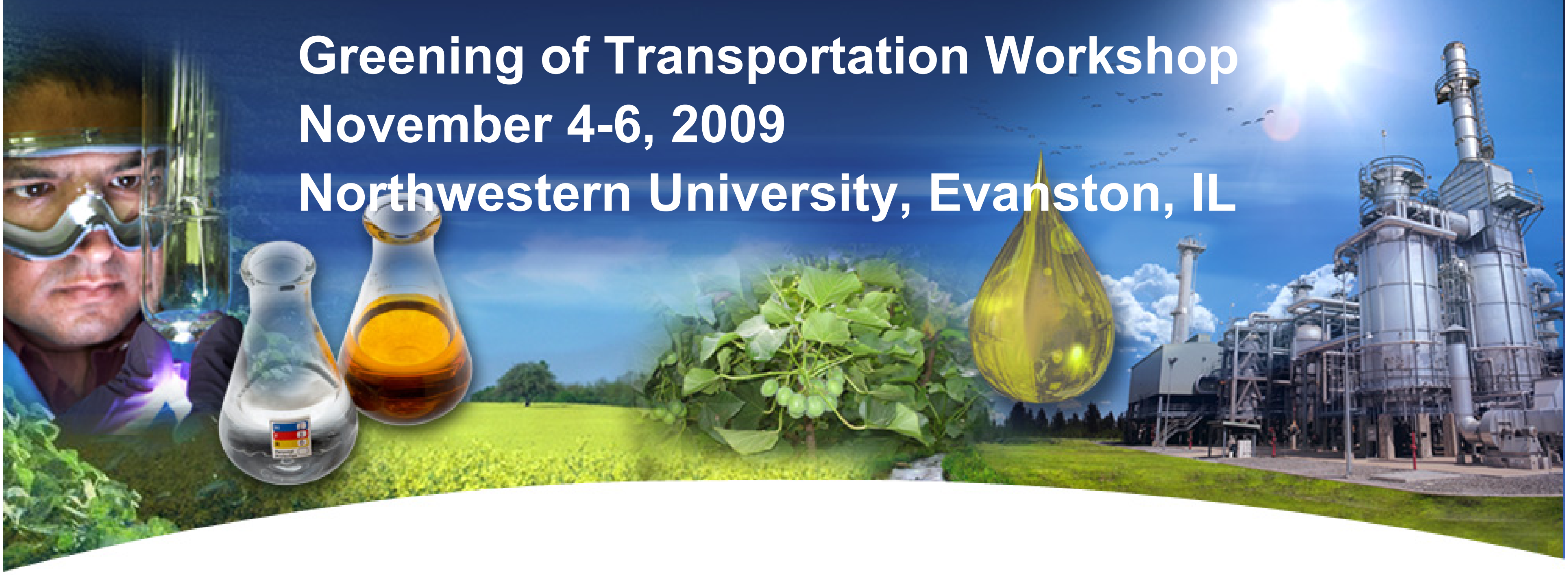
Biofuels: Unlocking the Potential

Greening of Transportation Workshop
November 4-6, 2009
Northwestern University, Evanston, IL



P. Nair, UOP LLC
Des Plaines, IL, USA

UOP
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Agenda

- UOP Introduction
- Global Primary Energy Demand Implications
- Global Renewable Legislation/Market Drivers
- UOP Biofuels Vision
- 2nd generation bio-feedstocks
- Conversion Technology Overview
- Sustainability

