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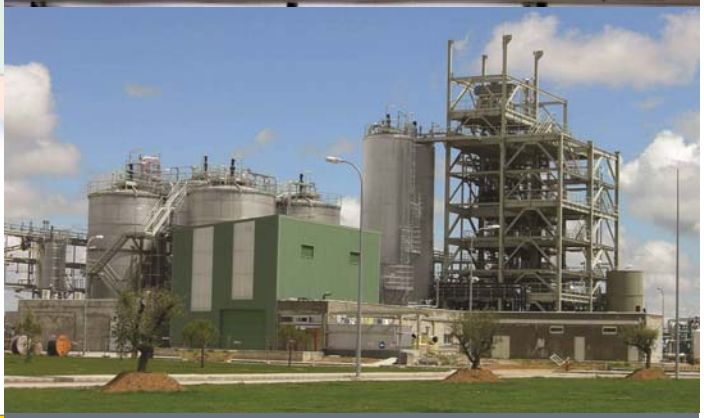
Biomass Program Perspectives on Anaerobic Digestion and Fuel Cell Integration at Biorefineries



Biogas and Fuel Cell Workshop
NREL June 11,2012

Brian Duff
DOE Biomass Program

Outline

- The Importance of Anaerobic Digestion for Fuels, Products, and Power
- Biomass Program Perspective
- The Potential for Biogas/Fuel Cell Integration at Biorefineries
  - Retrofit Applications for 1st-Generation Biofuels Plants
  - Integration Opportunities in Advance Biofuel Production
- Potential for EERE Multi-Program Joint Solicitation

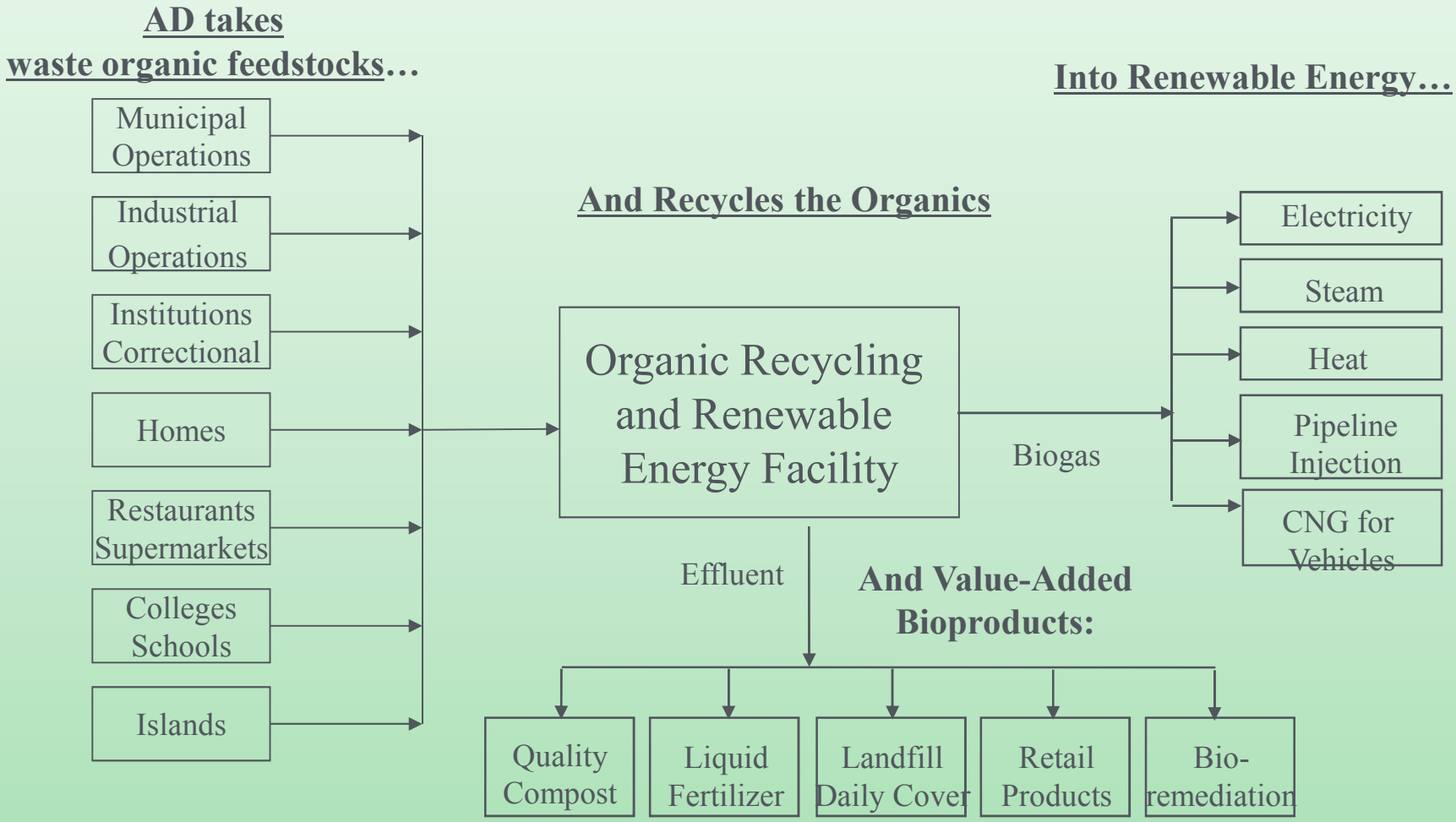
Anaerobic Digestion:

An Underappreciated and Underutilized Conversion Pathway for Biofuels, Bioproducts, and Bioenergy

Anaerobic Digestion

- Microbial bioconversion process generates methane
- Emerging global technology
- Has a "Bad Rep" in the US from numerous failed applications: still needs RD&D for widespread acceptance and commercialization
- Reduces GHG emissions (22:1 vs. CO2)
- Dependent on sales to grid like other distributed energy techs
- Lack of national feed-in tariff retarding deployment
- Lack of *process reliability* retarding financing and deployment

Organic Recycling for Renewable Energy



GOAL: Recycle the waste into energy as close to the point of generation as possible

Biomass Feedstock Applications

- 6.75 billion tons of domestic solid waste
- 240 million tons of MSW per year
- 5+ tons animal waste per person per year
- Growing at 3-5% per year

- Municipal Solid Waste
- Wastewater
- Spent Beverages
- Food Processing Wastes
- Food Residuals
- Agricultural Residues
- Animal Manure
- Industrial Sludges
- Biosolids
- Slaughterhouse Waste
- Animal Mortalities
- Industrial Wastes
  - Pharmaceutical
  - Rendering
  - Textile
  - Tannery

Anaerobic Digestion:

