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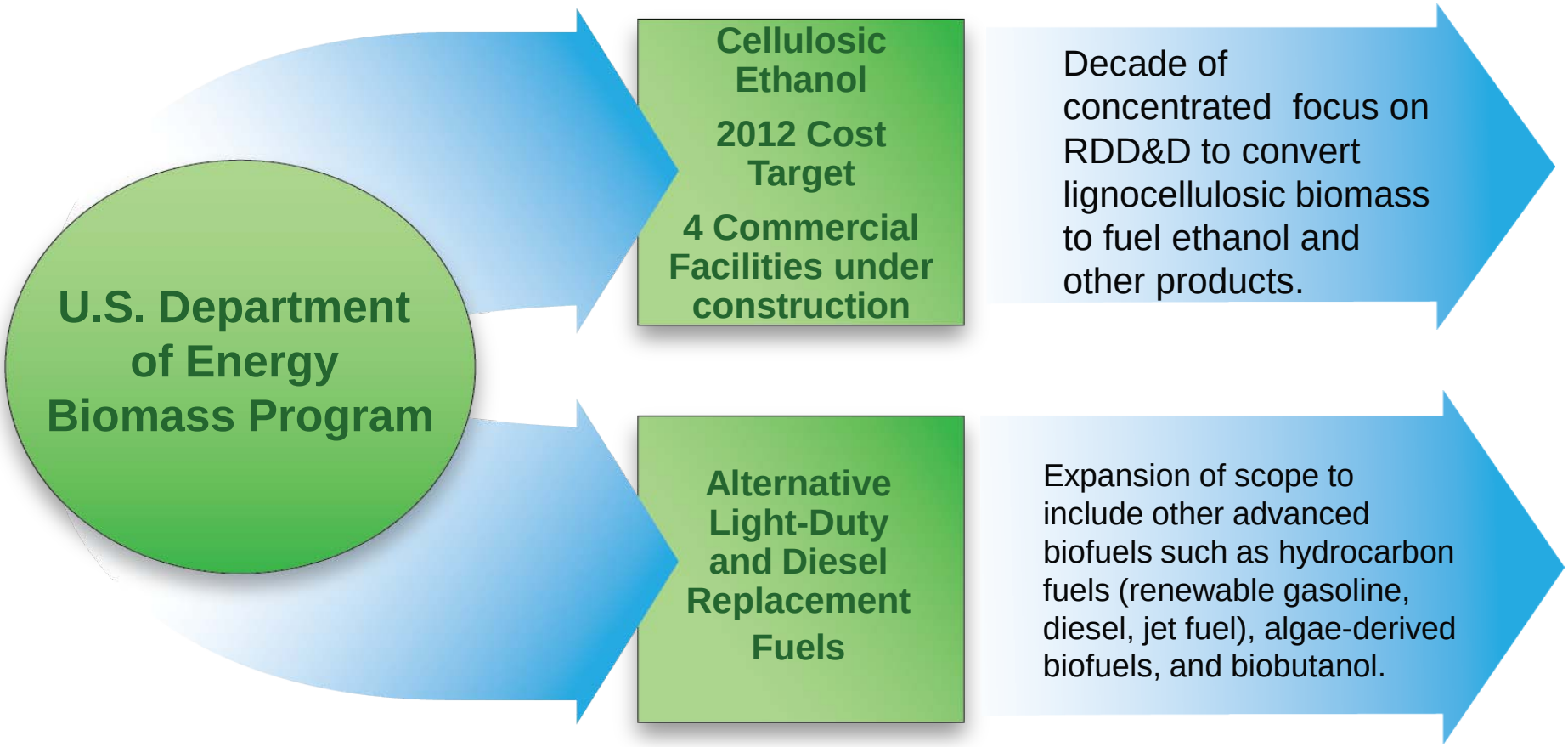
Program Focus



The Biomass Program forms cost-share partnerships with key stakeholders to develop, demonstrate, and deploy technologies for advanced biofuels, bioproducts, and biopower from lignocellulosic and algal biomass.

Technoeconomic Modeling

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- Design Case:
  - Detailed, peer reviewed process simulation based on ASPEN or Chemcad
  - Establishes cost of production at biorefinery boundary
  - Provides estimate of nth plant capital and operating costs
  - Based on best available information at date of design case
  - Scope: feedstock cost (harvest, collection, storage, grower payment), feedstock logistics (handling, size reduction, moisture control), conversion cost, profit for biorefinery
  - Excludes: taxes, distribution costs, tax credits or other incentives
- State of technology (SOT): annual updates to measure progress
  - Assessment of the current state of development for a given technology pathway
  - Based on best available information from literature, bench scale tests, integrated pilot scale operations

BC Conversion to Cellulosic Ethanol

2012 Target and State of Technology

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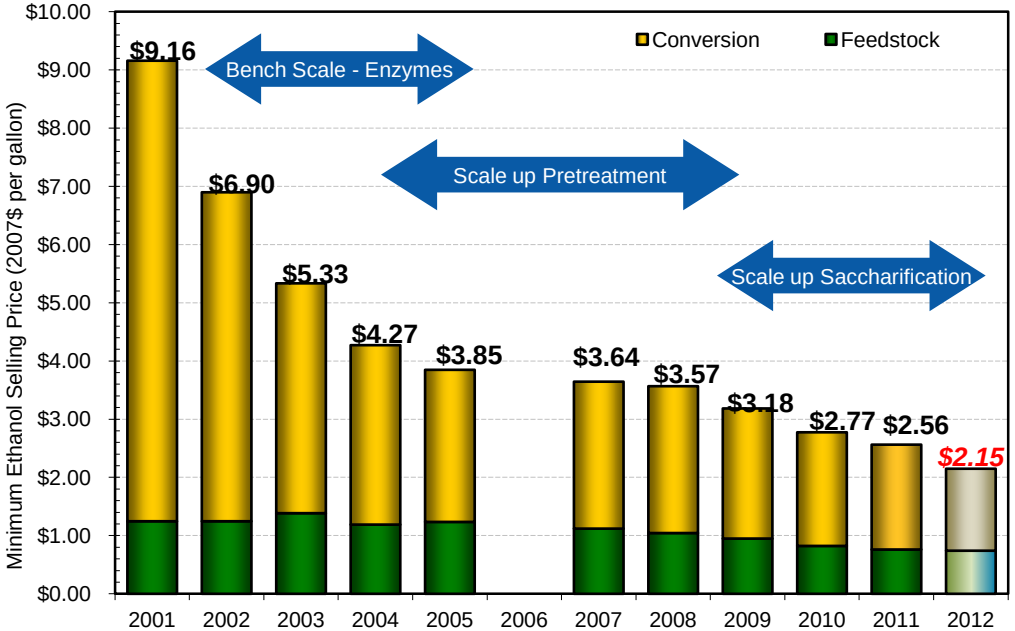
2012 Cellulosic Ethanol Successful Demonstration