UOP Overview

UOP
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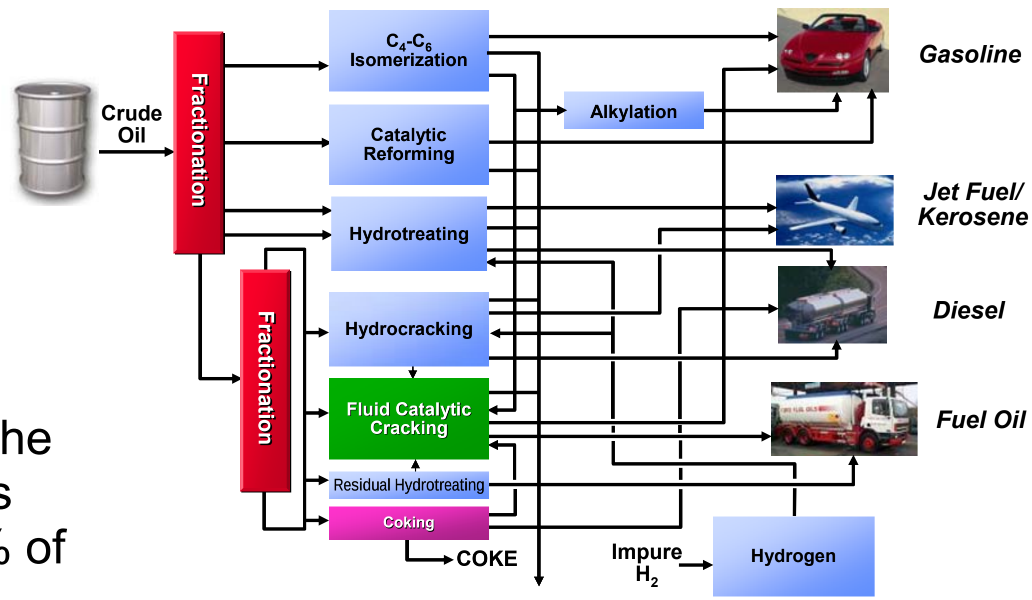
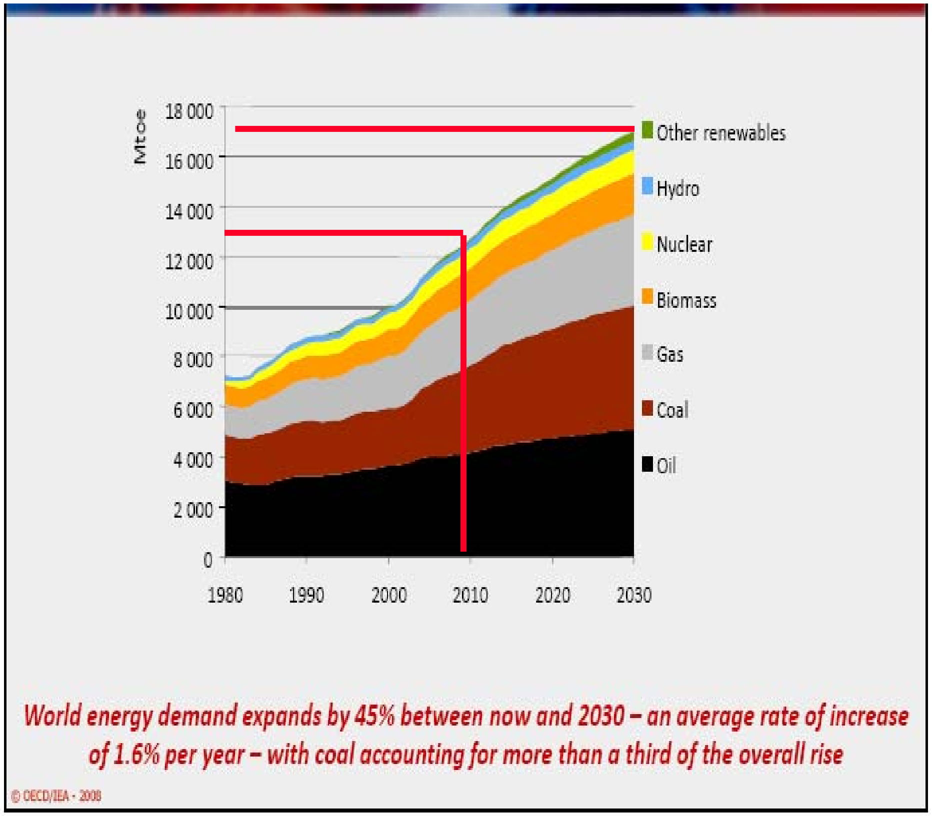
- Leading supplier and licensor of process technology, catalysts, adsorbents, process plants, and technical services to the petroleum refining, petrochemical, and gas processing industries
- 2008 Revenues - ~$2B
- UOP technology furnishes 60% of the world's gasoline, 85% of the world's biodegradable detergents, and 60% of the world's para-xylene
- Strong relationships with leading refining and petrochemical customers worldwide
- UOP's innovations enabled lead removal from gasoline, biodegradable detergents, and the first commercial catalytic converter for automobiles