Biomass Program Perspective

Anaerobic Digestion

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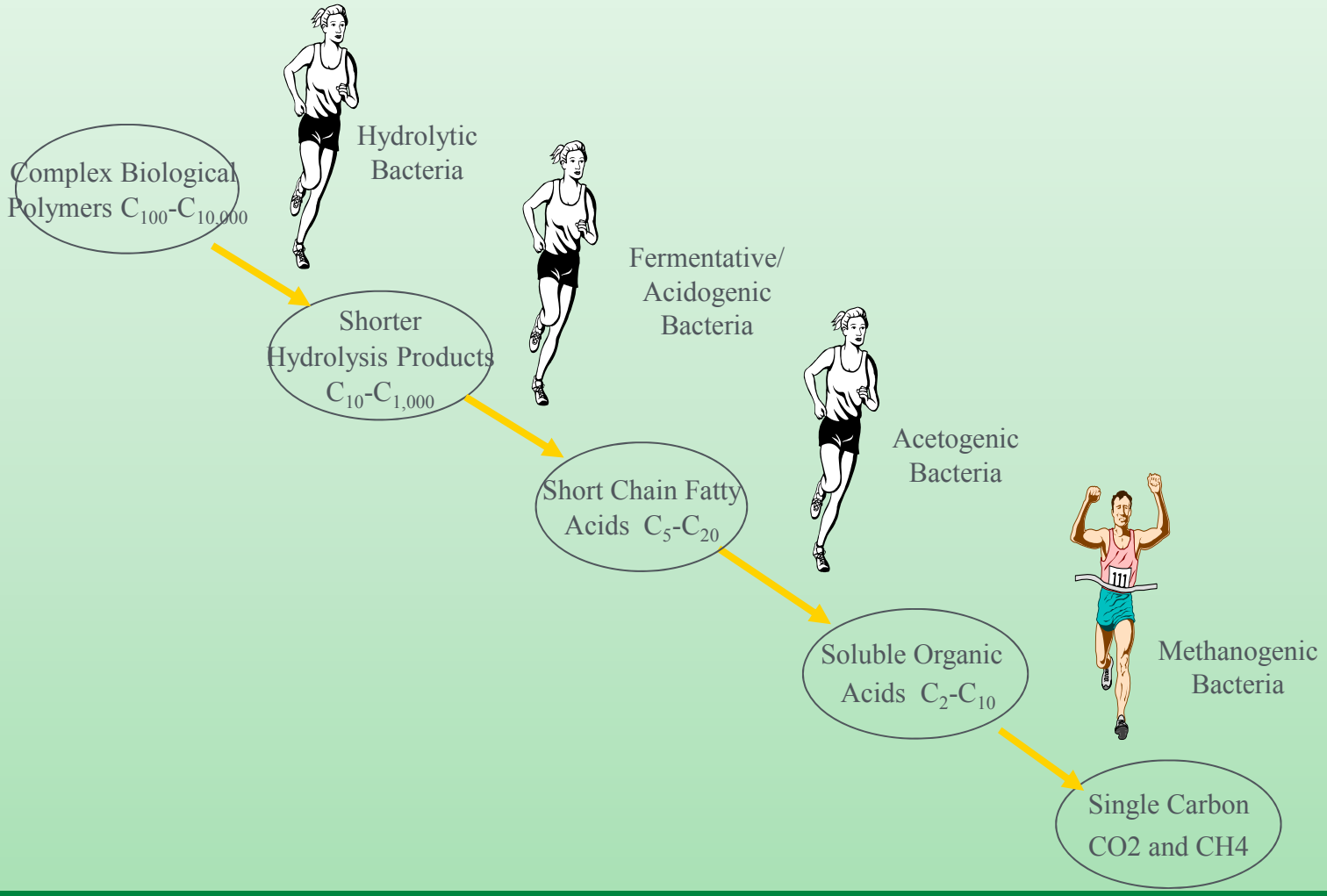
"The Anaerobic Digestion Relay Race: Passing the Carbon Baton"



Biomass Program Perspective: AD for Fuels

- Biogas can be used as a Transportation Fuel
- Biogas-derived Methane is equivalent to CNG
- Biogas-derived Methane qualifies for a RIN under RFS2
- Hard to compete for CNG market with Natural Gas at $2-3/mmbtu
- Need other incentives like RINs or carbon-credits to compete as CNG
- Excellent potential to fuel waste collection vehicles and milk tankers with CNG in closed/recycle system
- Also source of carboxylic acids/salts that can be converted to RE Hydrocarbons (Terrabon)
- Possible source of Hydrogen Fuel

Biomass Program Perspective: AD for Products

- Anaerobic digesters can be a source of Bioproducts
- Carboxylic salts, hydrogen
- Anaerobic Compost:
  - Soil amendments, erosion control, tilth
  - Berms, spill control products
  - Flowerpots, molded products
  - Fuel pellets
- Organic fertilizer, liquid nutrient solutions, “teas”
- Enormous, untapped potential in the mixed microbial consortia
- Potential is only limited by our ability to identify and culture anaerobic strains, need new techniques, expanded methodologies
- Potential exists along the entire continuum from hydrolysis, acidogenesis, acetogenesis, methanogenesis

Biomass Program Perspective: AD for Power

- Excellent for smaller scale, distributed power applications
- Opportunity for every community to become a link in a distributed generation “net”
- Highly appropriate for industrial CHP retrofits to reduce operating costs and improve profitability
- Convert organic wastes to heat and power at or as close to source of origin to minimize transport and GHG emissions
- Need to combine with RECs for profitability; feed-in tariffs
- Most efficient use can be thermal
- Need improvements for small scale reactor design
- Need improvements in remote operations and telemetry
- Opportunity for third party O&M/service industry as “hosts” may not want to be involved

Anaerobic Digestion

Need to maximize all revenue streams for profitability:

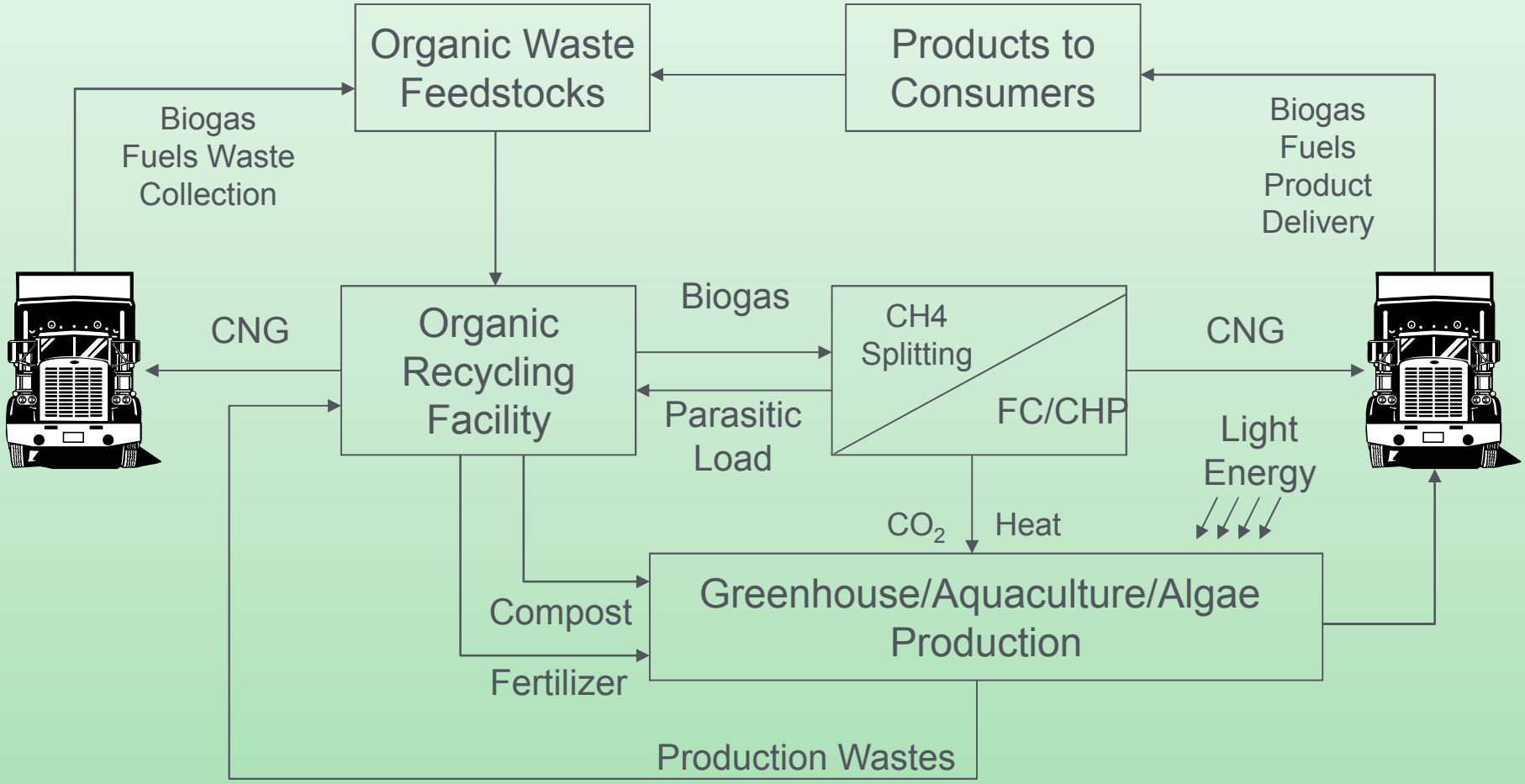
1. Tipping Fee/Service Fee/Recycling Fee
2. Sales of Bioenergy: Biogas/Methane/Electricity/Thermal
   - RECs, Carbon Credits
   - Avoided cost of CHP and waste disposal for industrial applications
3. Sales of the solid effluent: "Anaerobic Compost" and products
4. Sales of the pressate/centrate: "Liquid Fertilizer
5. Potential future value of recycled water
6. **Potential value of methane capture: carbon trading at 22:1**

Anaerobic Digestion:

An Integrated Waste and Energy Management Strategy

Anaerobic Digestion

An Integrated Waste and Energy Strategy: "Closing the Loop"



Anaerobic Digestion:

Process Technologies:

Feedstock Resource Drives Process Design

AD: Low Solids Applications

- <3% total solids by weight
- little or no suspended solids
- single phase liquid system, readily mixed