- Developed pretreatment/conditioning strategy (bench and pilot scale) capable of releasing 90% of the hemicellulosic sugars
- Reduced Enzyme Costs >20x and developed strategy for further reductions
- Developed Industrially Relevant Strains Capable of Converting C_5 and C_6 Cellulosic Sugars at conversion yields of 85-95% and tolerant of ethanol titers of >70 g/L
- Built/adapted fully integrated pilot scale capability for 2012 demonstration
- Developed peer reviewed model for extrapolation to commercial scale
- Demonstrated Cost Reductions that make cellulosic ethanol production cost competitive with gasoline production at ~$110/bbl crude oil
- Commercial demonstrations of similar design coming online (Poet, Abengoa)



	2011 Target	2011 Washed Solids	2011 Whole Slurry	2012 Targets
Minimum Ethanol Selling Price ($/gal)	**$2.62**	**$2.56**	**$2.37**	**$2.15**
Feedstock Contribution ($/gal)	$0.76	$0.76	$0.82	$0.74
Conversion Contribution ($/gal)	$1.86	$1.80	$1.55	$1.41
Yield (Gallon/dry ton)	78	78	71	79
Feedstock				
Feedstock Cost ($/dry ton)	$59.60	$59.60	$59.60	$58.50
Pretreatment				
Solids Loading (wt%)	30%	30%	30%	30%
Xylan to Xylose (including enzymatic)	88%	88%	78%	90%
Xylan to Degradation Products	5%	5%	6%	5%
Conditioning				
Ammonia Loading (mL per L Hydrolyzate)	25	25	25	25
Hydrolyzate solid-liquid separation	Yes	Yes	No	No
Xylose Sugar Loss	1%	1%	1%	1%
Glucose Sugar Loss	1%	1%	1%	0%
Enzymes				
Enzyme Contribution ($/gal EtOH)	$0.36	$0.34	$0.38	$0.34
Enzymatic Hydrolysis & Fermentation				
Total Solids Loading (wt%)	20%	17.5%	17.5%	20%
Combined Saccharification & Fermentation Time (d)	5	5	5	5
Corn Steep Liquor Loading (wt%)	0.60%	0.25%	0.25%	0.25%
Overall Cellulose to Ethanol	86%	89%	80%	86%
Xylose to Ethanol	85%	85%	85%	85%
Arabinose to Ethanol	80%	47%	47%	85%

Pathway Selection Process

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March 2012
18 potential pathways identified, 13 selected to move forward with initial analysis

July 2012
8 pathways selected from original 13

October 2012
Pathways prioritized and timeline for analysis developed

September 2013
Full design cases completed for 4 pathways (Fermentation of Lignocellulosic Sugars, ALU, AHTL, Fast Pyrolysis)

Completed Activities → *Planned Activities*

Preliminary TEA on proposed pathways performed by NREL and PNNL with input from other labs

September 2012
PNNL/NREL completed joint milestone report detailing analysis effort

March 2013
Preliminary cost goals published in MYPP and key areas of research identified

September 2014
Year-by-year targets completed for 2013 pathways. Full design cases completed for 4 additional pathways (ex situ and in situ Catalytic Pyrolysis, Catalytic Upgrading of Lignocellulosic Sugars, Syngas to Hydrocarbons).

Criteria for downselect included:

- Feasibility of achieving programmatic cost goal of $3/gal
- Near/Mid/Long-term techno-economic potential
- Potential national impact
- Feedstock availability/flexibility
- Data availability across the full pathway
- Co-product economics
- Potential volumetric impact in 2030
- Environmental Sustainability

Pathways included in initial analysis

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Technology Area	Pathway
Sugars	Fermentation of Sugars to Hydrocarbons
	Catalytic Upgrading of Sugars to Hydrocarbons
	Fermentation of Sugars via Heterotrophic Algae to Hydrocarbons
Oils	Fast Pyrolysis and Upgrading
	Catalytic Pyrolysis – ex situ
	Catalytic Pyrolysis – in situ
	Hydropyrolysis
	Hydrothermal Liquefaction
	Solvent Liquefaction
Algae	Whole Algae Hydrothermal Liquefaction (ABHTL)
	Algal Lipid Extraction Upgrading to Hydrocarbons (ALU)
Gaseous Intermediates	Syngas to Methanol to Triptyls
	Syngas Fermentation and Upgrading to Hydrocarbons
	Landfill Gas Upgrading to Hydrocarbons
	Gasification with Fermentation to Oxygenates
Other	Anaerobic digestion to CNG
	Anaerobic digestion to Hydrocarbons via GTL
	Coal Biomass to Liquids

Selected Pathway details

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Pathway	Description	Design Case	Opportunity (TBD)	Opportunities for research improvement
Fermentation of Lignocellulosic Sugars	fermentation of lignocellulosic sugars to HCs	FY13	Mid-long term	yield (C5s mainly), reduce residence time, increase titer
Catalytic Conversion of Lignocellulosic Sugars	Catalytic conversion of lignocellulosic sugars to HCs	FY14	Near-mid term	Higher yield, catalyst performance
Ex situ Catalytic Pyrolysis	Pyrolysis, vapor-phase upgrading, liquid-phase finishing	FY14	Mid term	Yield, catalyst performance
In situ Catalytic Pyrolysis	Catalytic. pyrolysis, liquid-phase finishing	FY14	Mid term	Increase yield, improve catalyst
Algal Lipid Upgrading (ALU)	Open pond algae, solvent extraction, hydrotreating	FY13	Long term	66% productivity inc, 50% extacted lipid increase, 19% harvest efficiency increase, 6% extraction efficiency increase
Algal Biofuels Hydrothermal Liquefaction (ABHTL)	Open pond algae, hydrothermal liquefaction, hydrotreating	FY13	Unknown	productivity increase, 19% harvest efficiency increase, 10% aqueous recovery increase
Syngas to MeOH to High Triptyls	Syngas to MeOH to high Triptyls	FY14	Mid term	Conversion catalyst for distillates, yields, selectivity via H2 addition