2003 National Medal of Technology Recipient

95 years of sustained technology leadership

Global Primary Energy Demand

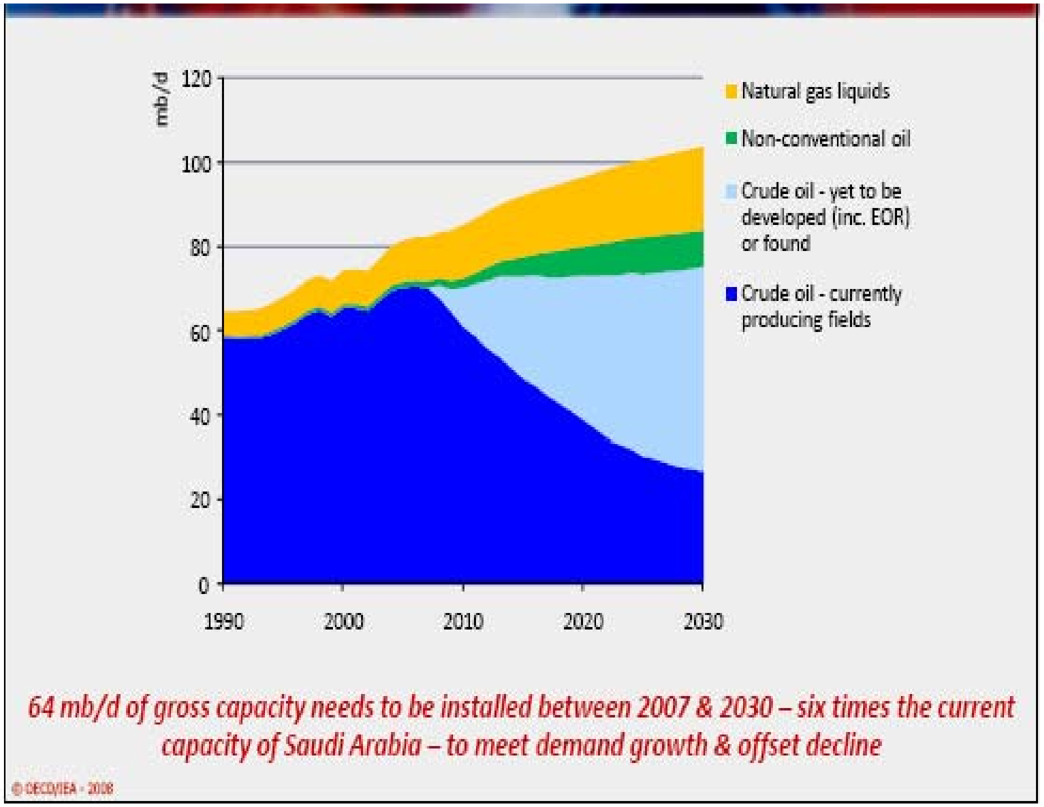


- Soaring energy prices to mid-2008, followed by a collapse –
  - what will it mean for demand?
- How will the financial crisis & economic slowdown affect
  - energy demand & investment?
- Will economic worries divert attention from strategic
  - energy-security & environmental challenges?
- Are we setting ourselves up for a supply-crunch once the
  - economy is back on its feet?
- Will negotiators at COP-15 in Copenhagen in 2009 have the
  - political support needed to succeed?

Global Primary Energy Demand - ~45% increase by 2030

Diversification is Key to Meet Future Needs

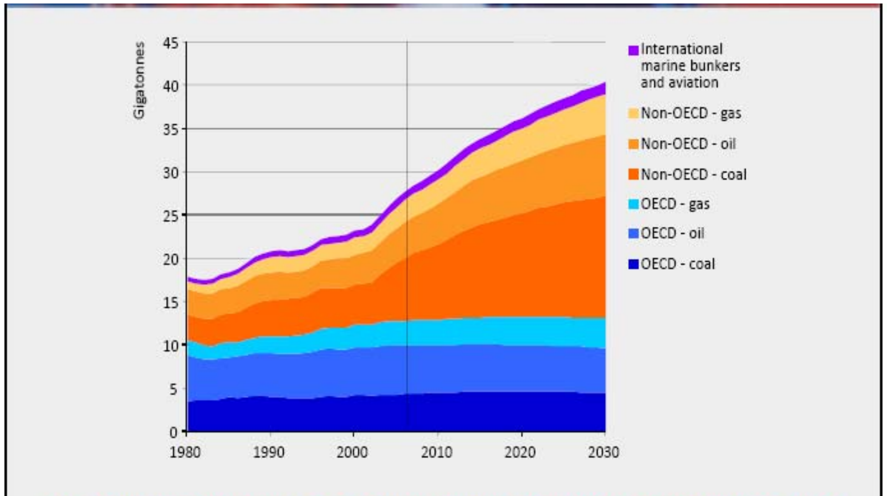
Global Crude Oil Production by Source



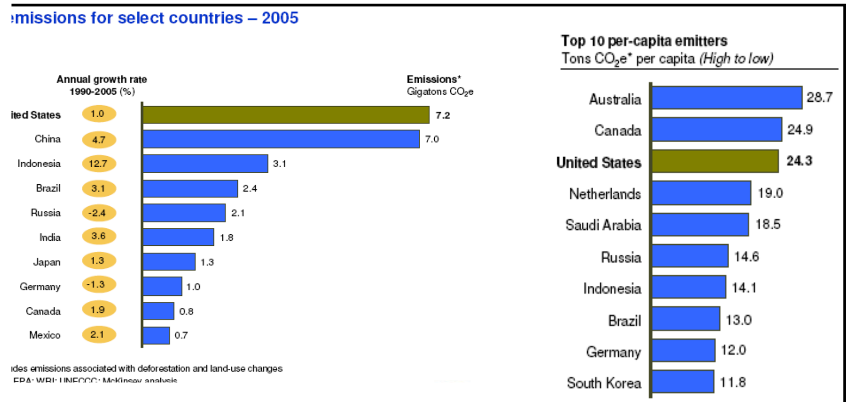
- **Current large fields depleting at a rapid rate**
- **New finds are largely smaller fields that deplete even faster**
- **Deep sea exploration and unconventional oils will increasingly fill the gap**
- **New crudes will tend to be heavier and more contaminated**