- Low Solids Feedstocks
  - Secondary wastewater treatment
  - Spent beverages & out of spec/expired products
  - Hydraulic flush manure systems (swine)
- Low Solids Processes
  - Anaerobic Lagoons - Fixed, Floating, or Submerged Covers
  - Completely Mixed Reactors
  - Anaerobic Filter Reactors
  - Upflow Anaerobic Sludge Blanket Reactors
  - Fixed-film Packed Bed Reactors

Low Solids Covered Lagoon

AD: Medium Solids Applications

- 3% to 12% total solids by weight
- contains suspended solids
- slurry system, can still be mixed

- Medium Solids Feedstocks
  - Dairy manure
  - “Scraped” swine manure
  - Industrial DAF sludges
- Medium Solids Processes
  - Plug Flow Reactors
  - Complete Mix Slurry Reactors
  - Slurry-Loop Reactors

Medium Solids Applications: Complete Mix Slurry Digesters

(Photo Courtesy of the Danish Biogas Program)

Medium Solids Applications: Plug Flow Slurry Digesters

Poultry and cattle manure digester at Coleraine, N. Ireland, built by Practically Green

Dairy cow manure digester at Craven Farms (1 000 cows), Oregon, USA

AD: High Solids Applications

- up to 30% total solids by weight
- “solids-processing” system
- requires non-traditional mixing

- High Solids Feedstocks
  - Organic Fraction of MSW
  - Ag-residues
  - Food Processing Waste; Food Residuals
  - Clarifier sludges (pulp/paper)
- High Solids Processes
  - “Dry” Continuous
  - Plug Flow
  - Dry Batch with Permeate Recycle
  - Sequencing Batch Reactors

High Solids Applications: Demo-Scale Plug Flow Digester

Photo of Plug Flow MSW Digester Courtesy of Pinnacle Biotechnologies
Developed at NREL and Sponsored by DOE 1991-2001

Anaerobic Digestion

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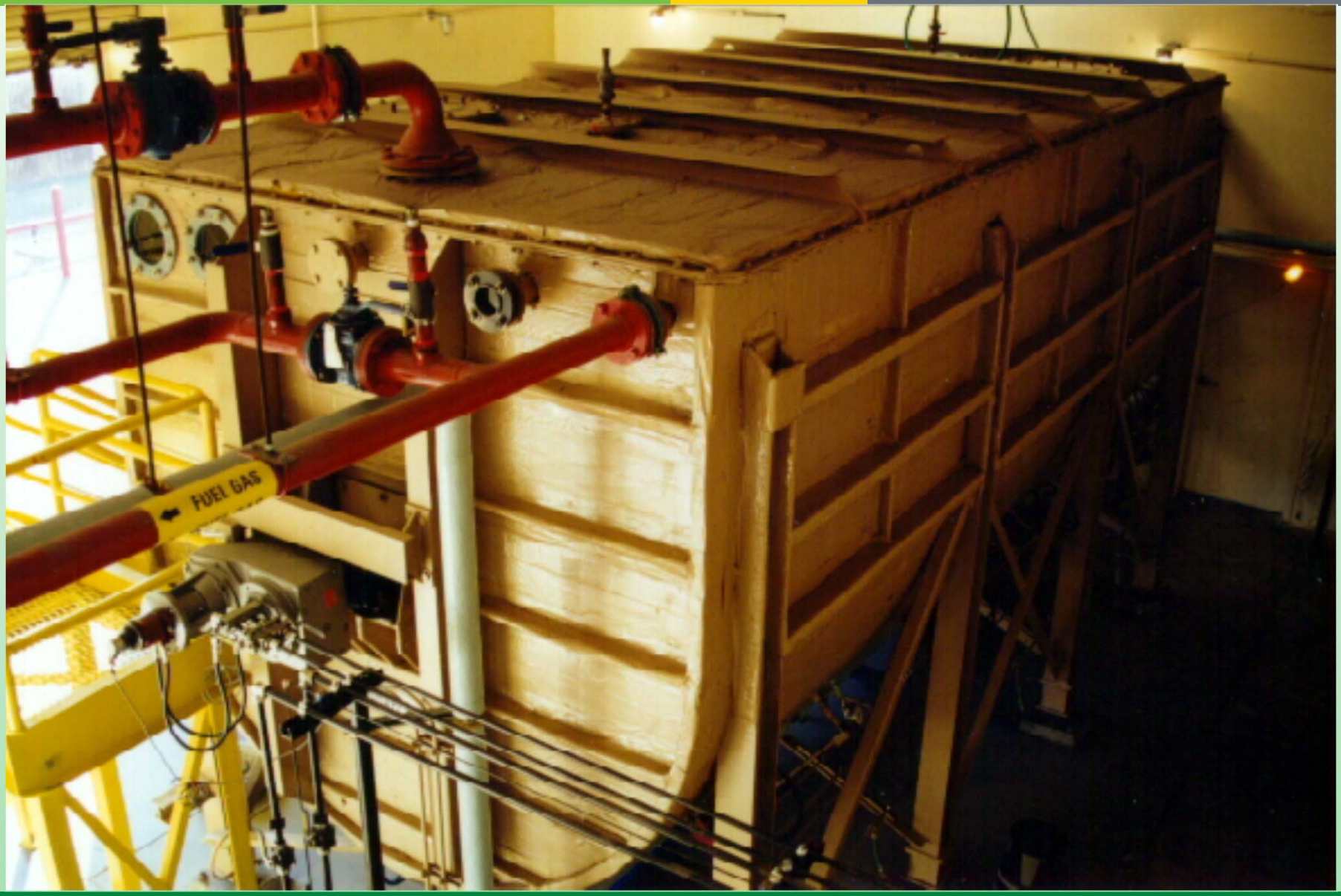

Anaerobic Digestion

High Solids Applications: Commercial Scale Plug Flow Digester

(Photo Courtesy of www.kompogas.ch)

Anaerobic Digestion:

A Success Story:
The Danish Model

Summary of Biogas Program in Denmark: Why it works

- Nationwide program started in 1988
- 21 centralized plants
- Laws prohibit landfilling or land application
- Laws mandate 7 month winter hold
- Government provides 20-40% financing subsidy
- Law mandates electricity purchase
- Law mandates minimum price
- Cities use centralized heat
- Collection trucks powered by biogas
- Effluent delivered back to farms

Anaerobic Digestion

Blaabjerg Plant Equipment:
1. Blending Tank
2. Industrial Sludge Holding Tank
3. Manure Hold Tank
4. Digester
5. Gas holder
6. Effluent Sludge Tank
7. CO-GEN Building
8. Office & Laboratory Bldg.

Blaabjerg Main Operating Data:
Animal manure..... 222 tons/day
Alternative biomass..... 87 tons/day
Biogas production..... 3,1 mill Nm³/year
Digester capacity (2 x 2500 m³).. 5000 m³
Process temperature..... 53,5° C
Utilisation of biogas..... CHP-plant
Average transport distance..... 5,0 km
Contact: Manager
Jens Riddersholm Jensen
Tlf./Fax: 75287948 / 75287348
Contractor: BWSC Ltd

Anaerobic Digestion

Arhus Main data:
Animal manure..... 346 tons/day
Alternative biomass..... 46 tons/day
Biogas production..... 3,8 mill Nm³/year
Digester capacity..... 8500 m³
Process temperature
- slurry + org. waste..... 38° C
- household waste..... 52° C
Utilisation of biogas..... CHP-plant
Average transport distance..... 5,5 km
Contact: Manager John Sønder Jensen
Tlf./Fax: 86989432 / 86989209
Contractor C.G. Jensen Ltd
Year: 1995

Lintrup Main data:
Animal manure..... 410 tons/day
Alternative biomass..... 137 tons/day
Biogas production..... 5,7 mill Nm³/year
Digester capacity (3 x 2400 m³).. 7200 m³
Process temperature..... 53,0° C
Post-digestion temperature..... 42,0° C
Utilisation of biogas..... CHP-plant/gas boiler
Average transport distance..... 7,5 km
Contact: Manager Tom Buhl
Tlf./Fax: 74855344 / 74855203
Contractor: Kruger Ltd
Year: 1990

Anaerobic Digestion:

R&D Needs for Broad Commercial Deployment:

Reducing the “Art of the Black Box” to Science:

R&D Needs for Broad Commercialization: Cost Reduction and Process Optimization for Reliability

