DOE Perspectives on Advanced Hydrocarbon-based Biofuels

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U.S. Department of Energy
Office of Biomass Program

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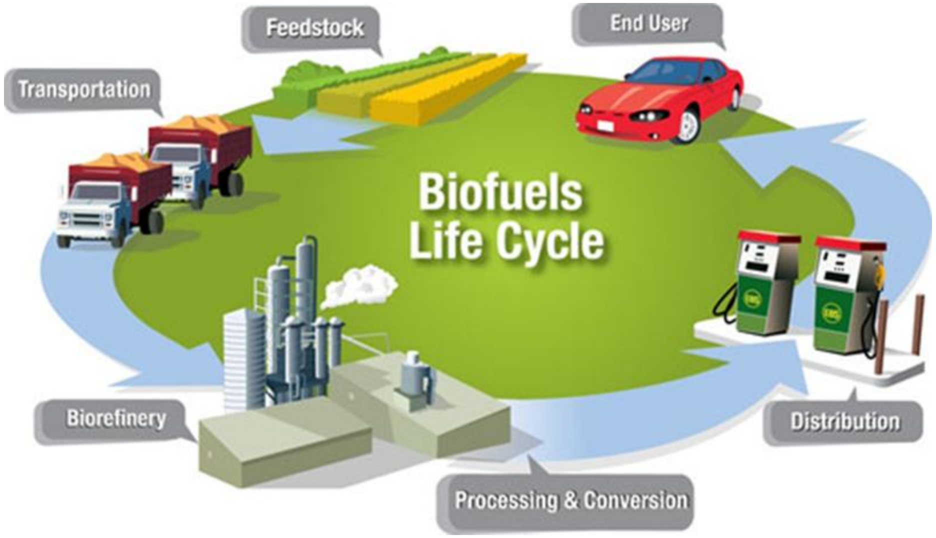
Biofuels Topics

- Resource assessment – do we have enough biomass?
- Techno-economic analysis – can biofuels be produced at competitive prices?
- Integrated biorefineries – what is being funded at DOE and what are future plans?



Resource Assessment – "Billion Ton Update"

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U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry

- Provides current and potential available biomass for 2012-2030
- Estimates are at the county level and for a range of costs to roadside
- Has scenarios based on crop yields and tillage practices
- Models land use for energy crops and ensures meet food, forage, and export commodity crop demands
- Includes sustainability criteria
- Report and data on the web

Data and analysis tools located on the Knowledge Discovery Framework: http://bioenergykdf.net

U.S. Billion-Ton Update: Findings

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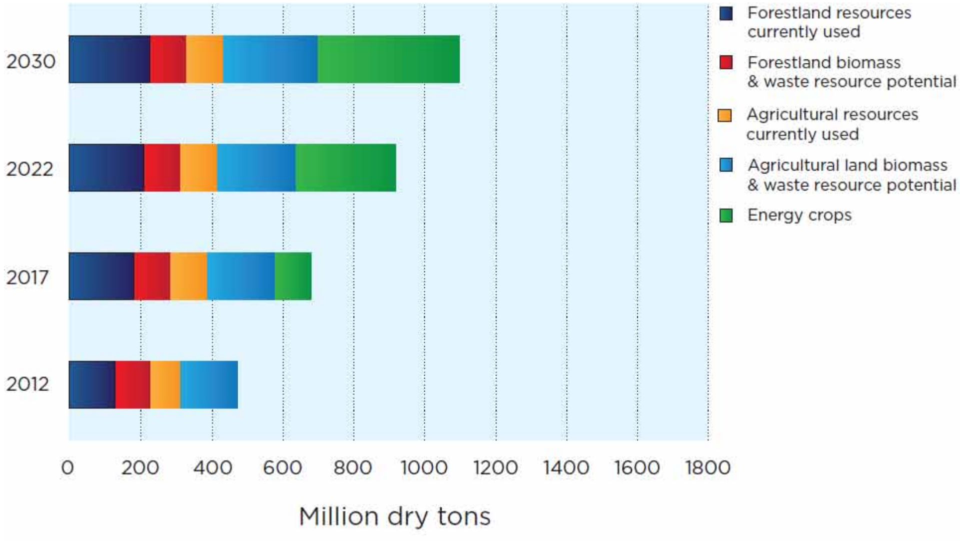
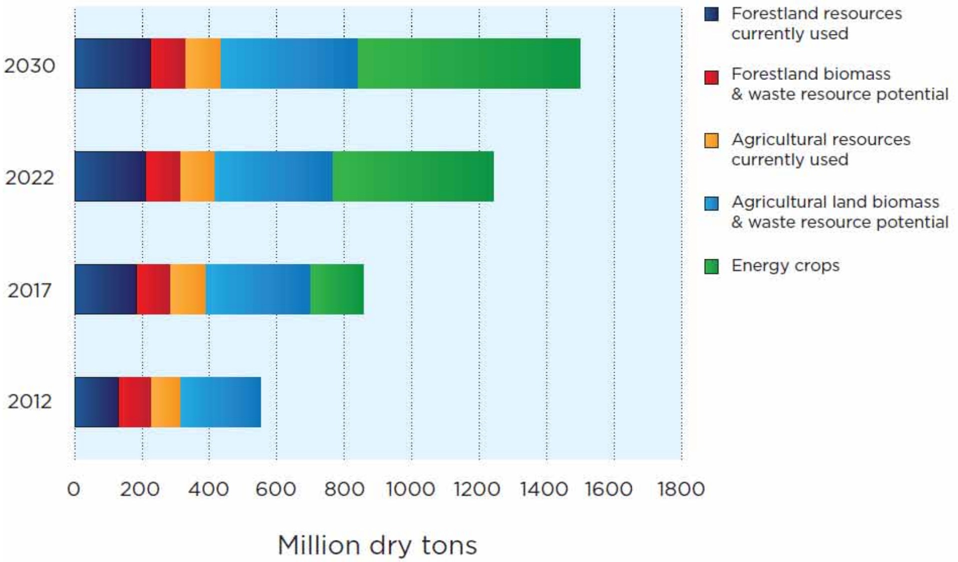
Baseline scenario

- Current combined resources from forests and agricultural lands total about 473 million dry tons at $60 per dry ton or less; <u>about 200 million dry tons from forestry</u>
- By 2030, estimated resources increase to nearly 1.1 billion dry tons; <u>about 300 million dry tons from forestry</u>



High-yield scenario

- Total resource ranges from nearly 1.4 to over 1.6 billion dry tons annually of which 80% is potentially additional biomass;
- No high-yield scenario was evaluated for forest resources, except for the woody crops