Heavier Crudes also Result in a Higher Carbon Footprint

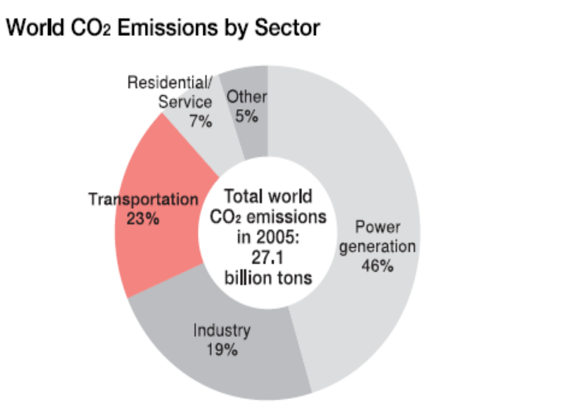
Global CO_2 Emissions by Energy Source, Region & Sector



97% of the projected increase in emissions between now & 2030 comes from non-OECD countries – three-quarters from China, India & the Middle East alone



- China surpassed the US in 2008
- China and India have low per capita emissions



Source: CO2 Emissions from Fuel Combustion 1971-2005, *International Energy Agency (2007)*

- **Power and Transport sector the largest CO_2 emitters**

Sustainably produced Renewable Power & Fuels will play an increasingly important role

Biofuels: A Quickly Changing Landscape

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2007

- All biofuels are good
- More, faster
- No criteria to measure impact of adopting biofuels
- Availability of "inexpensive" bio feedstocks
- Government mandates and incentives favor ethanol and biodiesel

2008

- Not all biofuels are good
- Concern for food chain impact & competition for land/water
- Measured biofuel adoption
- Utilization of LCA analysis to "qualify": link to GHG, energy, sustainability
- Bio feedstocks tracking energy prices
- Government mandates/ incentives increasingly technology neutral
- Emphasis on "real" biofuels

2009

- Credit Crisis: Stimulus focused on Green Tech

UOP Position

- Emphasis on life cycle analysis as a way of measuring "sustainability"
- Ensure technology is feedstock flexible
- Focus on 2nd generation technologies
- Create partnerships between feedstock suppliers and fuel producers

Increasing Awareness of Potential Impact

Global Legislation Overview

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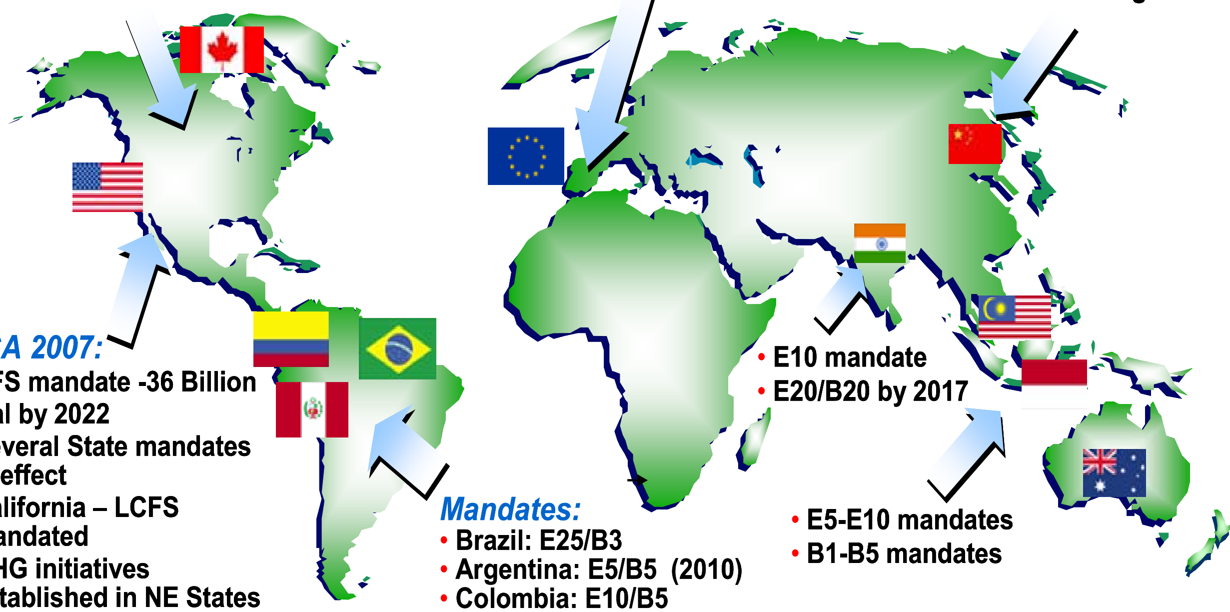
Canadian Law C-33 Mandates:
- E5 by 2010
- B2 by 2012
- B5 in British Colombia by 2010