Biofuel Production Costs

Detailed Example of renewable fuels via pyrolysis

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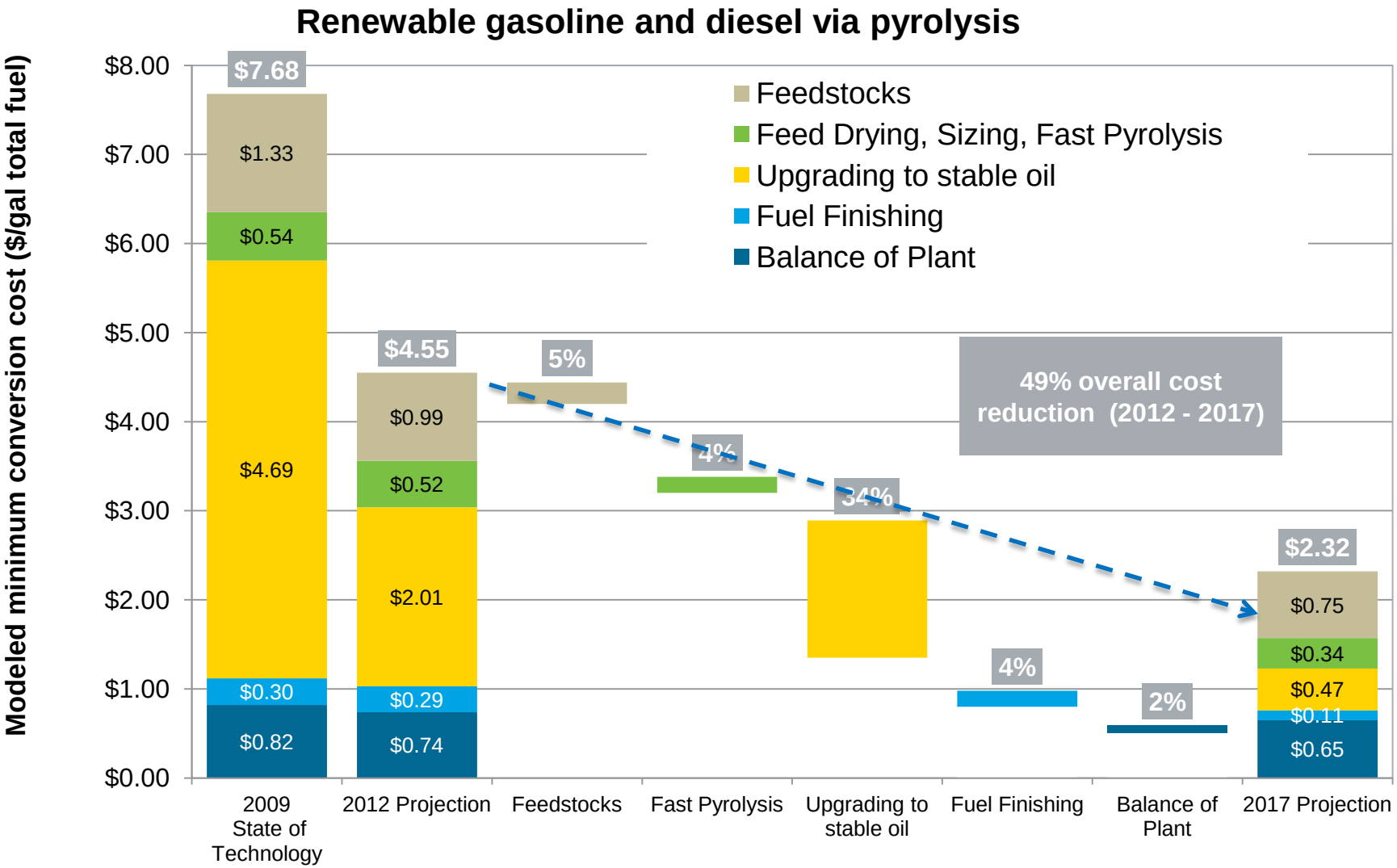
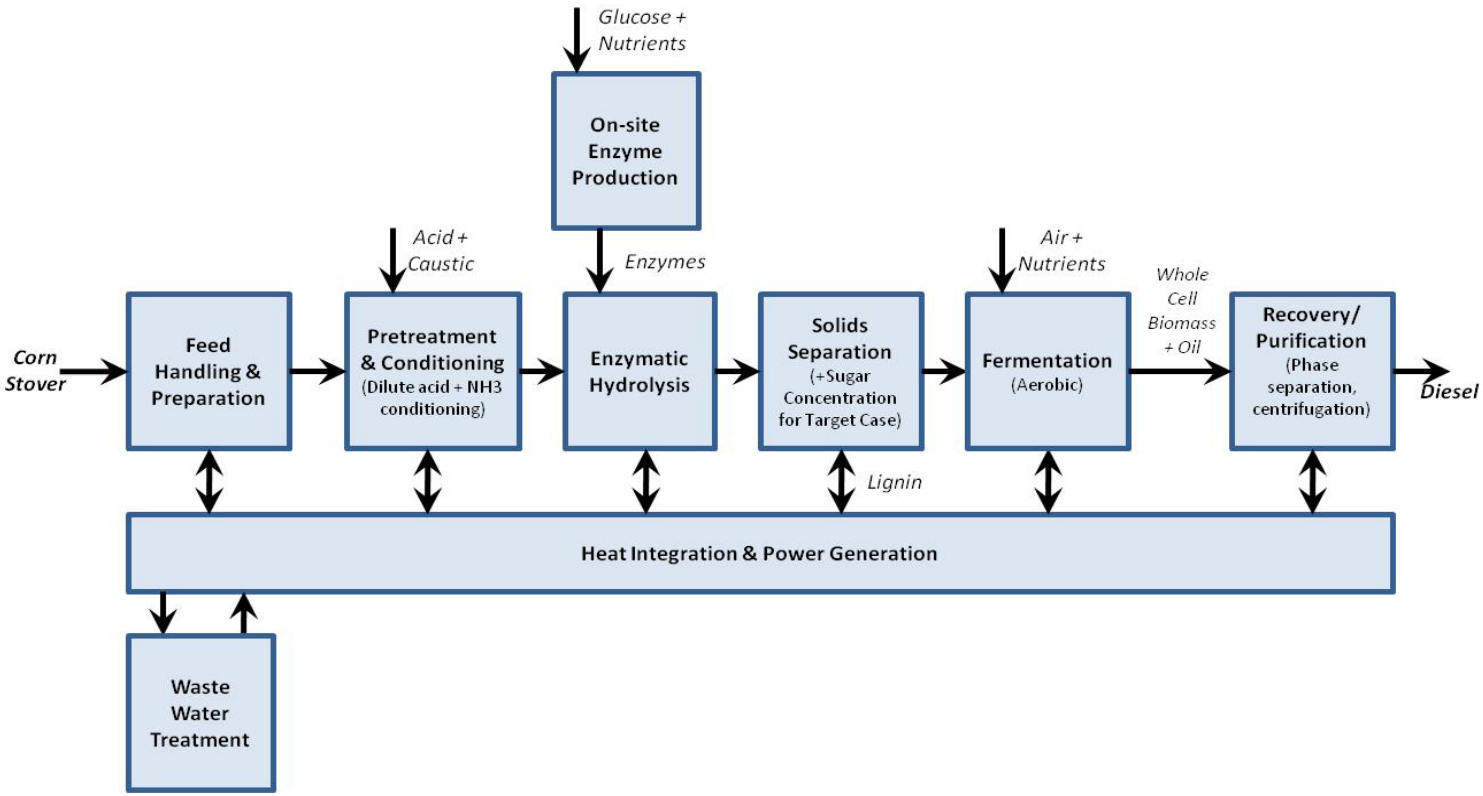