- Development of inoculum methodologies and anaerobic culture techniques
- Understanding the microbial population dynamics of the mixed consortium
  - consortium optimization and “health”
  - Prescriptive and preventative “therapeutic” methods
  - “Mining” the consortium for strains that make other products instead of biogas
- Reactor design optimization
- Process optimization: the 65% “wall”
  - Enhancing biogas productivity: higher yields from volatile solids
  - Enhancing biogas quality: higher methane content

R&D Needs for Broad Commercialization: Cost Reduction and Process Optimization for Reliability

- Process automation through real-time instrumentation and remote operations/telemetry
- Value-added effluent processing and co-product optimization
  - Compost stabilization
  - “Mining the Pressate”
  - Development of new products
  - Cheap and efficient water recycling technologies
- Methane splitting and cleanup
- Material Recovery Facility (MRF) technology development
- Community education for organic recycling

The Potential for Biogas/Fuel Cell Integration at Biorefineries

Benefits of Fuel Cell Integration with Biorefineries (or any industrial facility with organic wastes with potential for biogas production)

- Industrial retrofits with Fuel Cell applications reduce operating costs:
  - Onsite distributed power generation: CHP
  - Avoided cost of electricity
  - Avoided cost of waste treatment, collection and disposal
  - Fossil fuel displacement
  - Reduces production GHG footprint/LCA of products
- Distributed generation for energy security, environmental stewardship, economic development
- Industrial and municipal biogas facilities can become the backbone of a hydrogen Infrastructure: production and fueling

FC Integration for CHP in Biofuel Production

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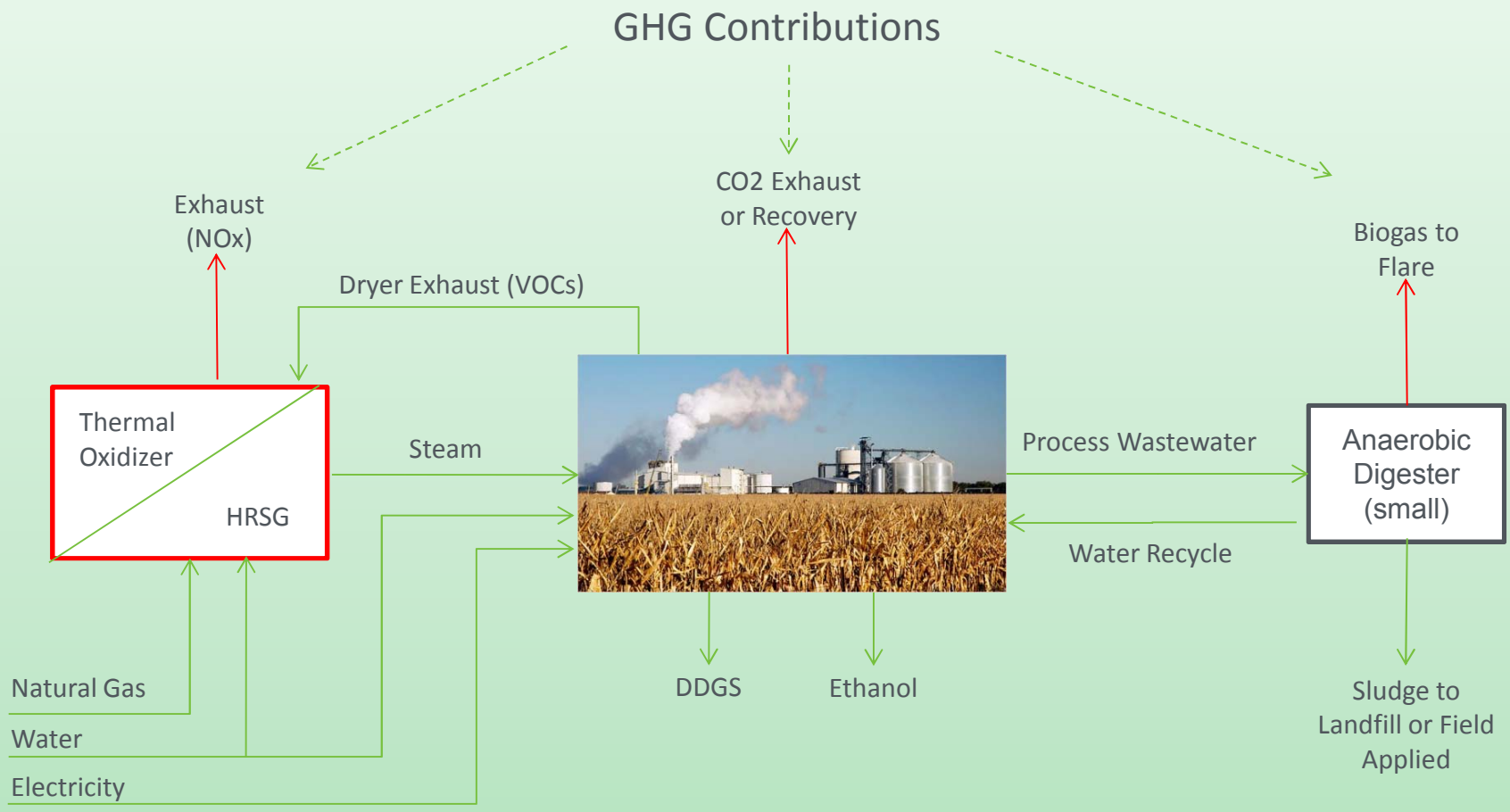

Dry Mill Ethanol Plant
(Current)

FC Integration for CHP in Biofuel Production

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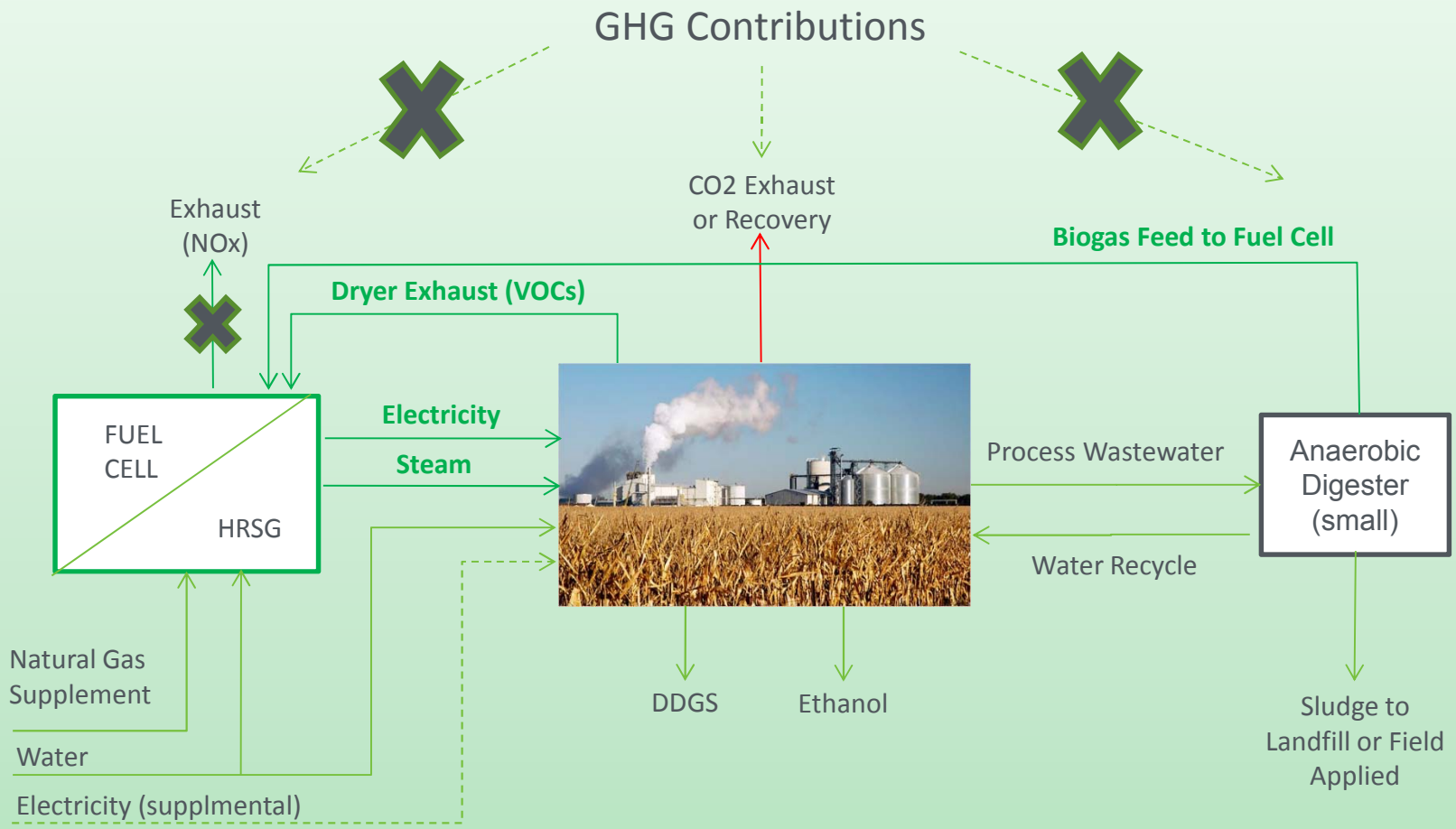