EU-27 – Adopted Mandates:
- RED – 10% by Energy content by 2020
- GHG – 6% reduction by 2020 from 2010 levels

- E10/B5 targets



EISA 2007:
- RFS mandate -36 Billion Gal by 2022
- Several State mandates in effect
- California – LCFS mandated
- GHG initiatives established in NE States

Mandates:
- Brazil: E25/B3
- Argentina: E5/B5 (2010)
- Colombia: E10/B5

- E10 mandate
- E20/B20 by 2017

- E5-E10 mandates
- B1-B5 mandates

E_ : % Renewable in Gasoline
B_ : % Renewable in Diesel

- **Biofuels Market Drivers:**
  - Government Legislation
  - Energy Security
  - Primary Energy Diversification
  - Climate Change

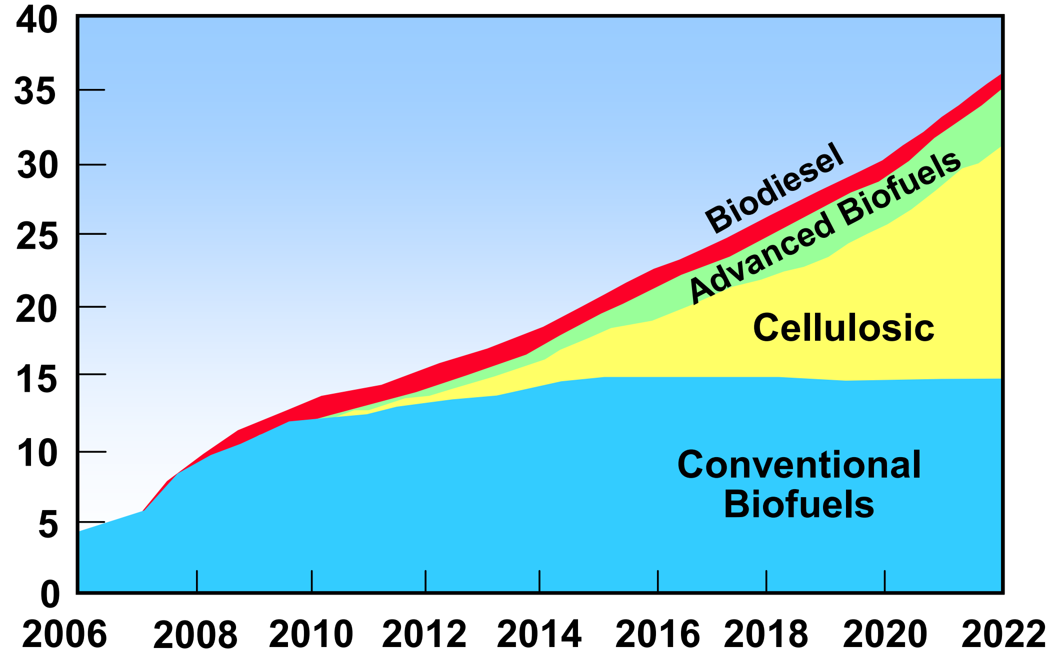
Global Biofuels use Trending Towards a Nominal E10 & B5

US Renewable Fuel Standard

US Mandates/Sustainability:

- EISA 2007 (Energy Independence and Security Act)
- Technology neutral legislation
- 36 B gallons biofuels , ~2.5M BPD by 2022
- Corn based ethanol, capped at 15 B gal
- Emphasis on transition to 2nd generation cellulosics
- Requires demonstration of LCA based GHG savings relative to baseline petroleum fuels
  - ≥20% for new corn based ethanol plants
  - ≥50% for advanced biofuels (non-corn based)
- Technology Neutral