Pyrolysis costs by unit and projected cost reductions through R&D

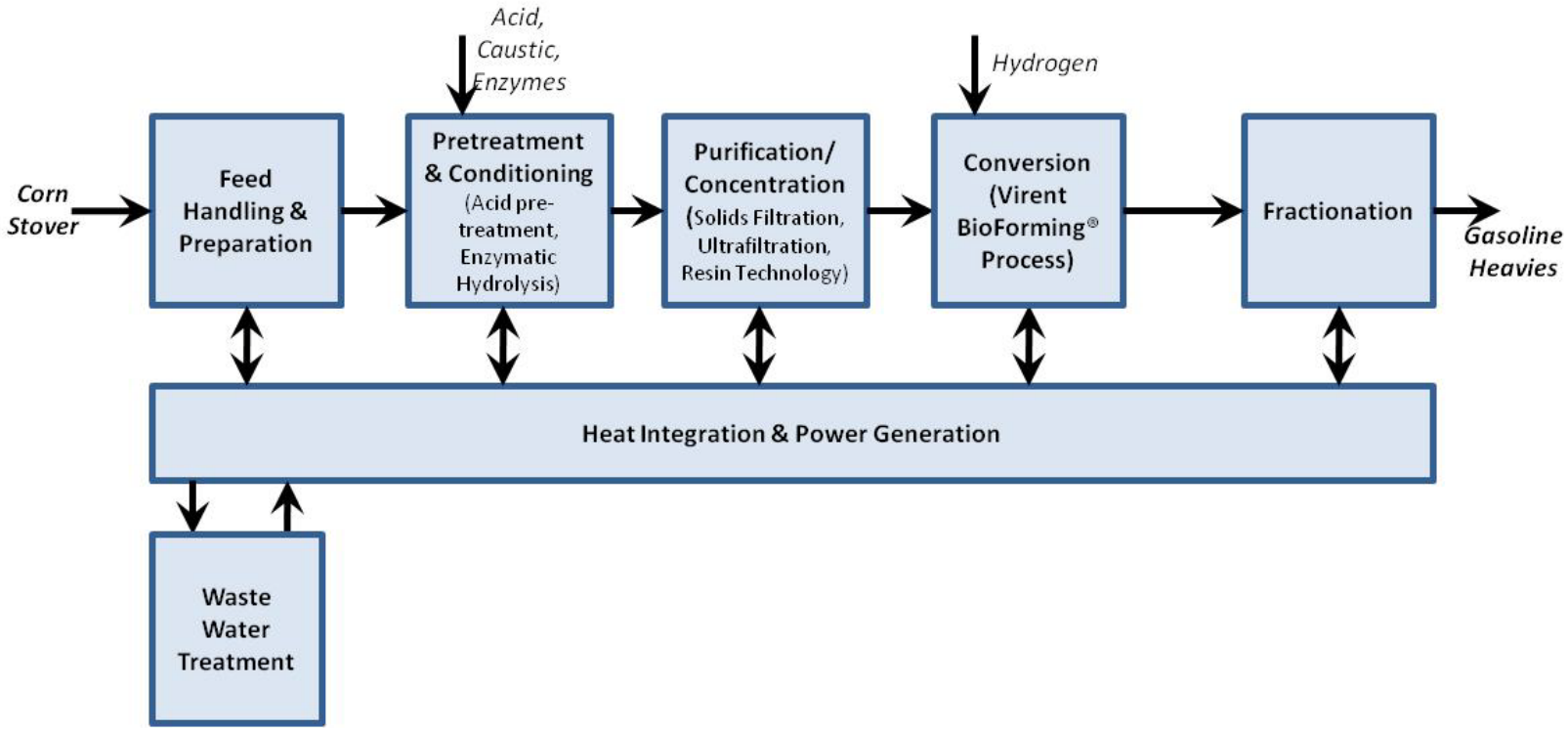
Fermentation of Sugars to Hydrocarbons



Rationale for Selecting Pathway

- Better utilization of biomass derived carbon sources (higher yields)
- Path to 2017 cost targets achievable via reasonable co-product credits
- Leverage previous front-end modeling and research through sugar production
- Back-integration and lessons-learned from IBR projects hasten process development