Potential County-level Resources at $60 Per Dry Ton or Less in 2030

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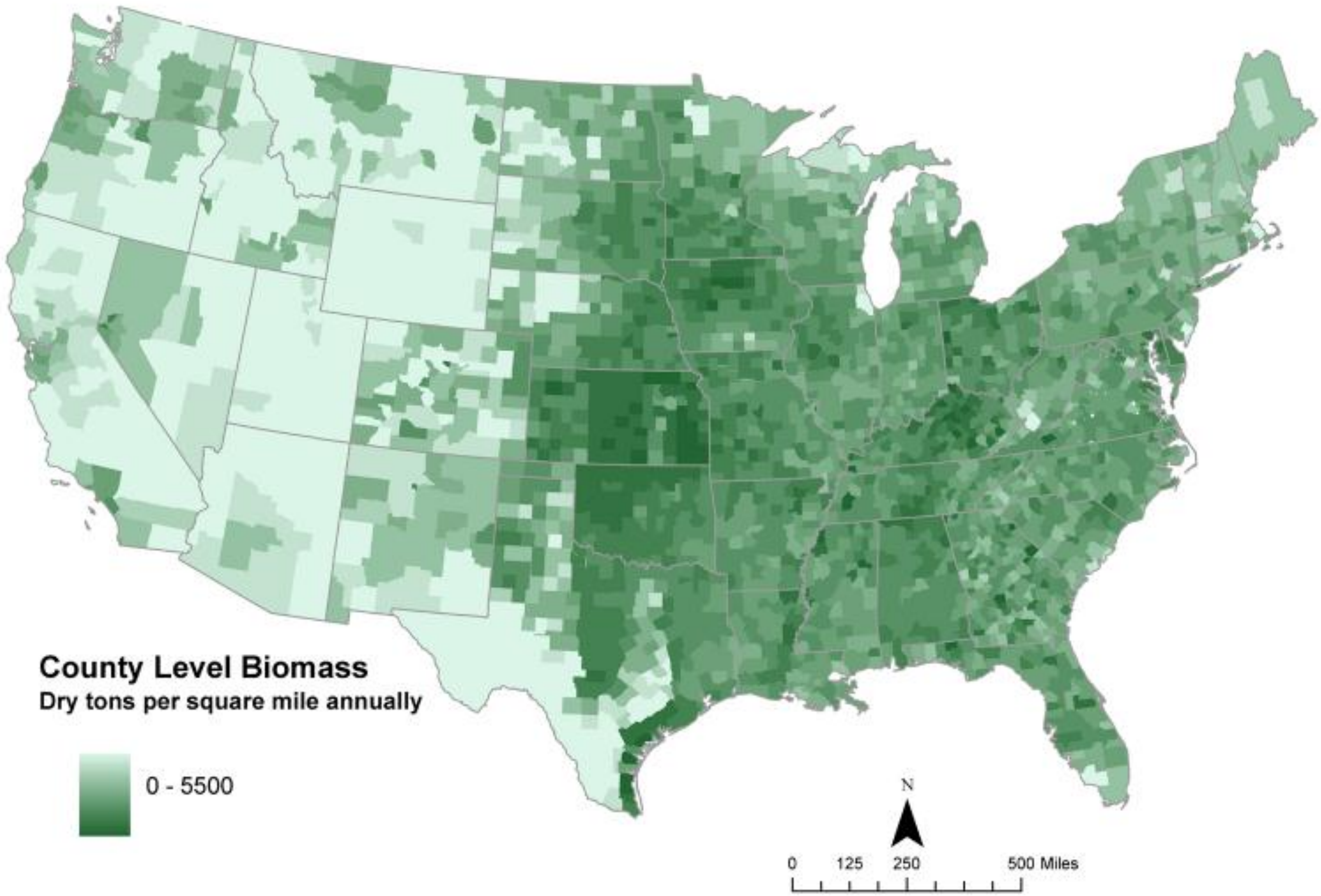
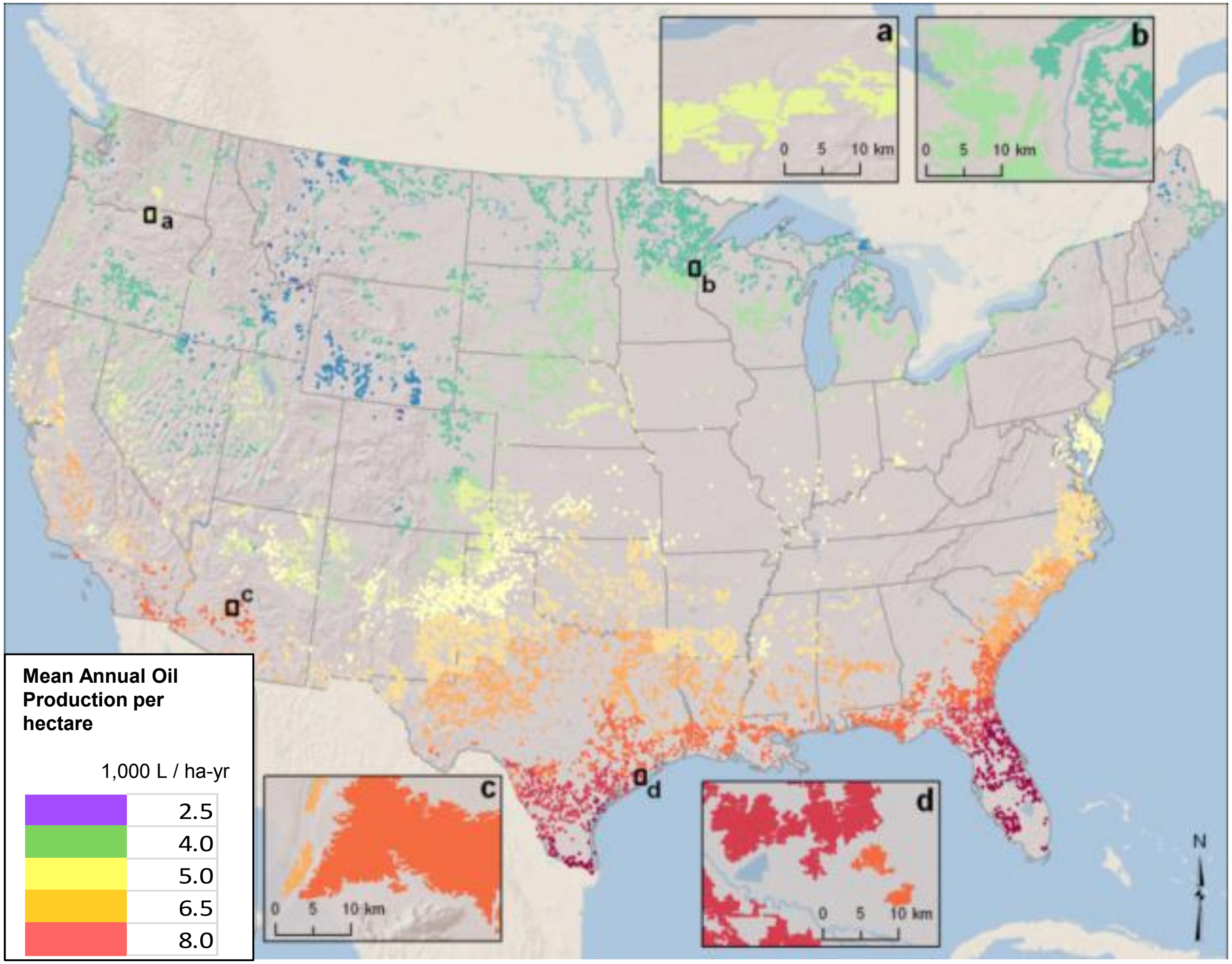
Under Baseline Assumptions