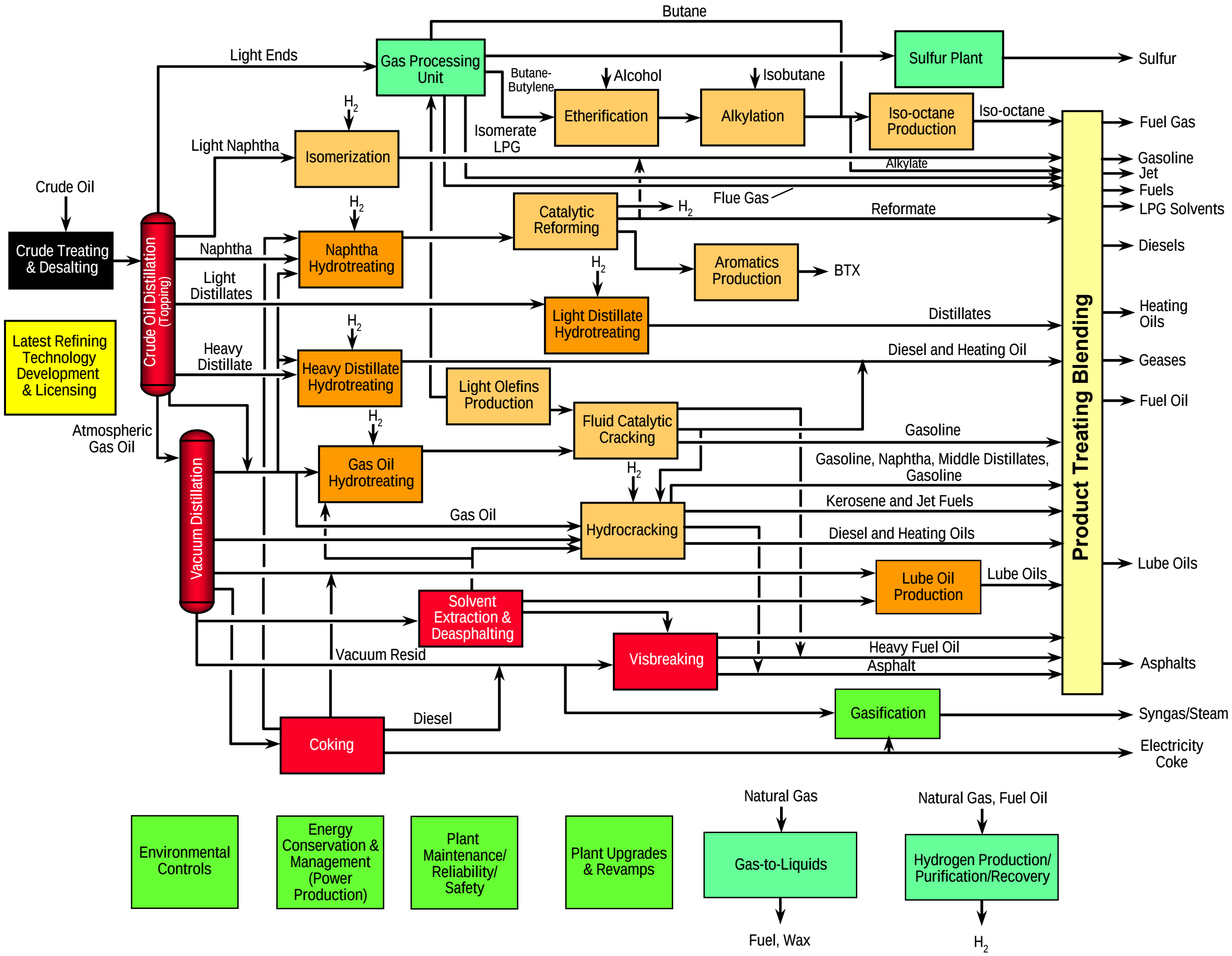
Volume and Type of Renewable Fuel Required by the RFS



Indirect Land Use will factor in LCA

1st gen: Will not qualify as advanced biofuels

Petroleum Refining Context



- Refining: ~100 years
- ~750 refineries
- ~85M BBL of crude refined daily
- ~50M BBL transport fuels
- Complex but efficient conversion processes
- Feedstock provider to the global petrochemical industry
- Established infrastructure for blending, distribution and traded globally

Massive Scale

Technology Evolution Expected

UOP Biofuels Vision

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- Produce <u>real</u> "drop-in" fuels instead of fuel additives/blends
- Leverage existing refining/ transportation infrastructure to lower capital costs, minimize value chain disruptions, and reduce investment risk.
- Focus on path toward second generation feedstocks

