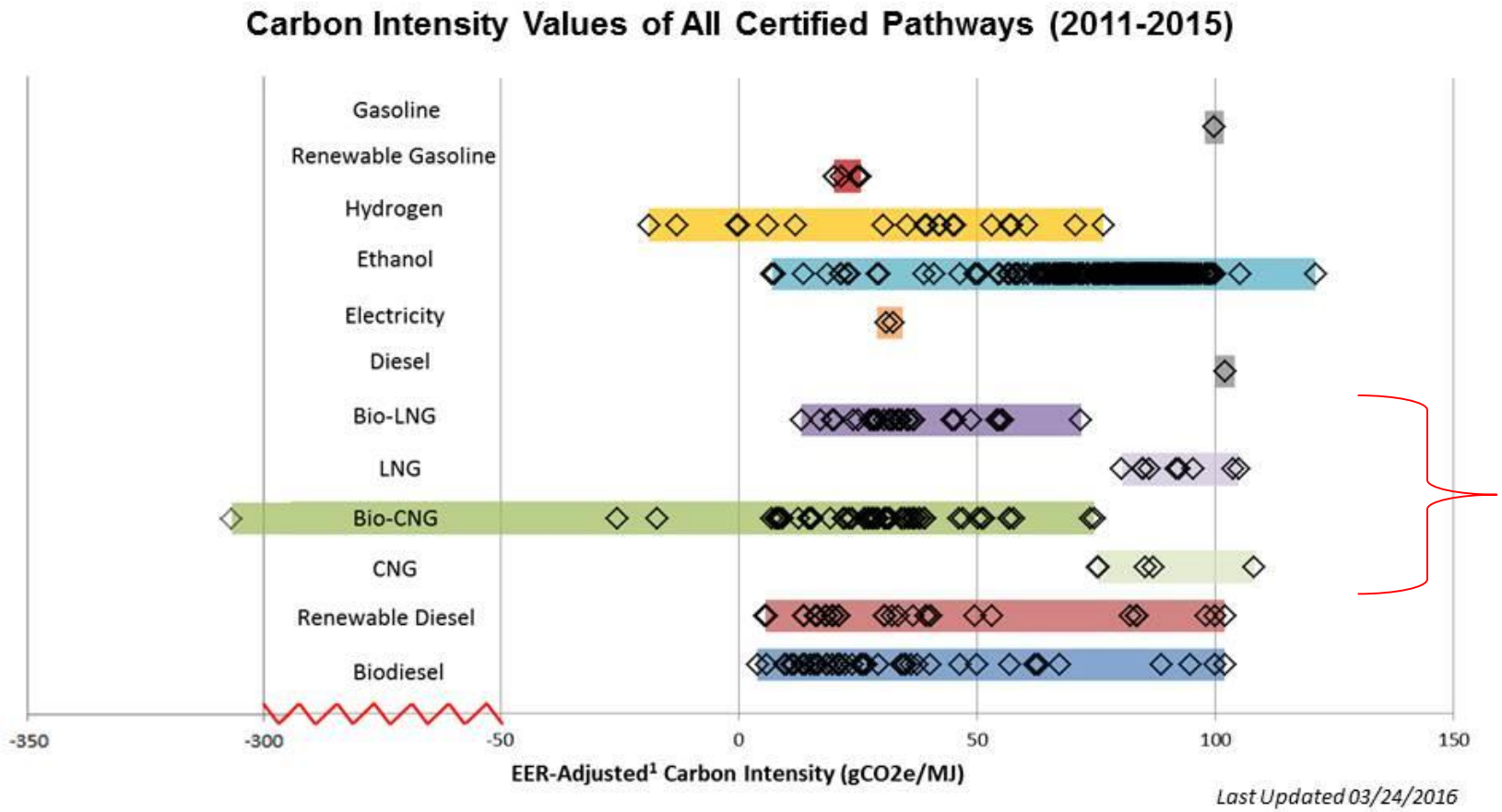
1. Utilize existing feedstock and supply chains
2. Utilize existing energy infrastructure
3. Repurpose existing biomass power plants
4. Create methane for pipeline injection – a storable renewable energy solution
5. Distribute as a low-carbon footprint fuel
6. Provide a concentrated CO_2 stream for storage or re-use (e.g., Power-to-Gas)

RNG from Woody Biomass



*Carbon capture & sequestration

California Air Resources Board Certified Low-Carbon Fuel Standard (LCFS) Pathways