Micro-algae Resource Assessment



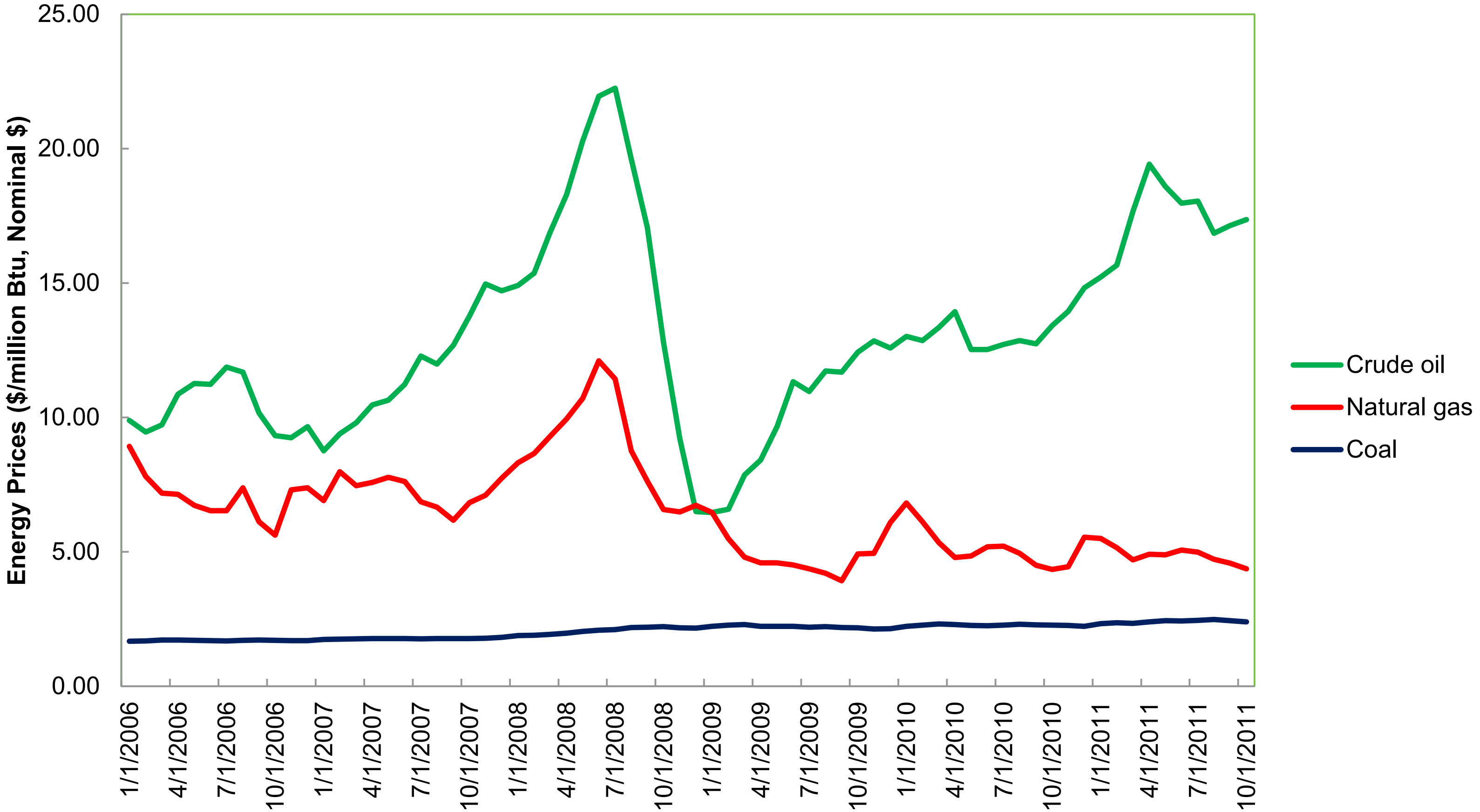
Wigmosta, M. S., A. M. Coleman, R. J. Skaggs, M. H. Huesemann, and L. J. Lane, 2011, National microalgae biofuel production potential and resource demand, Water Resour. Res., 47, W00H04

- A National resource assessment identified ~430,000 km^2 of suitable land for algae cultivation with potential for 58 BGY of algal oil production
- Optimizing to maximize productivity and minimize water use identifies 10,000 km^2, or about 3.7M acres, mainly around the Southwest and Gulf Coast
- These optimized sites would support production of 5 BGY

Techno-Economic Analysis

- Citable source for budget justification
- Setting R&D priorities
- Benchmarking
- Informing broader analytical activities (TEF, QTR)
- Track Program R&D progress against goals
- Identify technology process routes and prioritize funding
- Program direction decisions:
    - Are we spending our money on the right technology pathways?
    - Within a pathway: Are we focusing our funding on the highest priority activities?

Market Driver for Alternative Fuels – Energy Price Volatility



- Long term price trends indicate significantly higher value and higher price volatility for crude oil compared to natural gas or coal
- Certain sectors (military, aviation, marine, long-haul trucking, and long-distance rail) have limited alternatives to liquid transportation fuels