Dry Mill Ethanol Plant
(Fuel Cell Integration)

FC Integration for CHP in Biofuel Production

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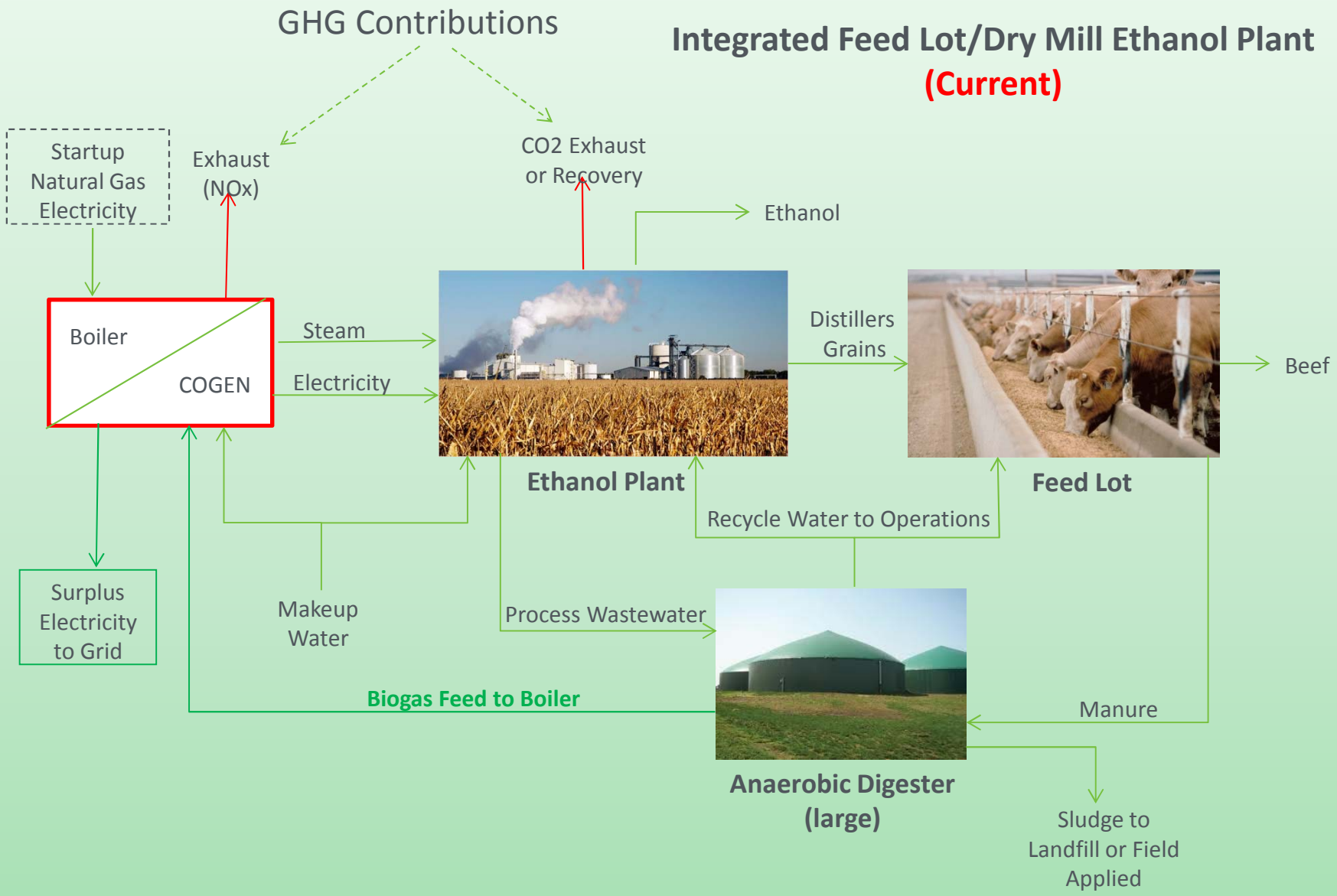

FC Integration for CHP in Biofuel Production

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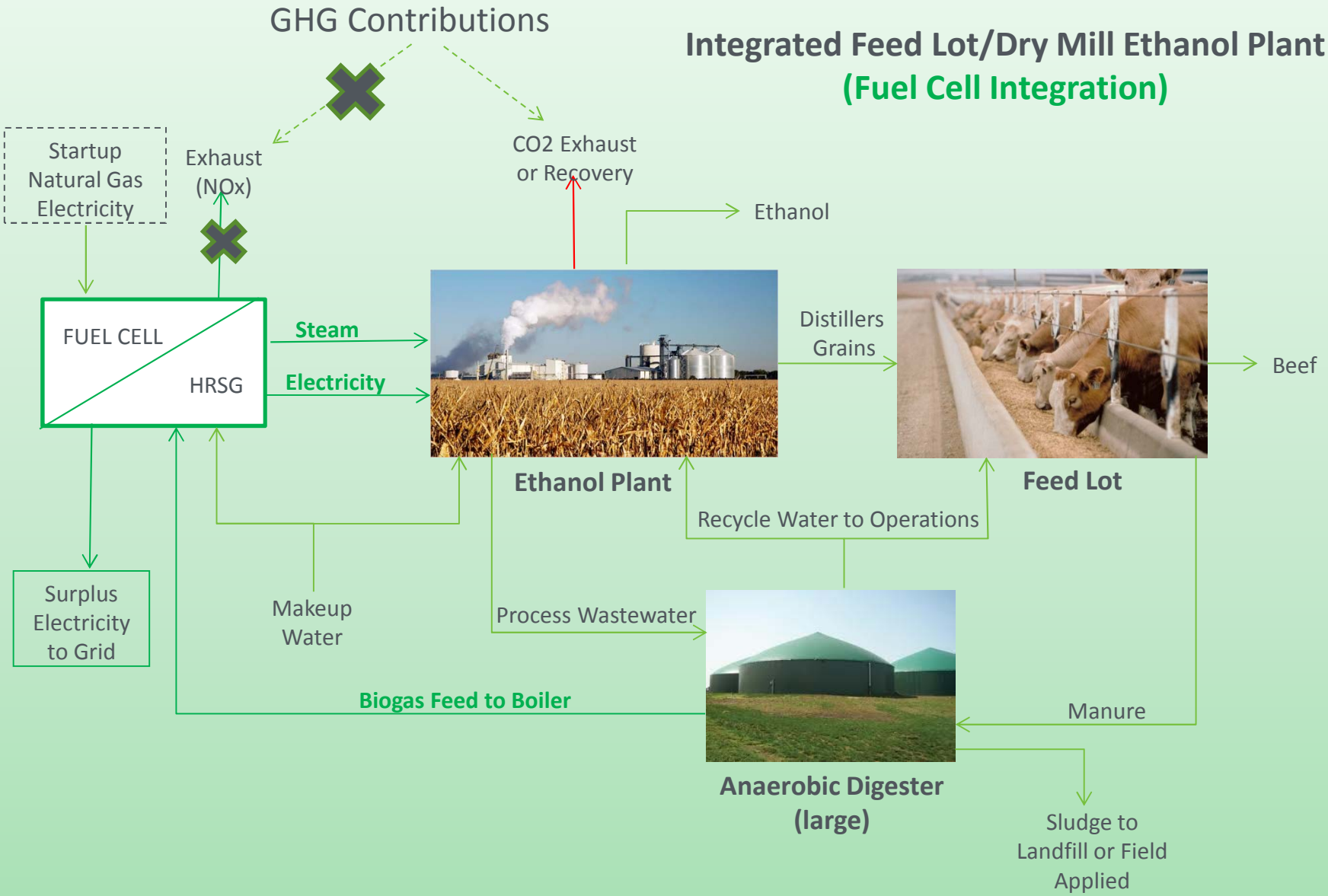