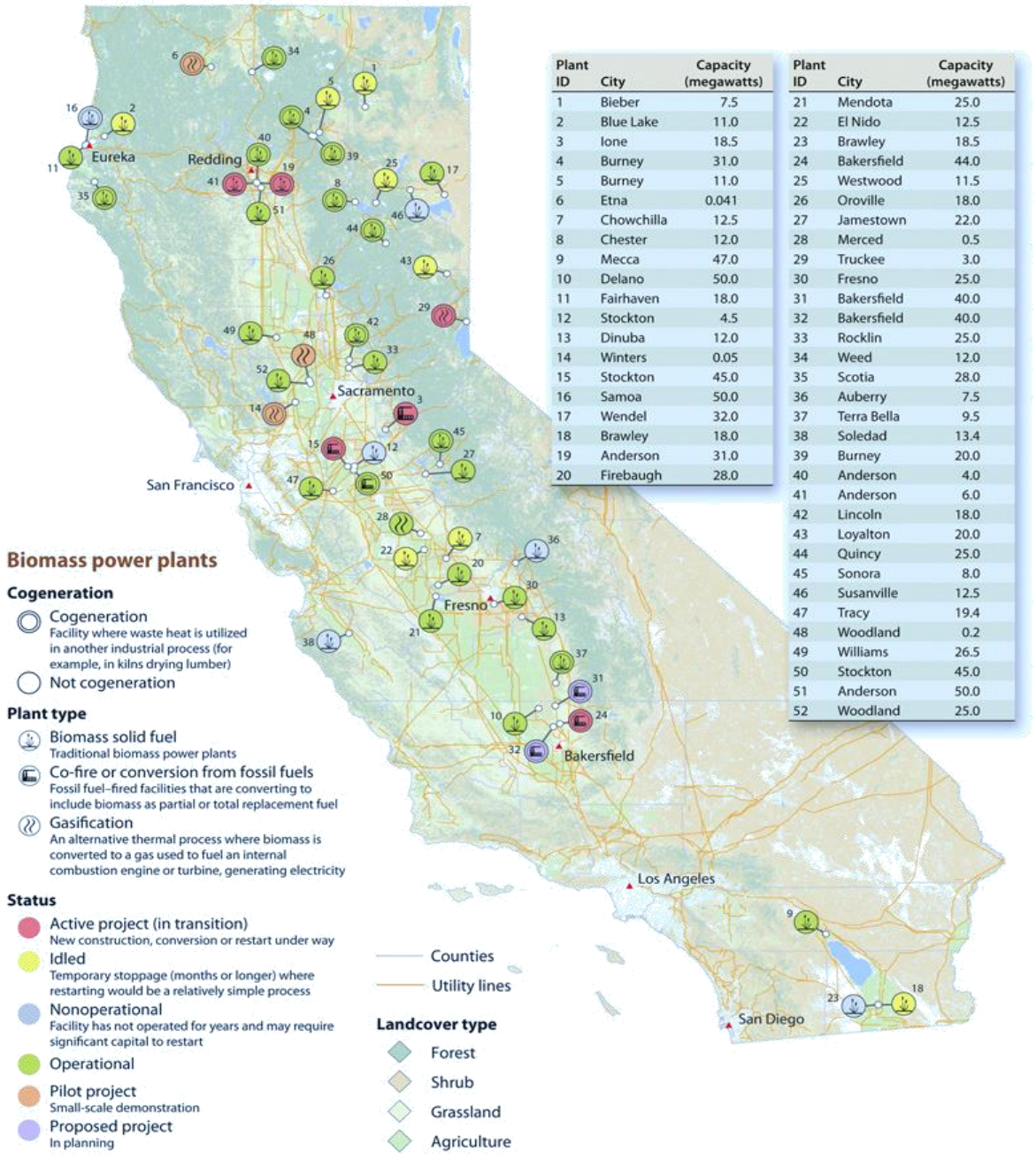


Alleviation of diesel NOx and particulate emissions, also.

[1] The alternative fuel's CI value is divided by its Energy Economy Ratio (EER) in order to obtain the EER-adjusted CI value, representing the emissions which occur from the alternative fuel *per MJ of conventional fuel displaced.*

Using RNG for Transportation in California

+	$2-4 /MMBtu	CA Low Carbon Fuel Standard
+	$6-13 /MMBtu	US Renewable Fuel Standard
+	$7-9 /MMBtu	Vehicle Fuel Price
=	$13-26 /MMBtu	**Fuel Price plus Incentives**



Plant ID	City	Capacity (megawatts)
1	Bieber	7.5
2	Blue Lake	11.0
3	Ione	18.5
4	Burney	31.0
5	Burney	11.0
6	Etna	0.041
7	Chowchilla	12.5
8	Chester	12.0
9	Mecca	47.0
10	Delano	50.0
11	Fairhaven	18.0
12	Stockton	4.5
13	Dinuba	12.0
14	Winters	0.05
15	Stockton	45.0
16	Samoa	50.0
17	Wendel	32.0
18	Brawley	18.0
19	Anderson	31.0
20	Firebaugh	28.0

Plant ID	City	Capacity (megawatts)
21	Mendota	25.0
22	El Nido	12.5
23	Brawley	18.5
24	Bakersfield	44.0
25	Westwood	11.5
26	Oroville	18.0
27	Jamestown	22.0
28	Merced	0.5
29	Truckee	3.0
30	Fresno	25.0
31	Bakersfield	40.0
32	Bakersfield	40.0
33	Rocklin	25.0
34	Weed	12.0
35	Scotia	28.0
36	Auberry	7.5
37	Terra Bella	9.5
38	Soledad	13.4
39	Burney	20.0
40	Anderson	4.0
41	Anderson	6.0
42	Lincoln	18.0
43	Loyalton	20.0
44	Quincy	25.0
45	Sonora	8.0
46	Susanville	12.5
47	Tracy	19.4
48	Woodland	0.2
49	Williams	26.5
50	Stockton	45.0
51	Anderson	50.0
52	Woodland	25.0

Situation

California biomass power plants are closing, in part, due to competition from other renewables.