Source: Energy Information Administration, Monthly Energy Review, January 2012

Cost Competitive Fuel – Crude Oil Price Forecast

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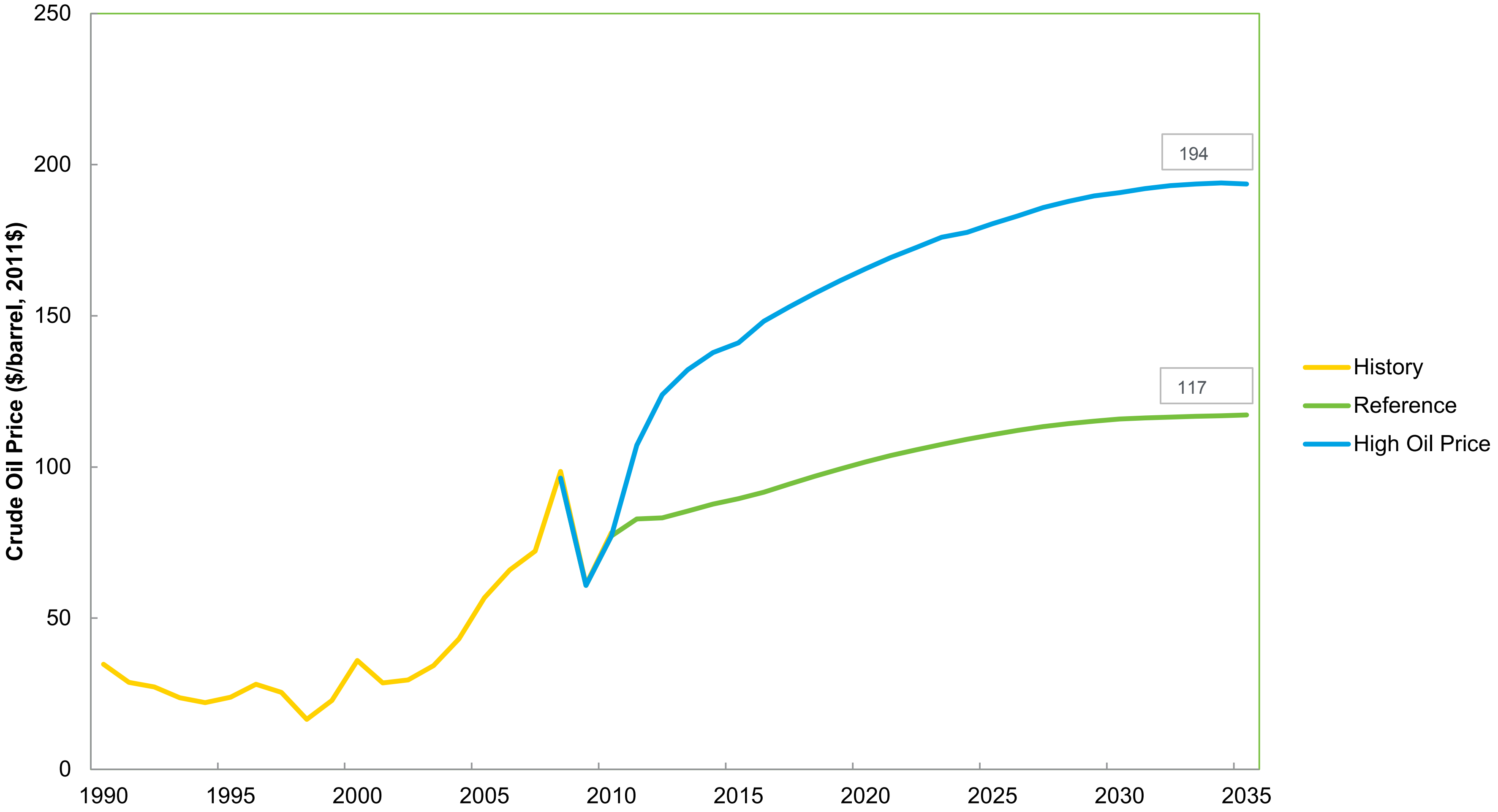
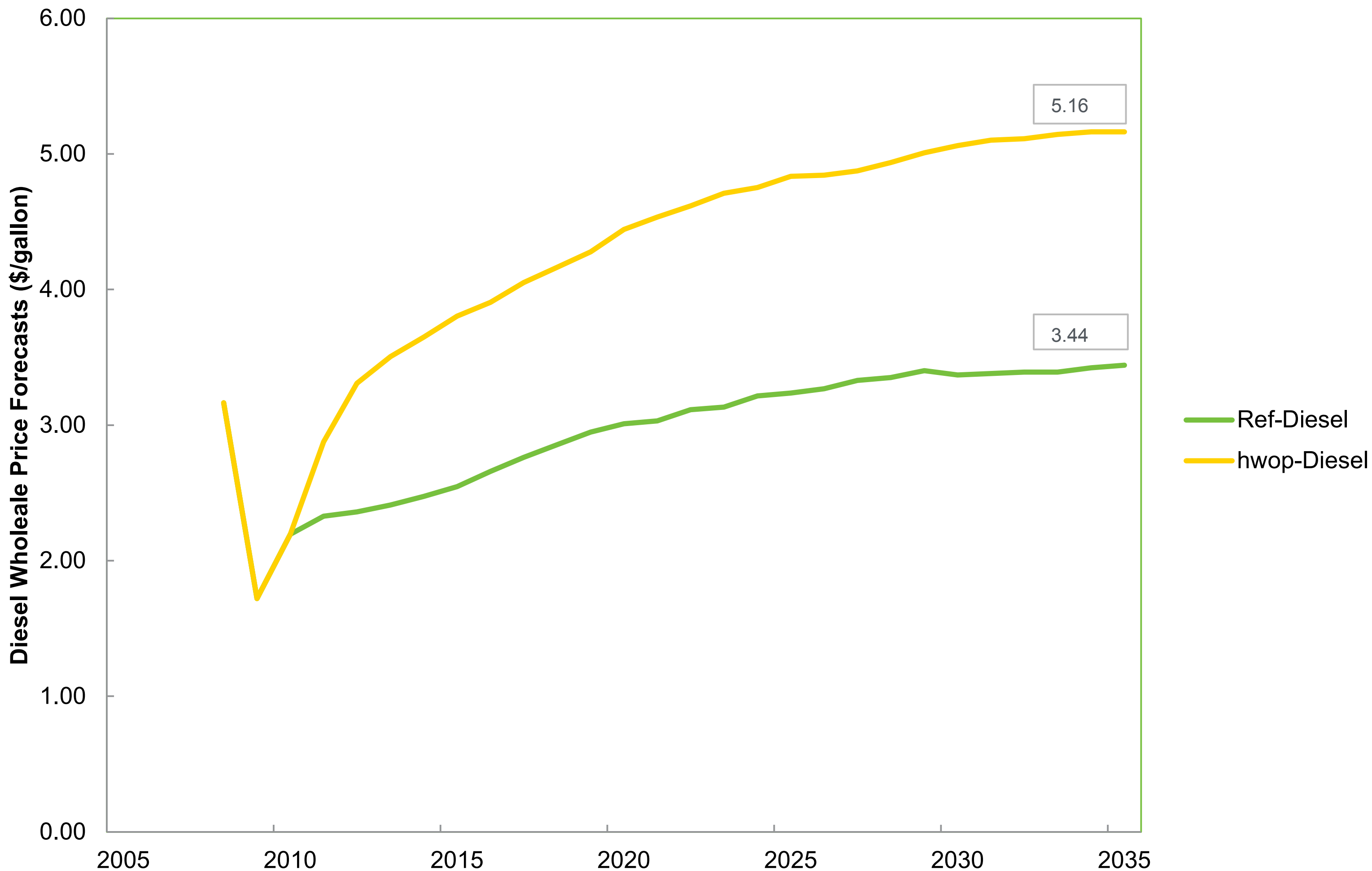


Source: Energy Information Administration, "Annual Energy Outlook 2011", DOE/EIA-0383(2011), available at http://www.eia.doe.gov, April 2011

Cost Competitive Fuel – Diesel



Source: Energy Information Administration, "Annual Energy Outlook 2011", DOE/EIA-0383(2011), available at http://www.eia.doe.gov, April 2011

Terminology and Concepts

- Nth plant economics
  - Costs represent the case where several biorefineries with this technology have been built, which assumes lower contingency and other cost escalation factors
  - Assumes no risk premiums, no early-stage R&D, or start-up costs
- Learning curves
  - The factors applied to costs to adjust pioneer to nth plant costs to account for learning
- Pioneer plant
  - Costs represent a first-of-a-kind construction, where added cost factors are included for contingency and risk
  - Most closely represented by IBR projects
  - Few estimates available in the public domain
- Time value of money
  - Basis of time when comparing costs because of the changes in costs due to inflation
  - Currently 2007$