Catalytic Upgrading of Sugars to Hydrocarbons



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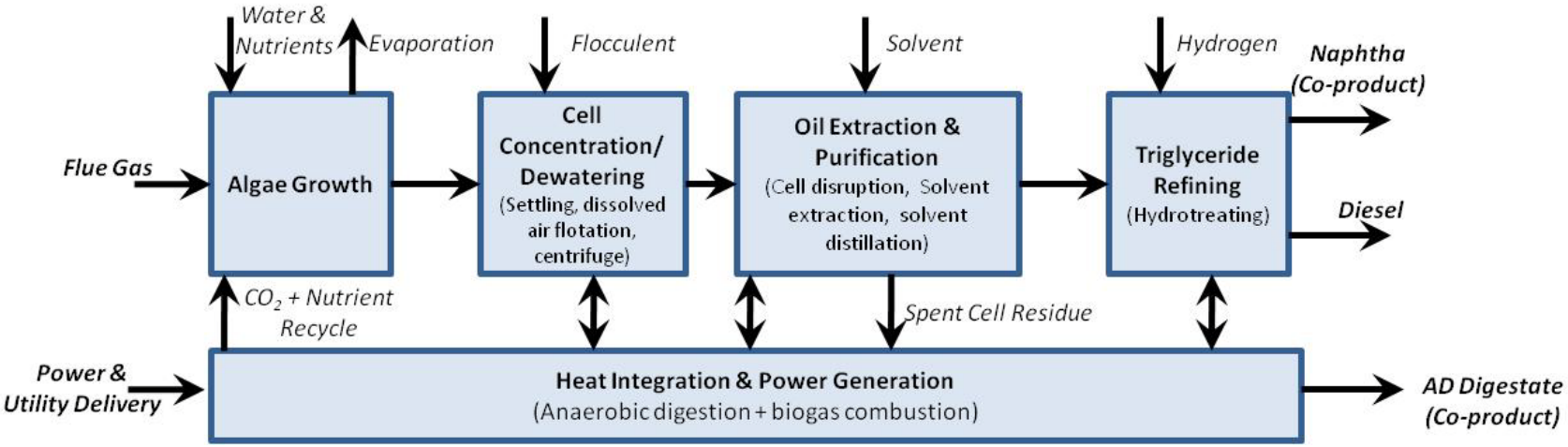
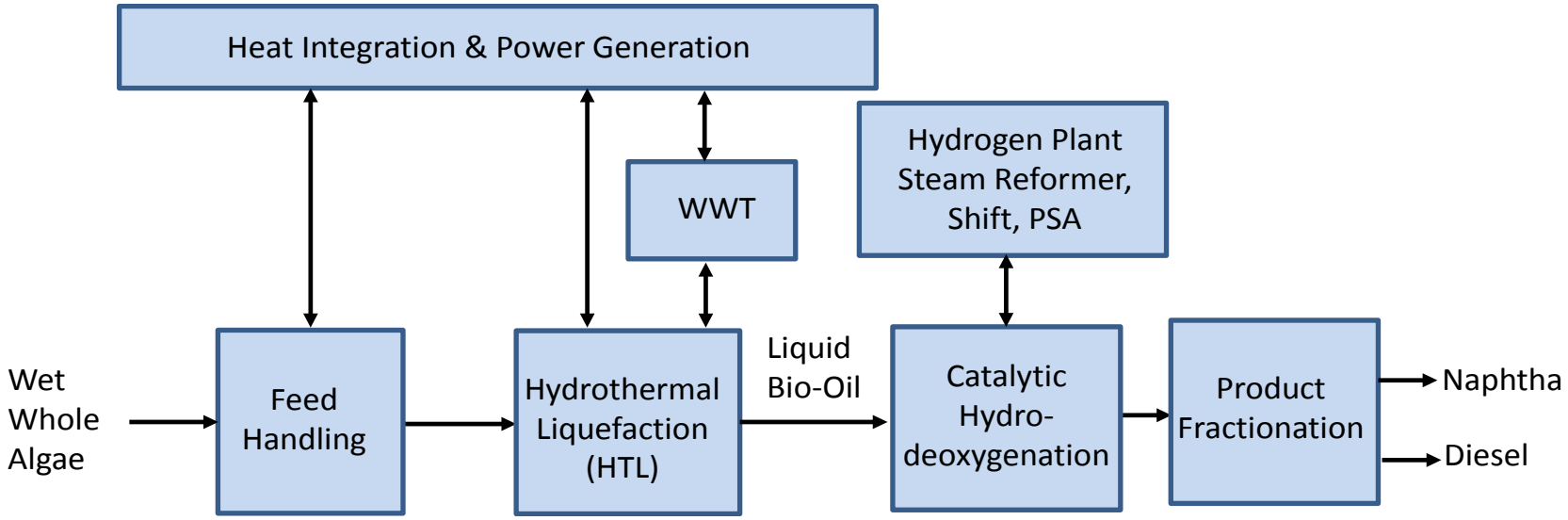
Algal Lipid Extraction and Upgrading to Hydrocarbons (ALU)



Rationale for Selecting Pathway

- Raw algal oil intermediate is expected to require relatively mild upgrading (hydrotreating) to finished fuels at marginal cost
- Algal biomass can be tailored to produce specific components for fuel and/or product markets (potential for high-value coproducts)
- Nutrient recycle and heat and power integration through anaerobic digestion improves process economics and sustainability profile