Oxygenated Biofuels

Ethanol | Biodiesel

Hydrocarbon Biofuels

Diesel | Jet | Gasoline

"Other" Oils: Camelina, Jatropha, Halophytes

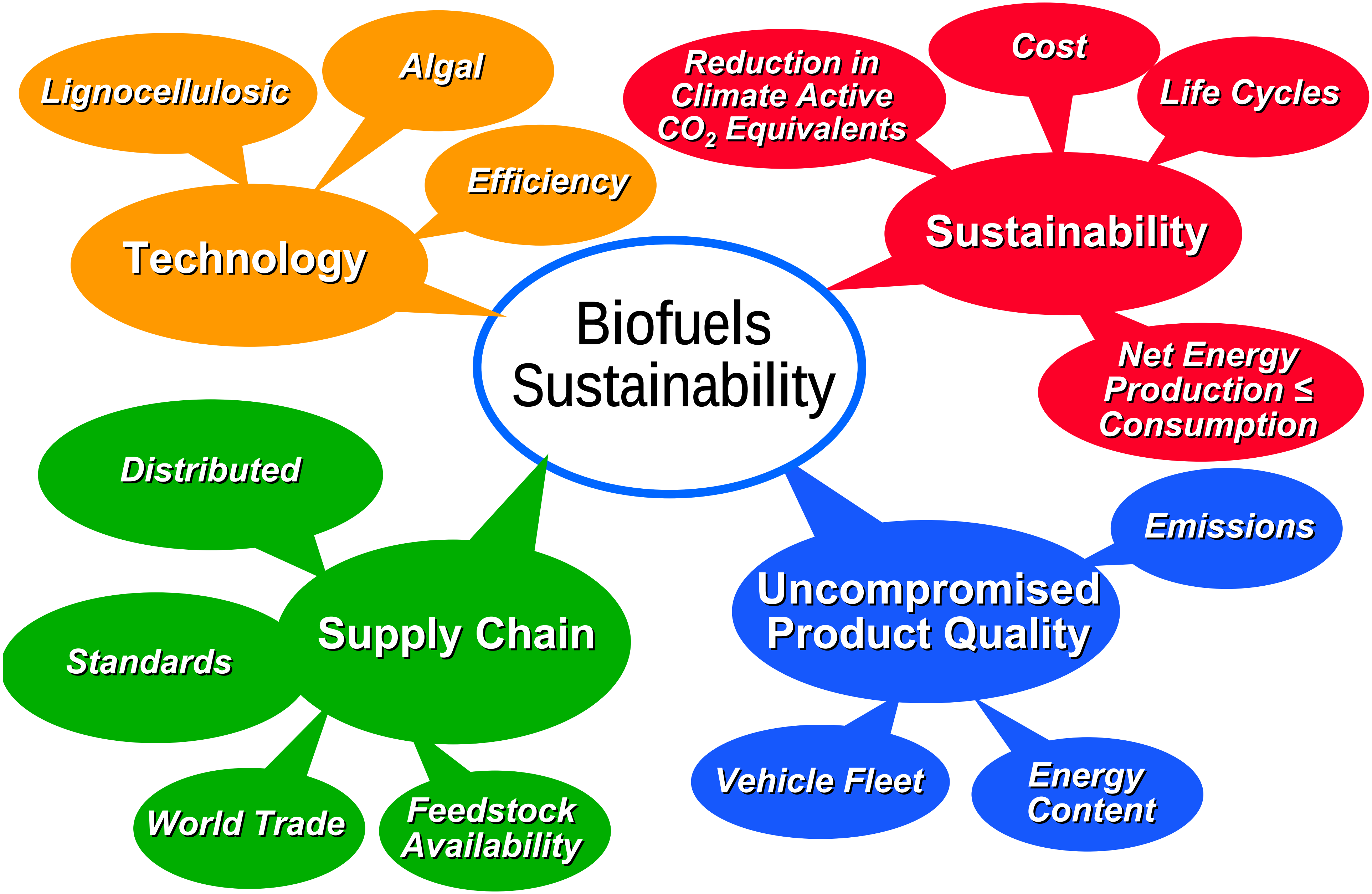
First Generation

Natural oils (vegetables, fats & greases)

Second Generation

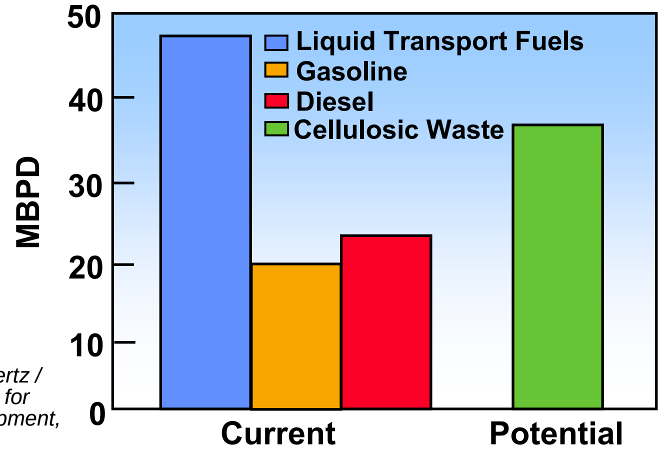
Lignocellulosic biomass, algal oils

Getting There



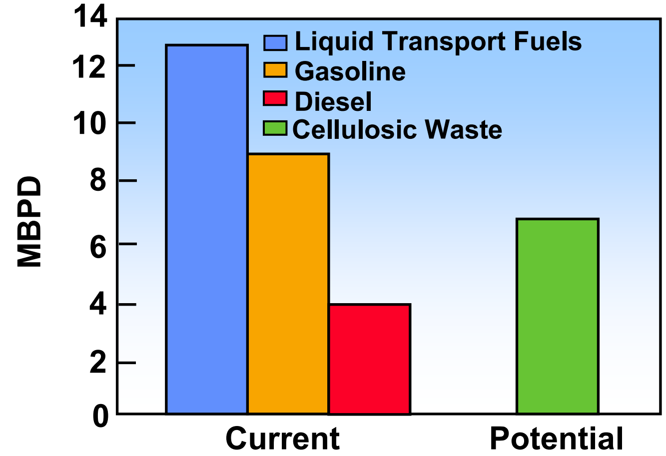
Enablers for a Sustainable Biomass Infrastructure