Terminology and Concepts

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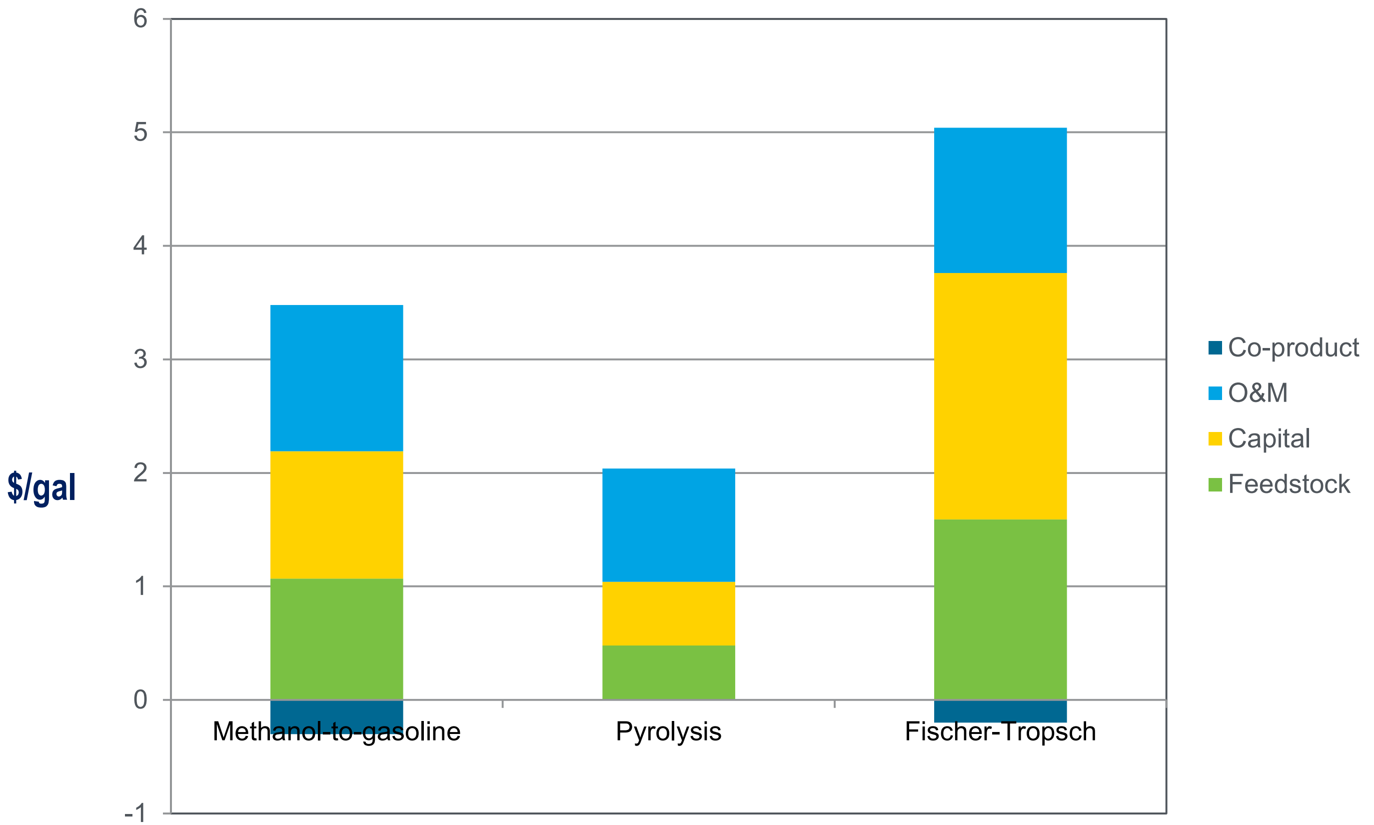
- Design Case:
  - Detailed, peer reviewed process simulation based on ASPEN or Chemcad
  - Establishes cost of production at biorefinery boundary
  - Provides estimate of nth plant capital and operating costs
  - Based on best available information at date of design case
  - Scope: feedstock cost (harvest, 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):
  - 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

Cost of Production for Hydrocarbon Biofuels



- Other economically viable technology routes for hydrocarbon biofuels exist, such as conversion of waste and plant oils, and sugar-to-hydrocarbons
- These costs are projected for the Nth Biorefinery Plant, after operation of initial commercial-scale Pioneer Plants

Sources:

1. Sue Jones et. al., “Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case”, Pacific Northwest National Laboratory, PNNL-18284, available from http:/www.pnl.govFebruary 2009.
2. Sue Jones et. al., “Techno-Economic Analysis for the Conversion of Lignocellulosic Biomass to Gasoline via the Methanol-to-Gasoline (MTG) Process”, Pacific Northwest National Laboratory, PNNL-18481, available from http://www.www.pnl.gov, February 2009.
3. Anex, R. A., et. al., “Techno-Economic Comparison of Biomass-to-Transportation Fuels via Pyrolysis, Gasification, and Biochemical Pathways”, Fuel, July 2010.