FC Integration for CHP in Biofuel Production

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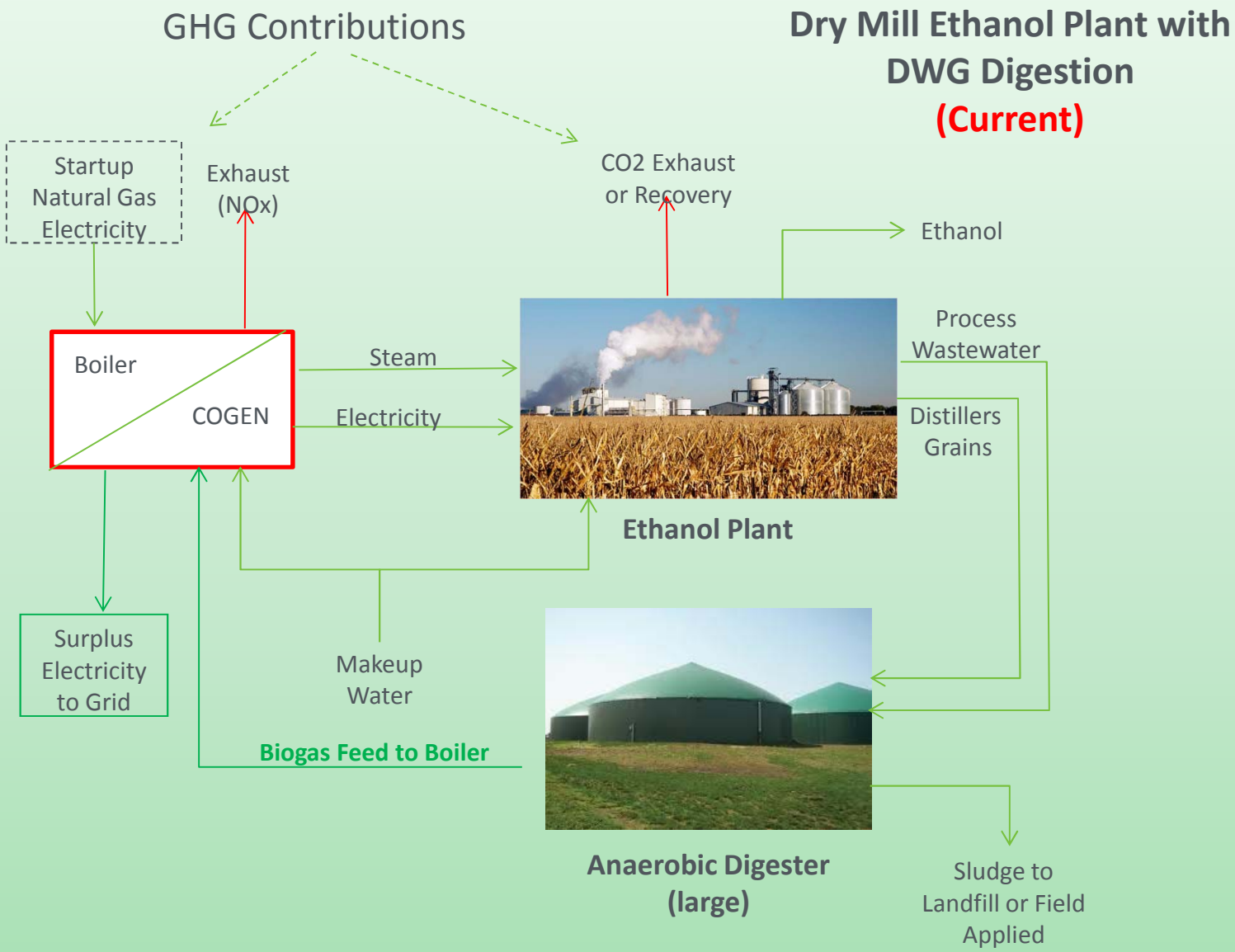

FC Integration for CHP in Biofuel Production

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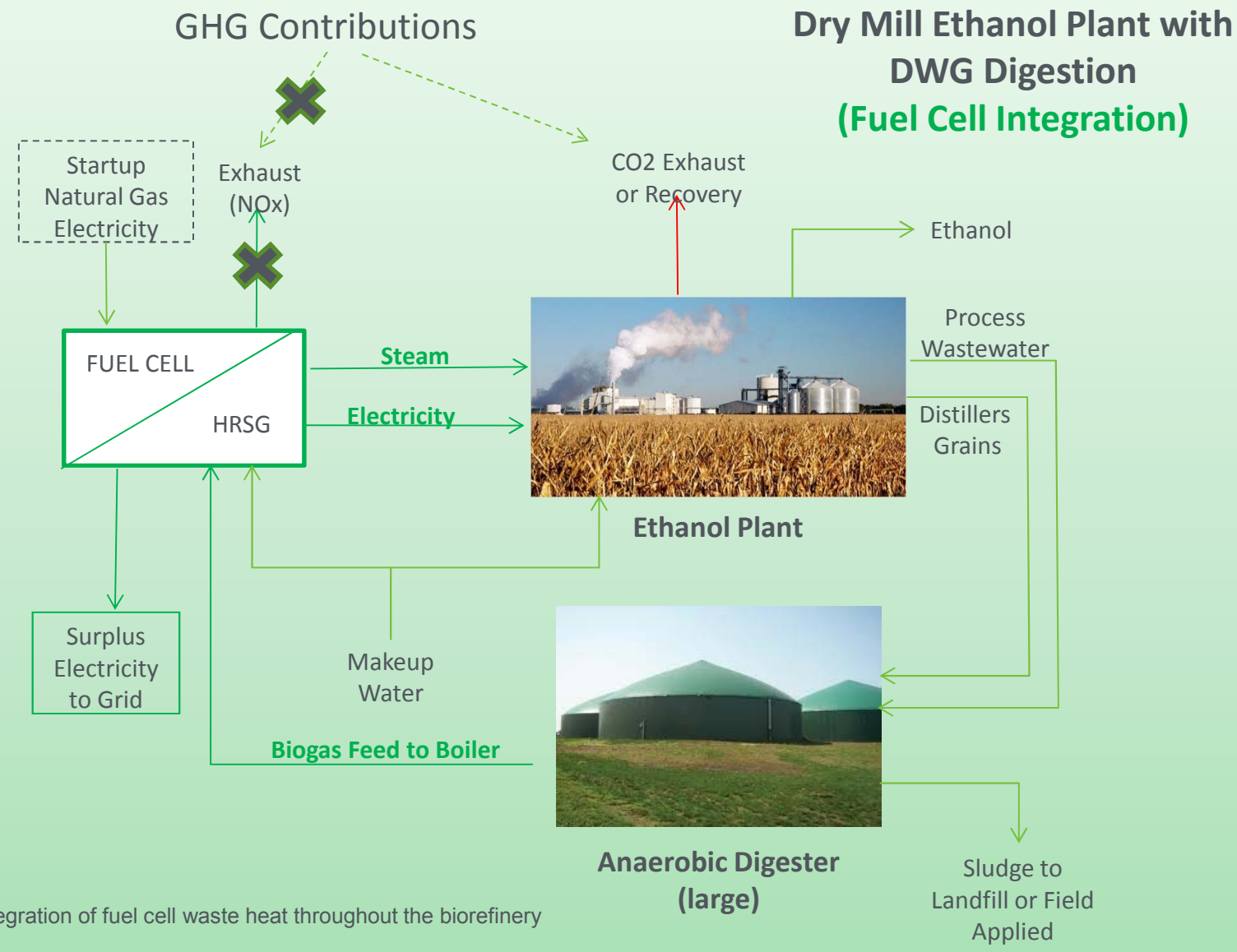

Not shown:
- Full heat integration of fuel cell waste heat throughout the biorefinery