Scale

52 existing biomass power plants

= 1,075 MW_e total capacity

Annual capacity of plants for RNG

= 65 BCF total

= 4x NGV use in 2012

= 5% non-power use in 2012

Opportunity

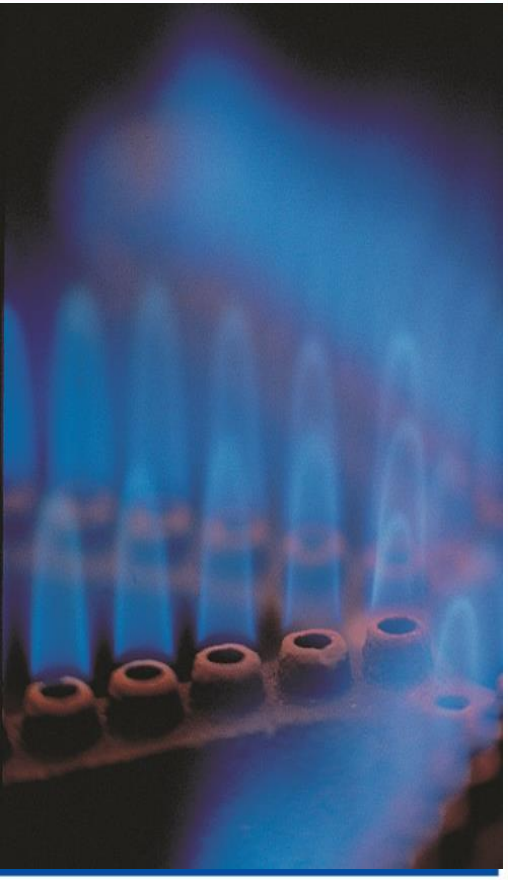
Transform existing biomass power plants to RNG production facilities.

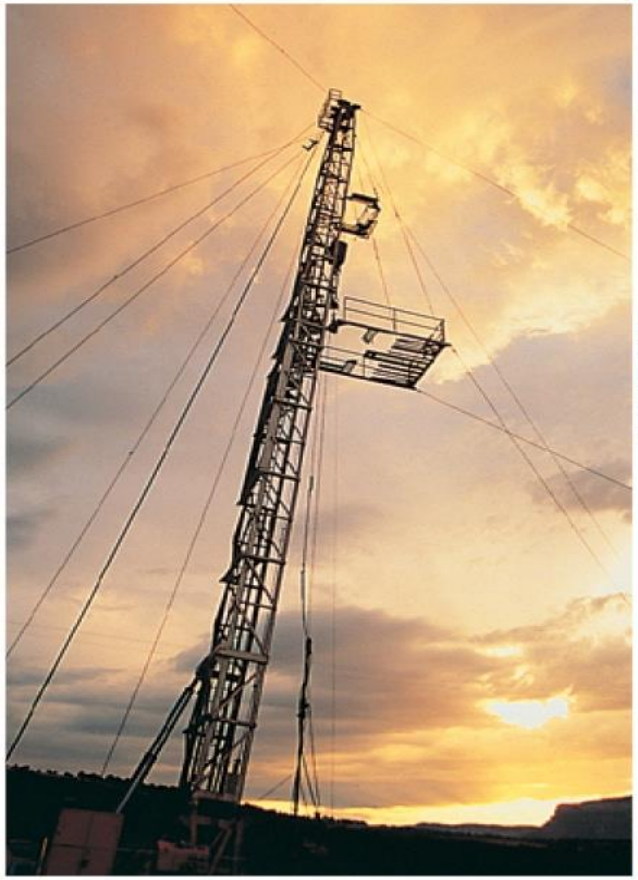
Site-Specific FEL-2 Engineering Study

- Funding from natural gas utility partners in California; additional interest from State agencies and Canadian gas utilities
- Cooperate with biomass power facility as host site
  - ✓ Wood supply access
  - ✓ Fuel processing and handling
  - ✓ Natural gas pipeline on site
  - ✓ Water access
  - ✓ Open space
  - ✓ Local support
- Cooperate with technology providers
  - ✓ Feed prep and gasification island
  - ✓ Gas processing
  - ✓ Methanation and polishing

- Produce site-specific equipment layouts and connections for RNG production
- **Confirm CAPEX estimates for pro forma and quantify value of site integration**

Turning Raw Technology into Practical Solutions





www.gastechnology.org | @gastechnology