Biofuel Production Costs
Example of renewable fuels via pyrolysis

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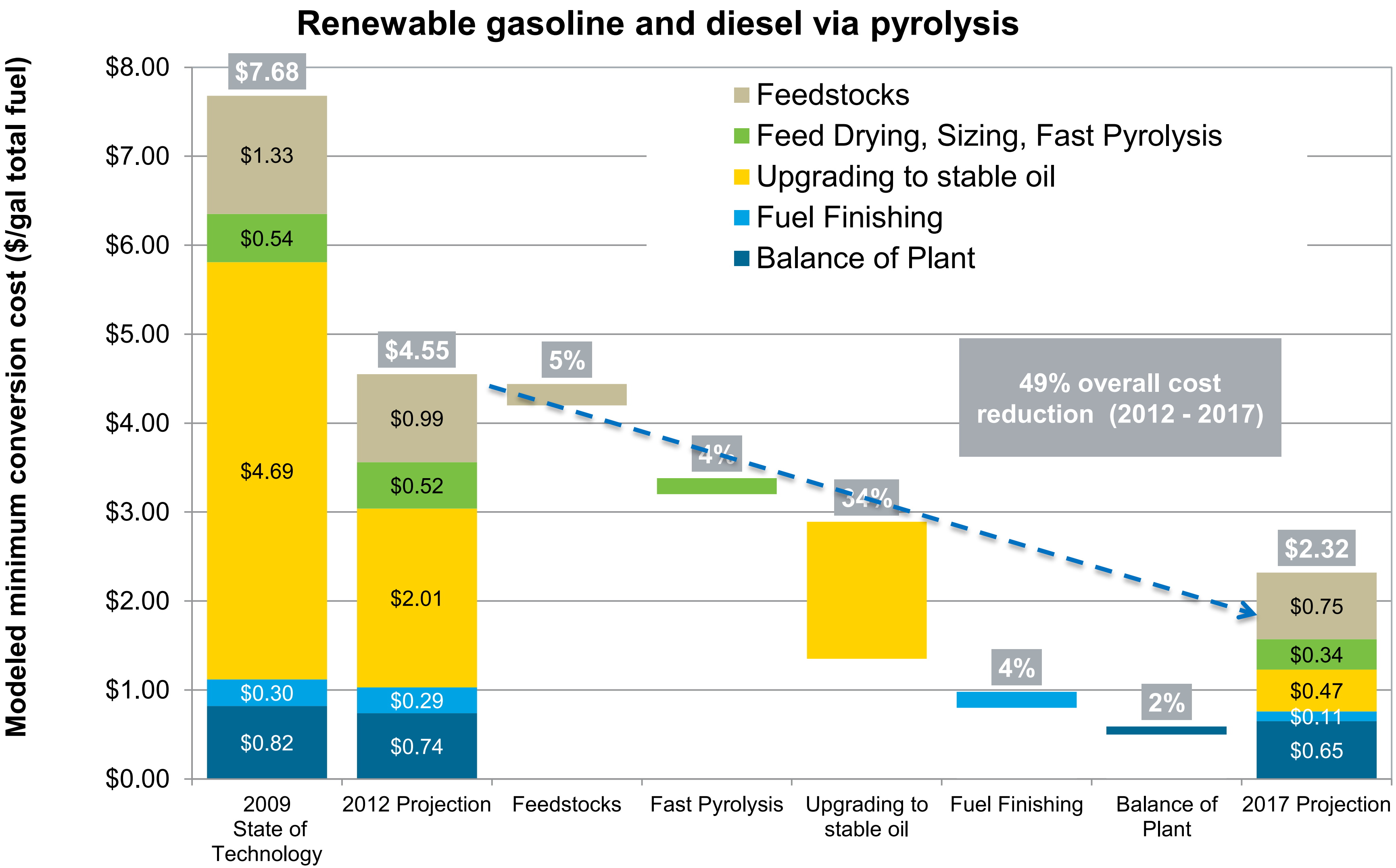
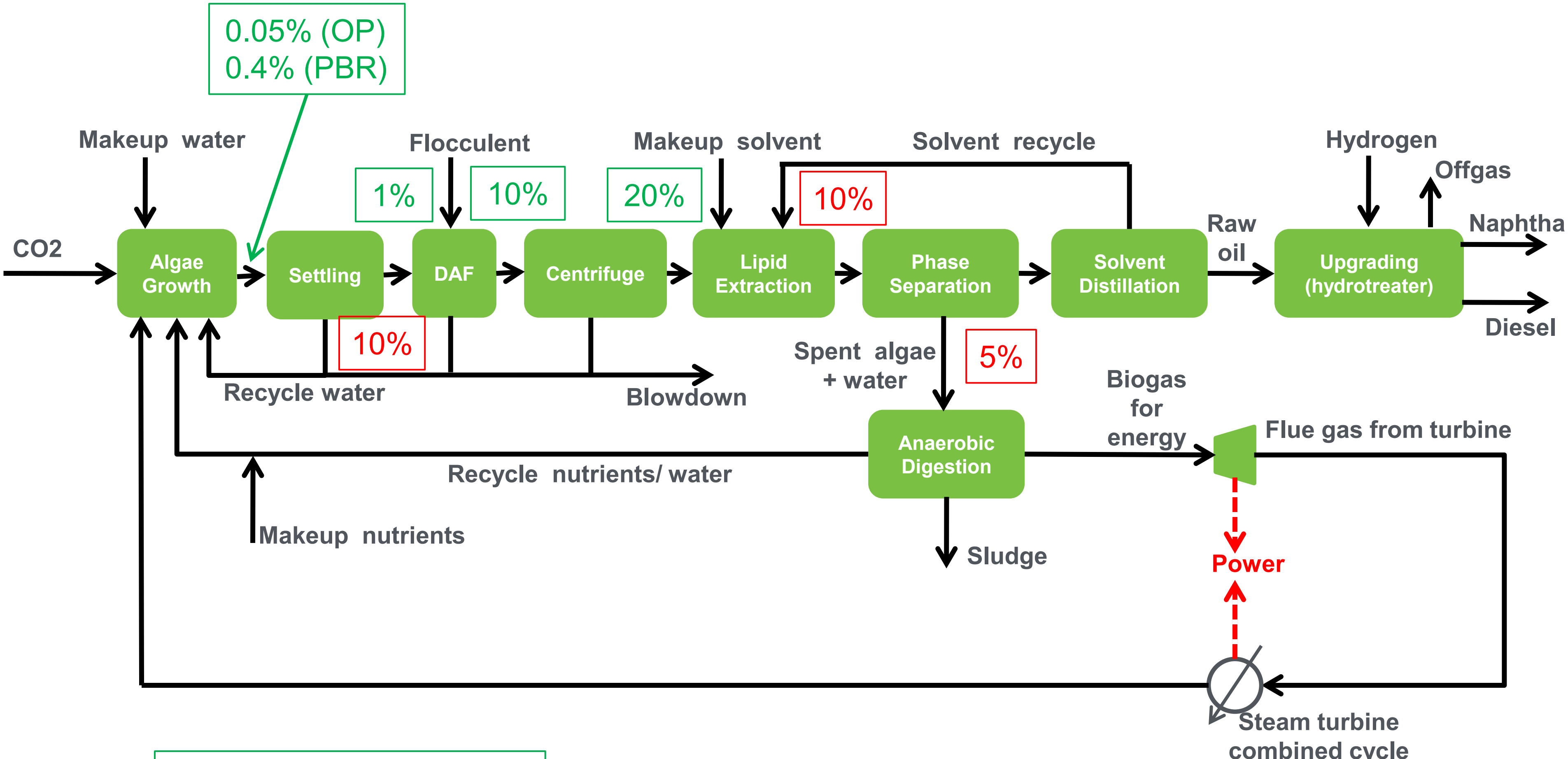