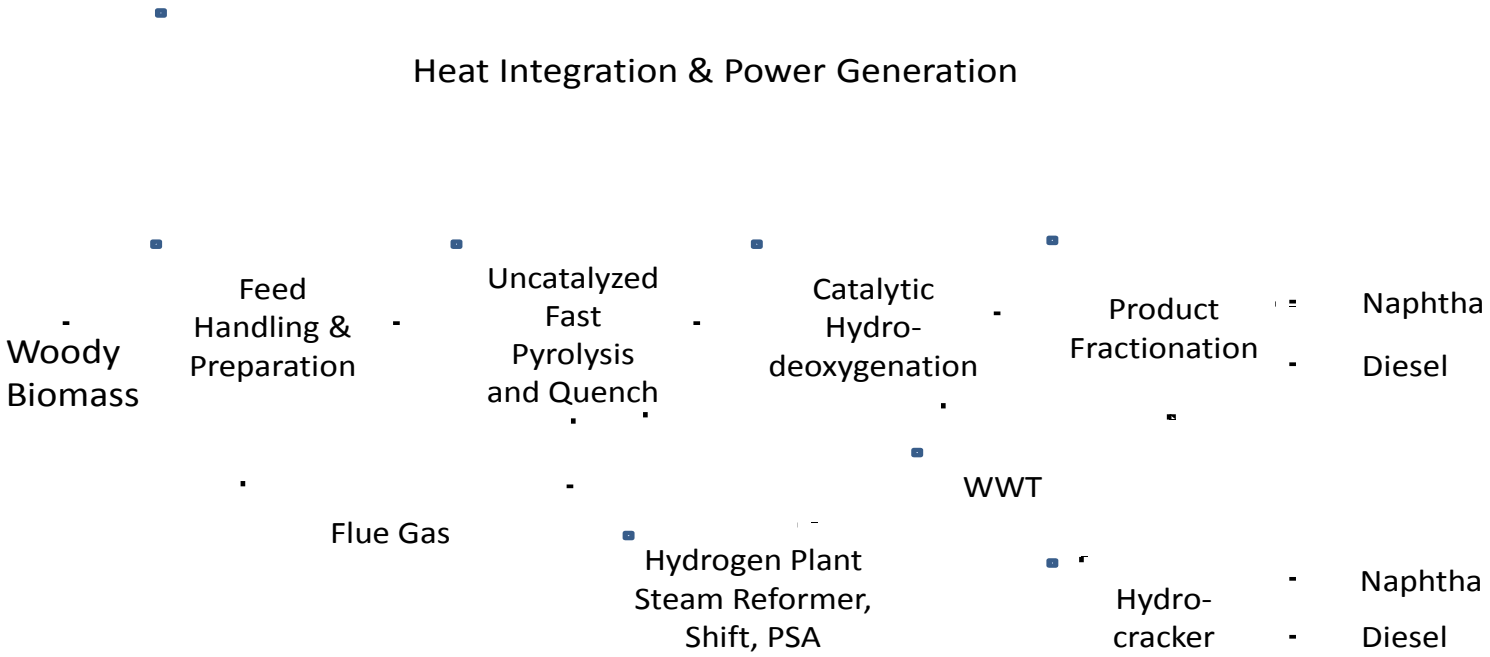
Whole Algae Hydrothermal Liquefaction (ABHTL)



Rationale for Selecting Pathway

- HTL both extraction and conversion process (50-70% of carbon captured)
- Higher yield than other known extractions
- HTL is wet process using only water, no drying or solvent recovery needed
- Oil phase lower in oxygen content and easy to upgrade to hydrocarbons
- CHG is faster, smaller, and more complete than Anaerobic Digestion (AD)
- Leverages NABC, NAABB, and new AOP work in FY13

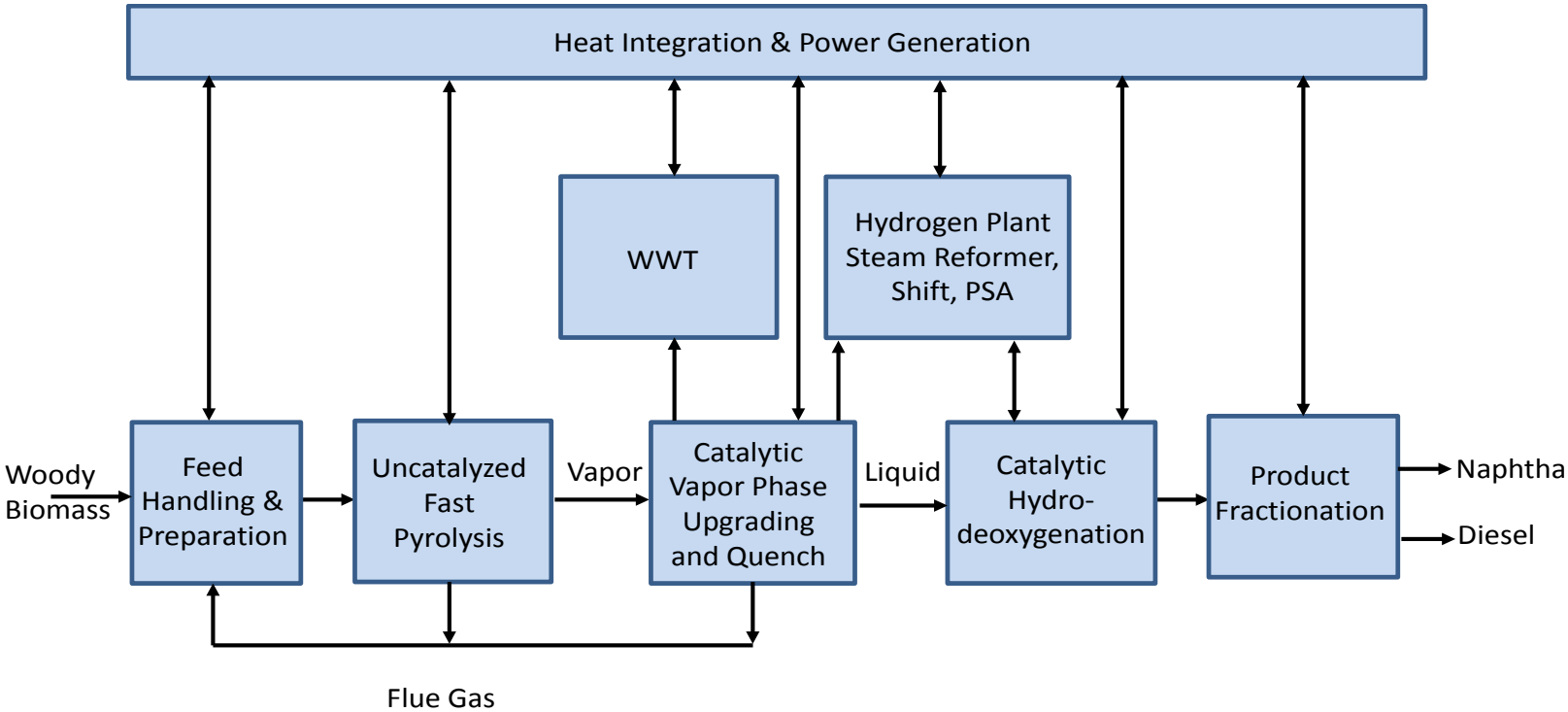
Fast Pyrolysis and Upgrading



Rationale for Selecting Pathway

- Continuation of existing pathway (rationale unchanged)