FC Integration for CHP in Biofuel Production

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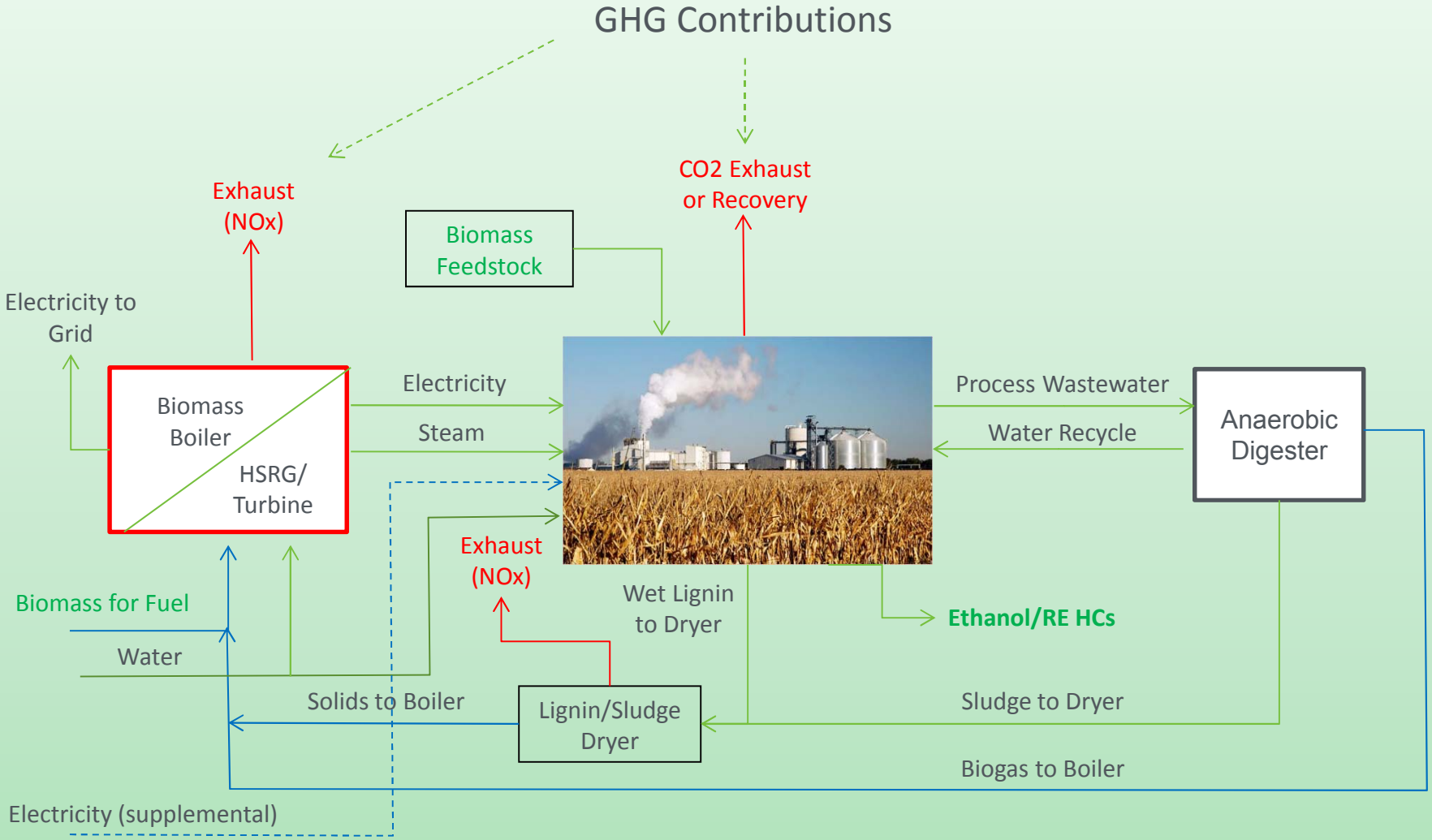

Integrated Biorefinery – Biochemical
(Current Envisioned)

FC Integration for CHP in Biofuel Production

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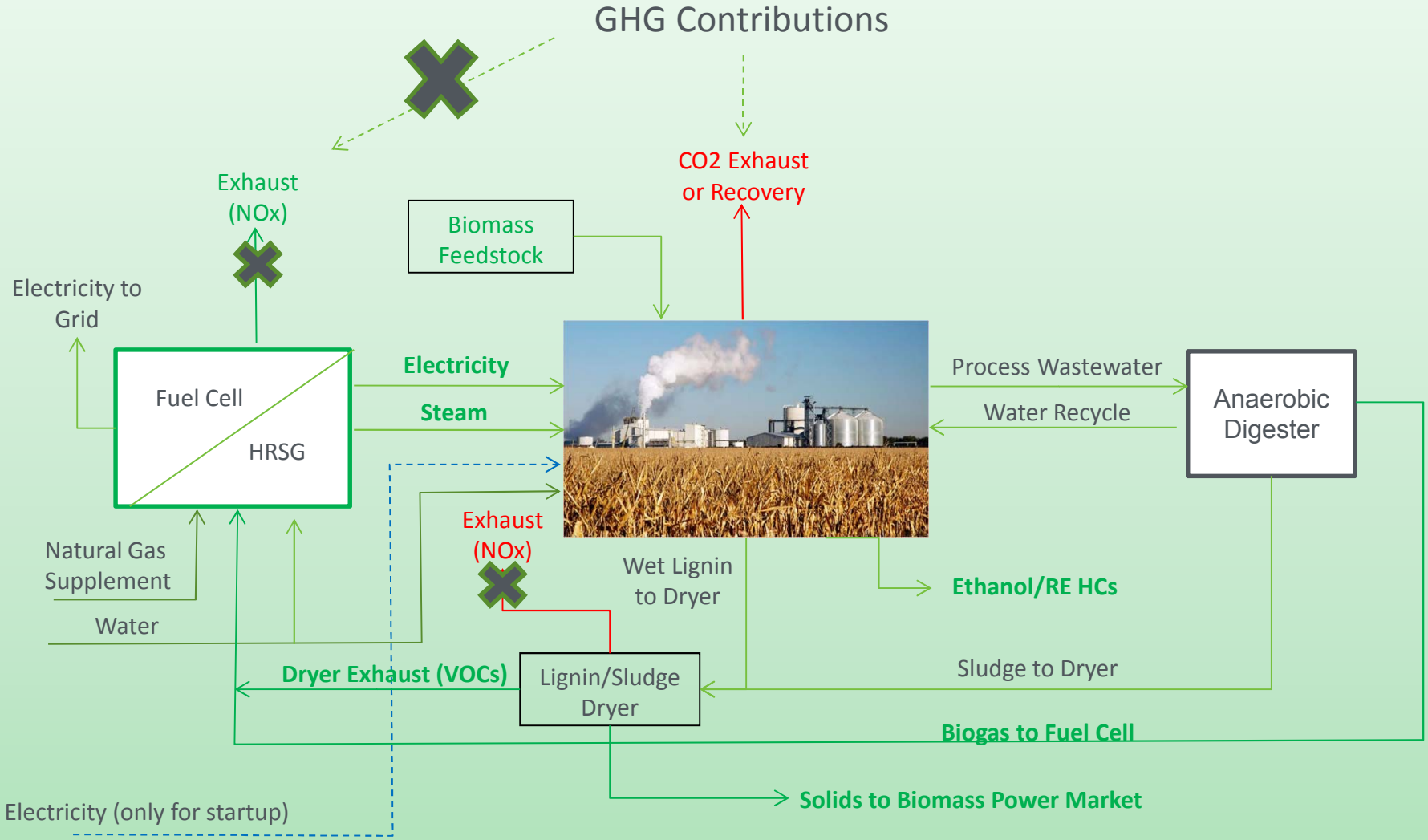

Integrated Biorefinery – Biochemical Ethanol (Fuel Cell Integration)