Pyrolysis costs by unit and projected cost reductions through R&D

Algae Design Configuration



Green = algae cell density

Red = harvesting/extraction losses

FY11 Techno-economic Analysis: Algal Baseline Costs

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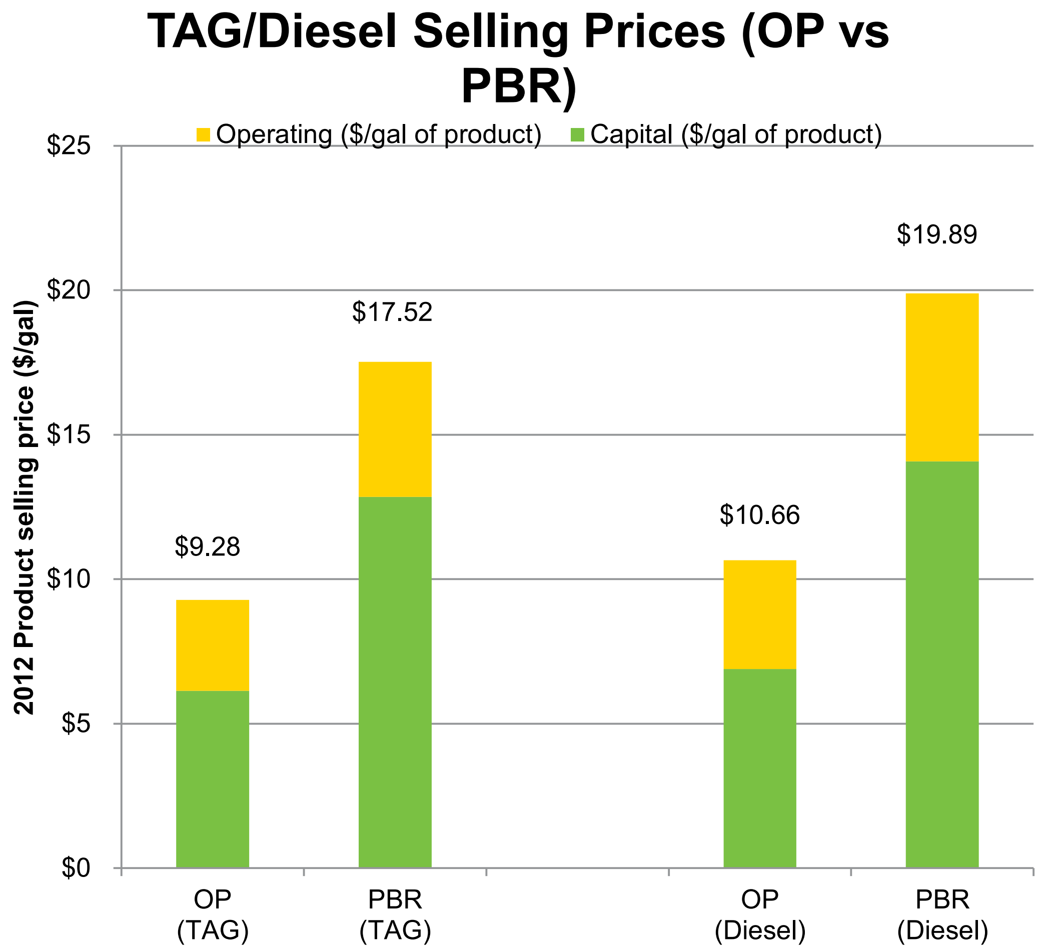
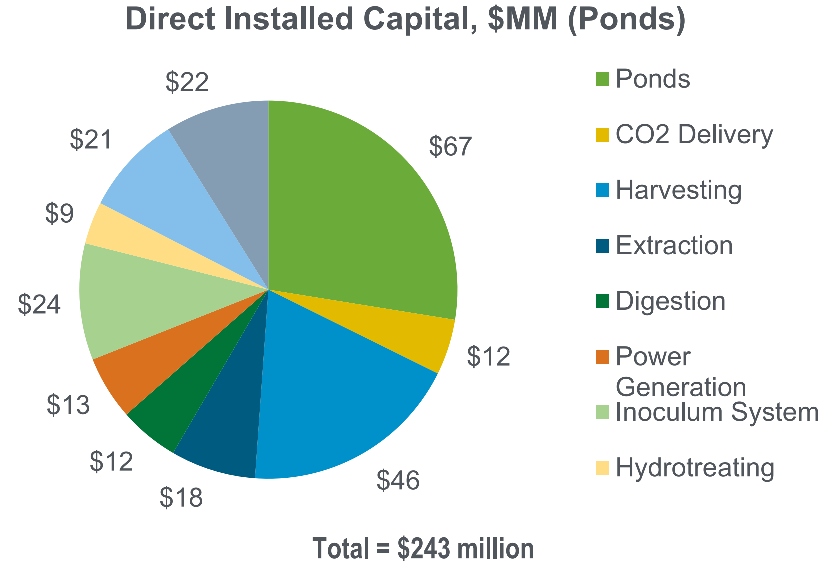
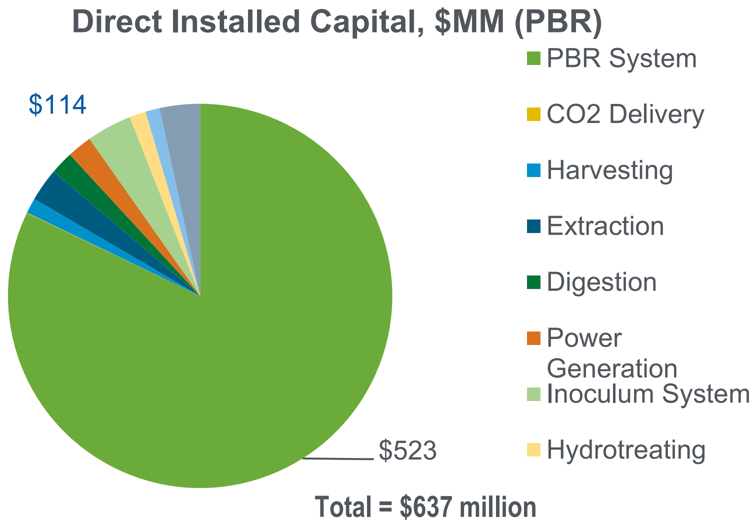


Source: Davis R et. al., "Techno-Economic Analysis of Autotrophic Microalgae for Fuel Production", Applied Energy 88 (2011) 3524 – 31.





Projecting Future Algal Costs – How Can We Get There?

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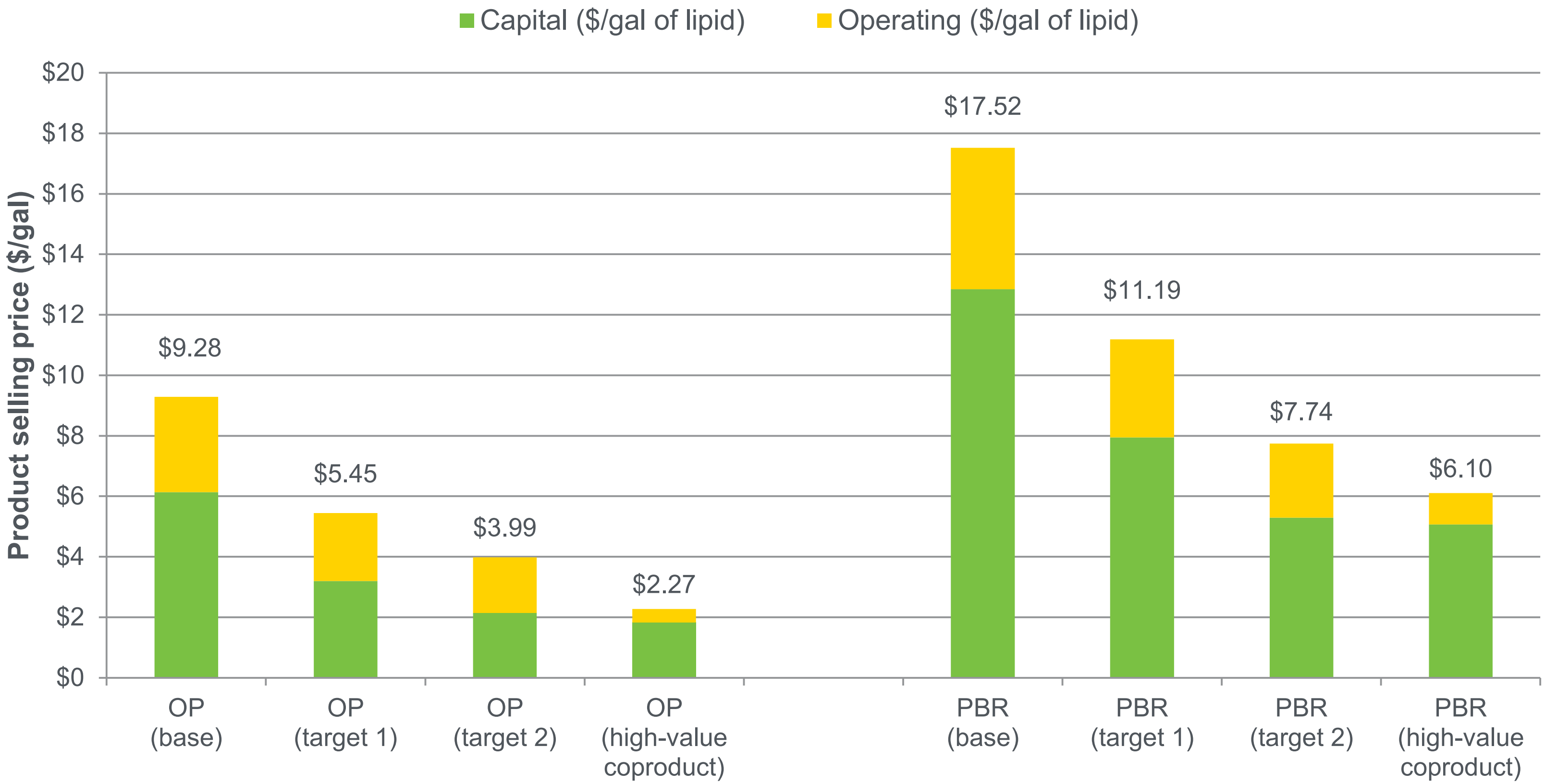