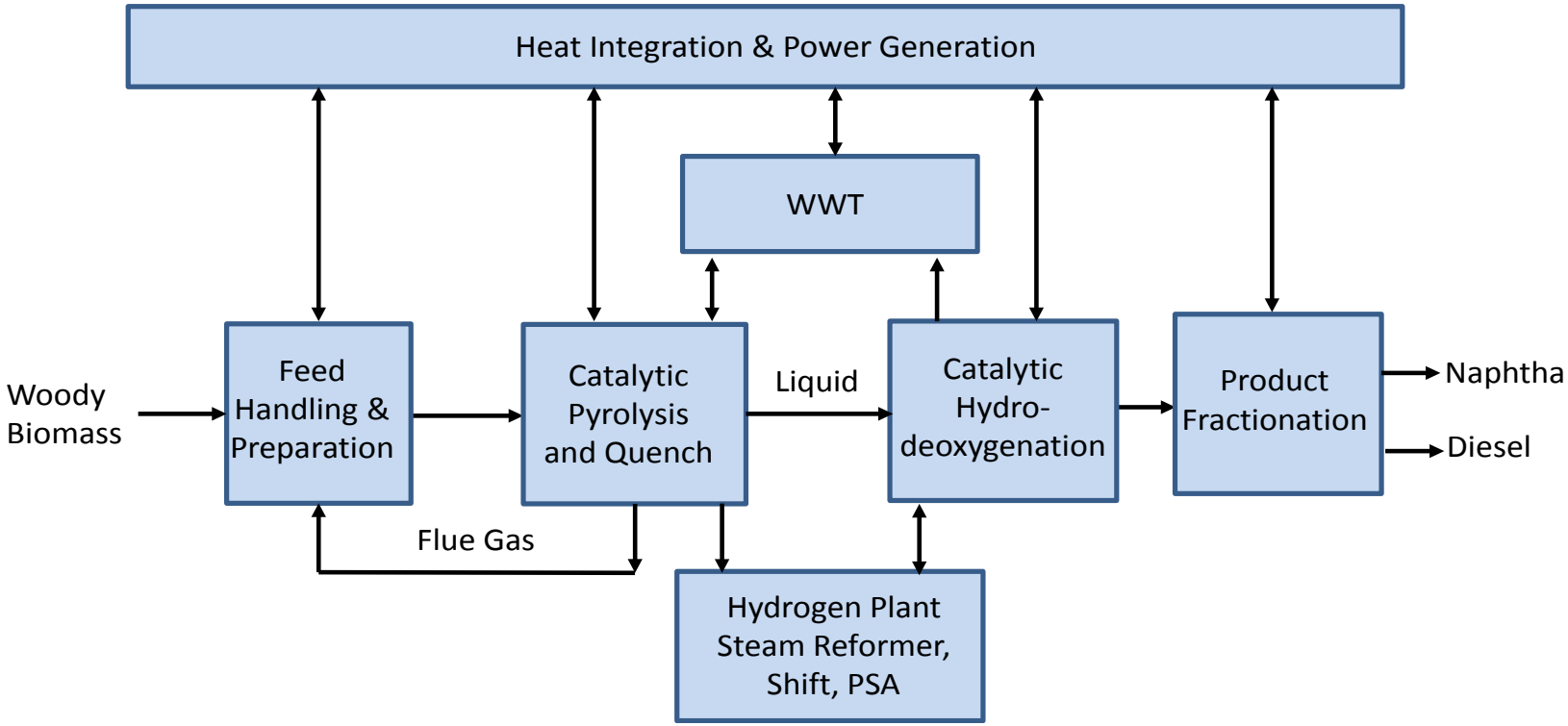
Ex situ Catalytic Pyrolysis



Rationale for Selecting Pathway

- Oil is lower in oxygen and likely easier to upgrade to hydrocarbons than fast pyrolysis derived bio-oil
- Greater control of gas/solid/liquid distribution as compared to fast pyrolysis
- May have a lower catalyst inventory
- Pathway R&D will facilitate upgrading step chemistry understanding and optimum catalyst/operating conditions