FC Integration for CHP in Biofuel Production

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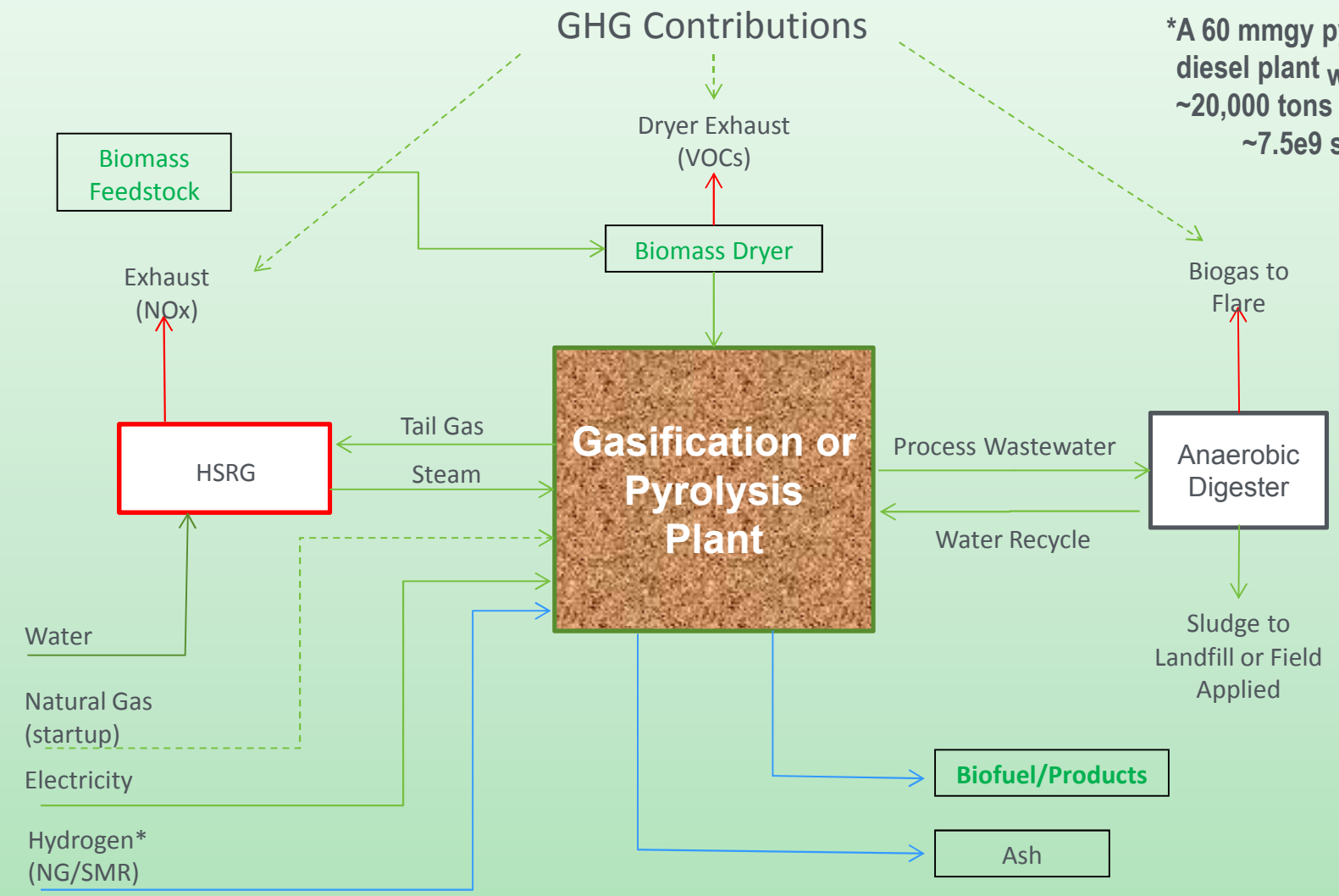

Integrated Biorefinery – Thermochemical (Current Envisioned)

FC Integration for CHP in Biofuel Production

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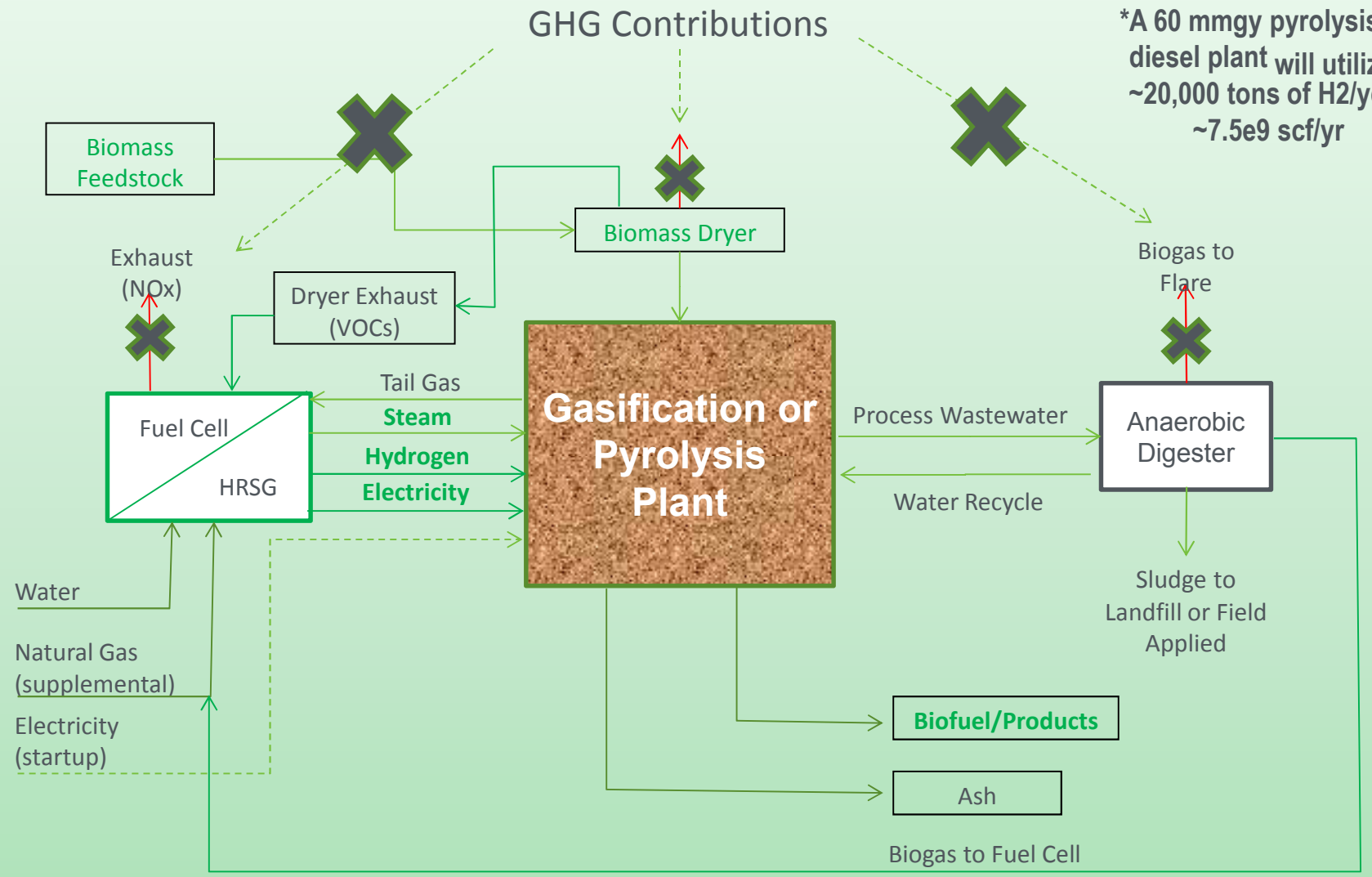

Integrated Biorefinery – Thermochemical (Fuel Cell integration)

Concept for an EERE Multi-Program Joint Solicitation:

"Integration and Demonstration of a Biogas/Fuel Cell CHP/Tri-gen System at a Biorefinery"

Concept Basis

An innovative approach to meeting the Administration's goals in a cost-effective and sustainable manner:

- Integration of stationary combined heat and power (CHP) and Tri-gen fuel cell systems at biorefineries and biofuel production facilities
- Use the biogas generated from anaerobic digestion of biorefinery wastes as a feedstock in stationary combined heat and power (CHP) fuel cell utility systems to further reduce production costs and GHG footprint and LCA
- Potential to utilize hydrogen for catalytic applications
- Capitalize on *stranded renewable energy resources* for distributed generation, economic development, and environmental stewardship

Potential EERE Program Collaboration

- **FCTP** – sponsorship of Molten Carbonate Fuel Cells with Industrial Partners
- **OBP** - sponsorship of Advanced Biofuel Integrated Biorefinery with Industrial Partners
- **AMO** – sponsorship of biogas/FC retrofit packages for 1st-generation biorefineries and other industrial applications with Industrial Partners
- **VTP** – sponsorship of hydrogen fueling infrastructure with Industrial/Municipal Partner(s)

Anaerobic Digestion

Goals/Benefits/Outcomes

- Develop optimized biogas production technologies
- Improve anaerobic digestion reactor design and control
- Develop cheaper biogas cleanup, splitting and methane separation technologies
- Fuel cell integration
- Hydrogen production for on-site use or vehicles
- Improvements in waste heat recovery and integration/interface with plant utility systems
- Development of retrofit packages for biorefineries and other industrial applications involving biogas
- Validation of business model and operating cost reductions

Goals/Benefits/Outcomes

- Develop optimized biogas production technologies
- Improve anaerobic digestion reactor design and control
- Develop cheaper biogas cleanup, splitting and methane separation technologies
- Develop markets for fuel cell integration
- Produce hydrogen for on-site use or vehicles
- Improve waste heat recovery systems and integration/interfacing with plant utility systems
- Develop retrofit packages for biorefineries and other industrial applications involving biogas
- Validate the business models and operating cost reductions

Thank you!

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