Growth rate	25 $g/m^2/d$	25 $g/m^2/d$	30 $g/m^2/d$	30 $g/m^2/d$		1.25 g/L/d	1.25 g/L/d	1.5 g/L/d	1.5 g/L/d
Lipid content	25%	40%	50%	50%		25%	40%	50%	50%
Harvesting cost	Base	Cut by 50%	Cut by 50%	Cut by 50%		Base	Cut by 50%	Cut by 50%	Cut by 50%
Extraction cost	Base	Base	Cut by 50%	Cut by 50%		Base	Base	Cut by 50%	Cut by 50%
Spent biomass utilization	AD	AD	AD	Sell @ $500/ton		AD	AD	AD	Sell @ $500/ton

Integrated Biorefinery Projects

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IBR project investments will accelerate U.S. bioindustry growth and ramp up production of a range of biofuels and bioproducts.

A groundbreaking in February 2011 at the INEOS demonstration IBR.

Over $1B in DOE investments in 29 IBR projects is helping bridge "Valley of Death"

5 projects have received loan guarantees to build first-of-kind commercial facilities
At least 3 projects have IPOs that support their commercialization strategies
The successful first-of-kind facilities will allow for rapid replication and expansion of capacity

- Over $1 billion Biomass Program investment is being cost shared with over $1.7 billion from industry
- DOE investment has enabled equity investments, initial public offers (IPOs), venture capital (VC) funding, joint ventures (JVs), and joint development agreements (JDAs)

DOE Biomass Program and Hydrocarbon Fuels

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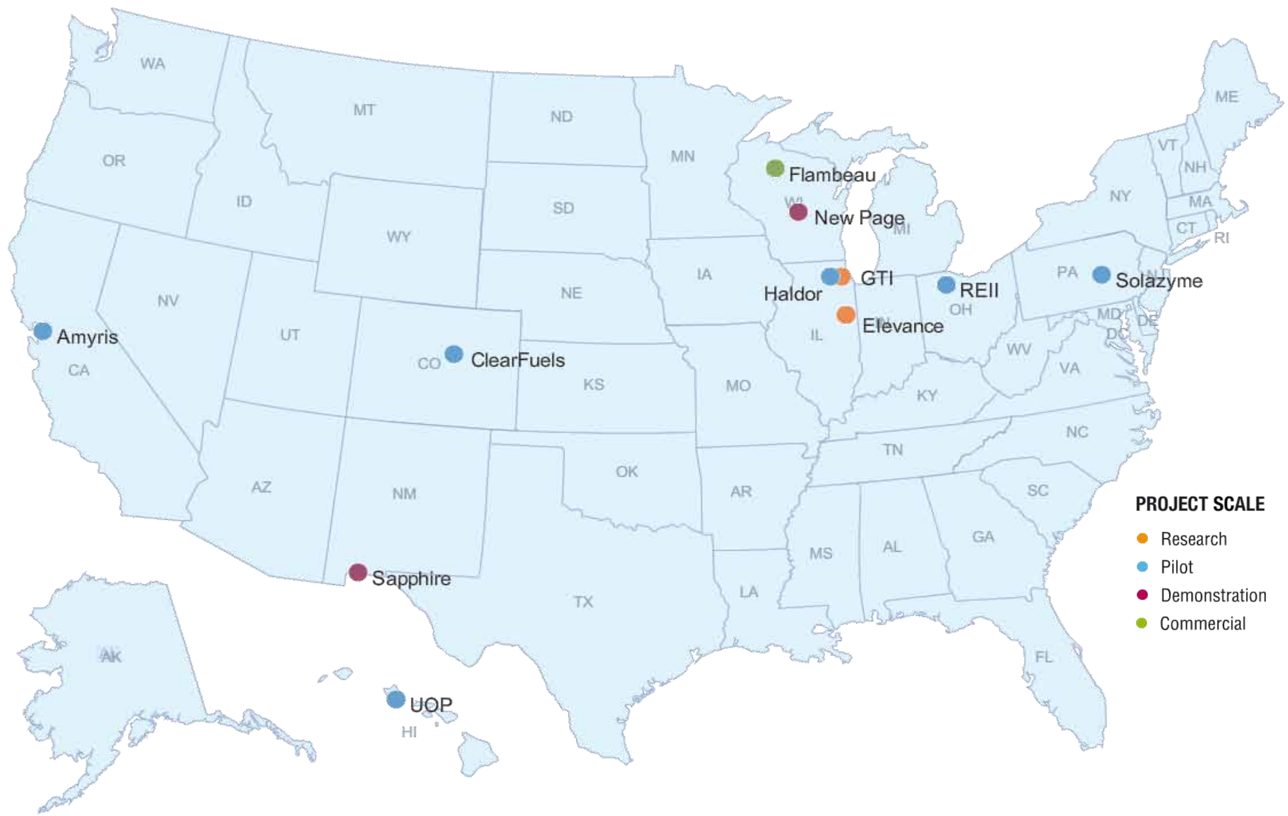
11 integrated biorefinery projects are investigating hydrocarbons from biomass resources:

- Flambeau
- New Page
- Haldor
- GTI
- REII
- Elevance
- Solazyme
- ClearFuels
- Amyris
- Sapphire
- UOP

GTI and Elevance are R&D projects.

9 projects are pilot, demonstration, or commercial scale.



For more information visit:
http://www.eere.energy.gov/biomass/integrated_biorefineries.html

Status of Technology

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- Throughput – DOE assumptions (nominal), Pilot minimum 1 tons/day, Demonstration minimum 50 tons/day, commercial minimum 500 tons/day
- Run time – DOE assumptions (nominal), 1,000 hours of integrated run time to provide basic understanding of conversion process characteristics
- Production scale – Pilot, Demonstration, and Commercial
- Conversion process data
  - Process simulation leading to mass and energy balance
  - Cost of production pro-forma data
- Structuring advanced biofuels initiatives
  - Multiple phases with go/no-go decisions
  - Financial and technical milestones that form the basis of go/no-go decisions
  - Annual comprehensive project reviews

Scale	Feed in (dry tons/day)	Yield (gallons/dry ton)*	On-stream Time (days/year)	Production (million gallons/year)
Pilot	1	35	100	0.0035
Demonstration	50	40	200	0.4
Commercial	500	45	350	8

*Assumed yields for calculation purposes only. Actual yields could be higher.

Innovative Pilot/Demo FOA

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- Objective – Production of hydrocarbon fuels at pilot or demonstration scale facilities that meet military blend fuel specifications. Two topic areas will be supported:
  - Technologies that utilize algae (micro, macro, cyanobacteria, heterotrophic
  - Technologies that utilize ligno-cellulosic biomass and other waste feedstocks

- The innovative pilot FOA will:
  - Enable the production of hydrocarbon blendstocks at pilot or demonstration scales – JP-5 (jet fuel primarily for the Navy), JP-8 (jet fuel primarily for the Air Force, or F-76 (diesel)
  - Lead to better understanding of the cost of production, fuel characteristics, and emissions impacts of biofuels