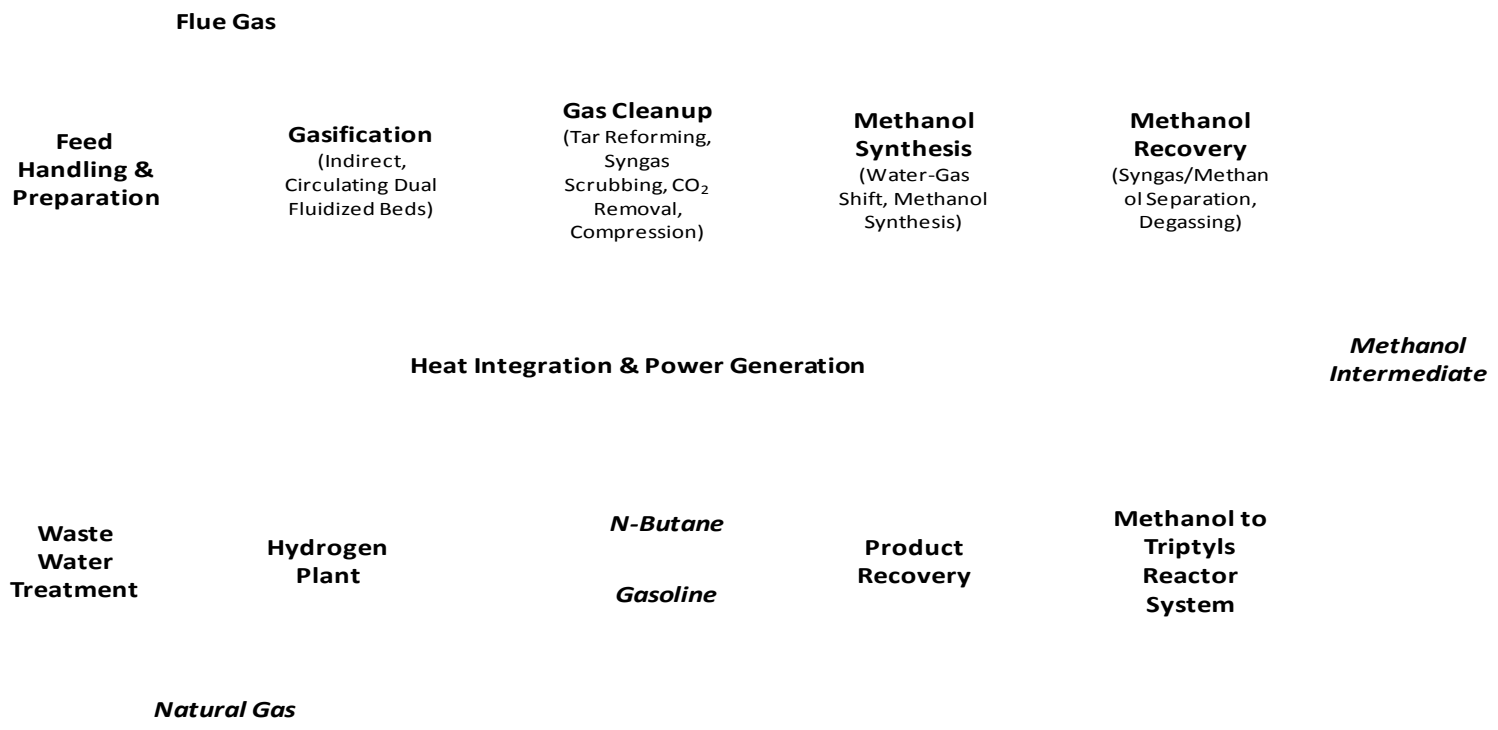
In situ Catalytic Pyrolysis



Rationale for Selecting Pathway

- Requires only one liquefaction reactor and will have lower CapEX
- May have a lower OpEx if larger size feedstock particles are acceptable
- Oil is lower in oxygen and likely easier to upgrade to hydrocarbons than fast pyrolysis derived bio-oil
- Leverages ex-situ Catalytic Pyrolysis R&D upgrading step chemistry understanding and optimum catalyst/operating conditions

Syngas to Methanol to High Triptyls



Rationale for Selecting Pathway

- Exploits mixed alcohol synthesis catalysts advances, leverages existing work in gasification and syngas cleanup
- Opportunity to improve catalyst performance (selectivity, lifetime, coking) to enable higher hydrocarbon yields
- Process intensification opportunity

Recent Budget History

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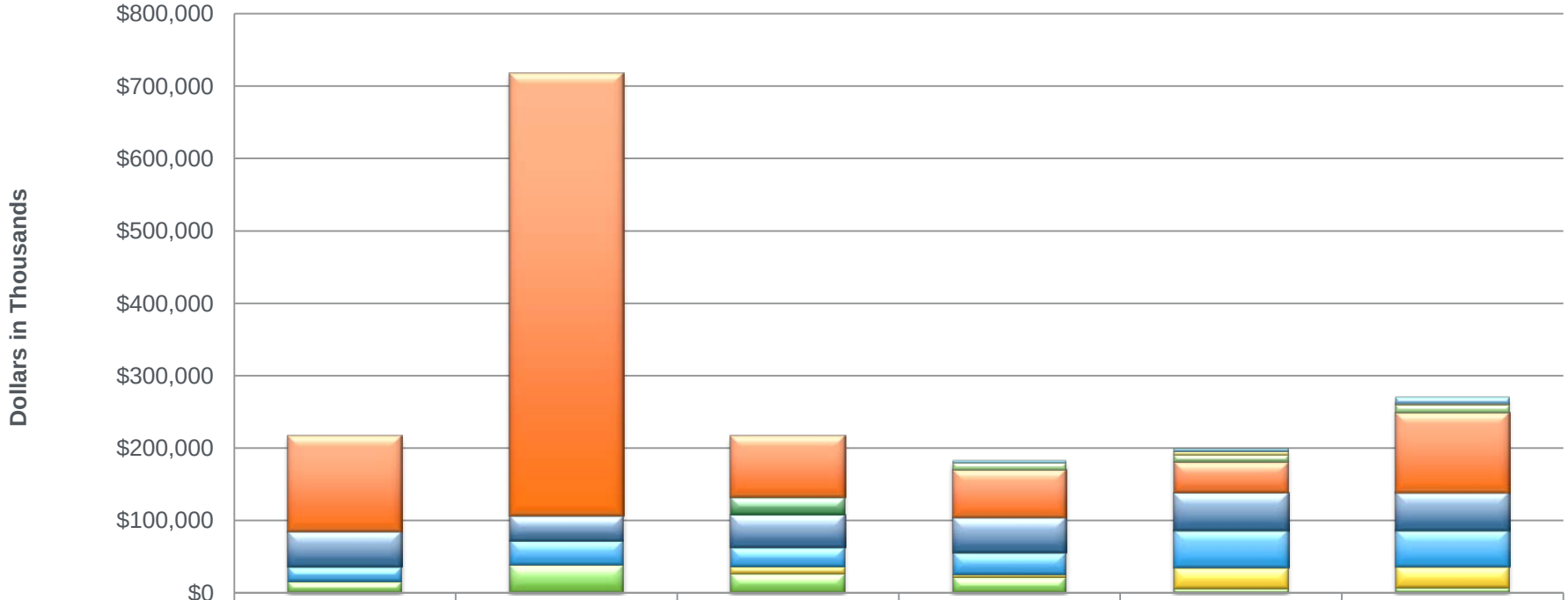
Fiscal Year 2009-13 Budget



	FY09	FY09 ARRA	FY10	FY11	FY12	FY13 Request
SBIR/STTR				$2,716	$4,281	$8,234
Biopower/Stoves					$4,829	$2,909
Analysis/Sustain				$10,000	$9,813	$9,695
Int Biorefineries	$132,000	$611,000	$84,278	$66,695	$42,897	$110,523
Algal Conversion Tech.			$24,465			
Biochem	$49,000	$35,000	$44,440	$47,765	$50,733	$51,868
Thermochem	$20,000	$34,000	$26,830	$30,184	$51,685	$50,899
Algae Feedstock	$0	$0	$9,250	$3,895	$29,067	$29,085
Feedstock Infrastrucure	$16,000	$38,000	$26,962	$21,440	$5,971	$6,787

FY 13 FOA Plan

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Fundamentals in Direct Liquefaction of Lignocellulose and Bio-Oil Upgrading – $15M

- Improve the fundamental understanding of how lignin, hemicellulose, and cellulose thermally depolymerized during biomass pyrolysis and how inorganic content impacts bio-oil production and upgrading processing to final fuels. **Supports all direct liquefaction technologies.**

Algal Biomass Yield (ABY) – $4.4M – Supports algae pathways

- Improve downstream processing with the goal of lowering the cost of algae processing by improving process efficiency and scalability

Feedstock Logistics - $5.7M – Supports all pathways

- Design, build and demonstrate variable rate agriculture residue removal systems to increase sustainable volumes & improve feedstock quality
- Develop systems that produce infrastructure-compatible feedstock such as pre-conversion technologies that produce feedstocks that seamlessly integrate into existing solids and liquids handling infrastructure
- PDU deployment with partners