Global

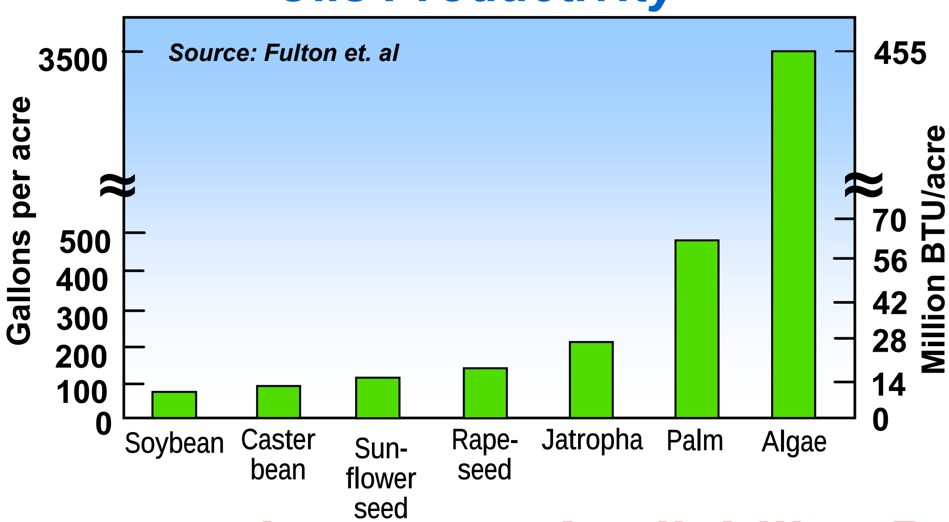


Source: Purvin & Gertz / Eric Larsen: Energy for Sustainable Development, 2000

US



Oils Productivity

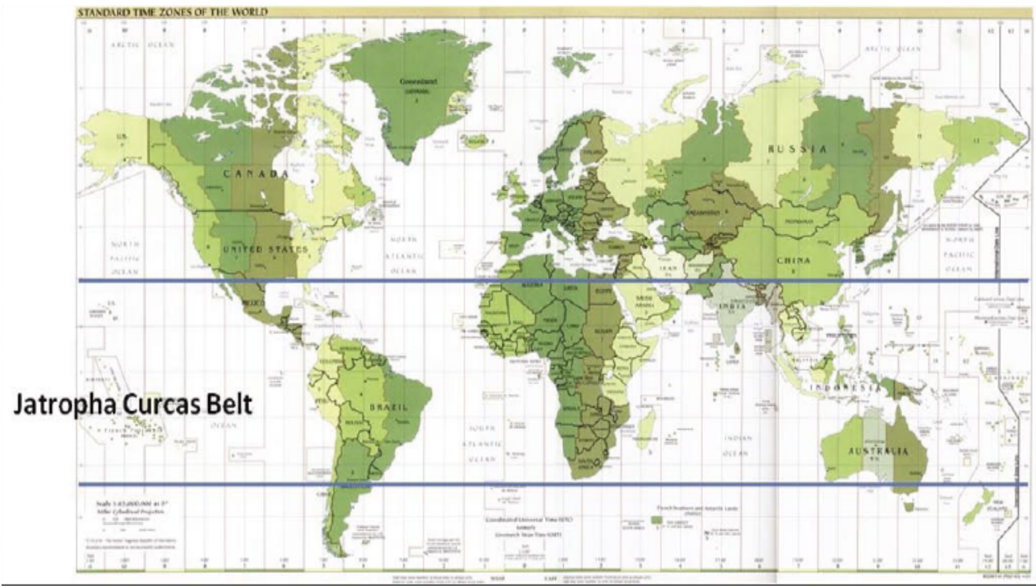


- **Cellulosic waste could make a significant contribution to liquid transportation pool.**
- **Algal Oils could enable oils route to biodiesel, Green Diesel and Green Jet.**

Increases Availability, Reduces Feedstock Cost
Technology Breakthroughs Required

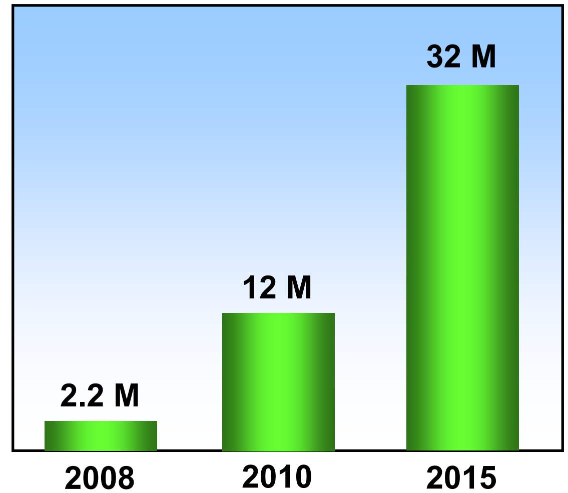
Jatropha: Key Attributes

11 million hectares → 26 million acres jatropha planned in India



Source: Global Biofuels Center, University of Texas Library, August 2008

Scale of Jatropha Plantations
2008-2015 (Acres)



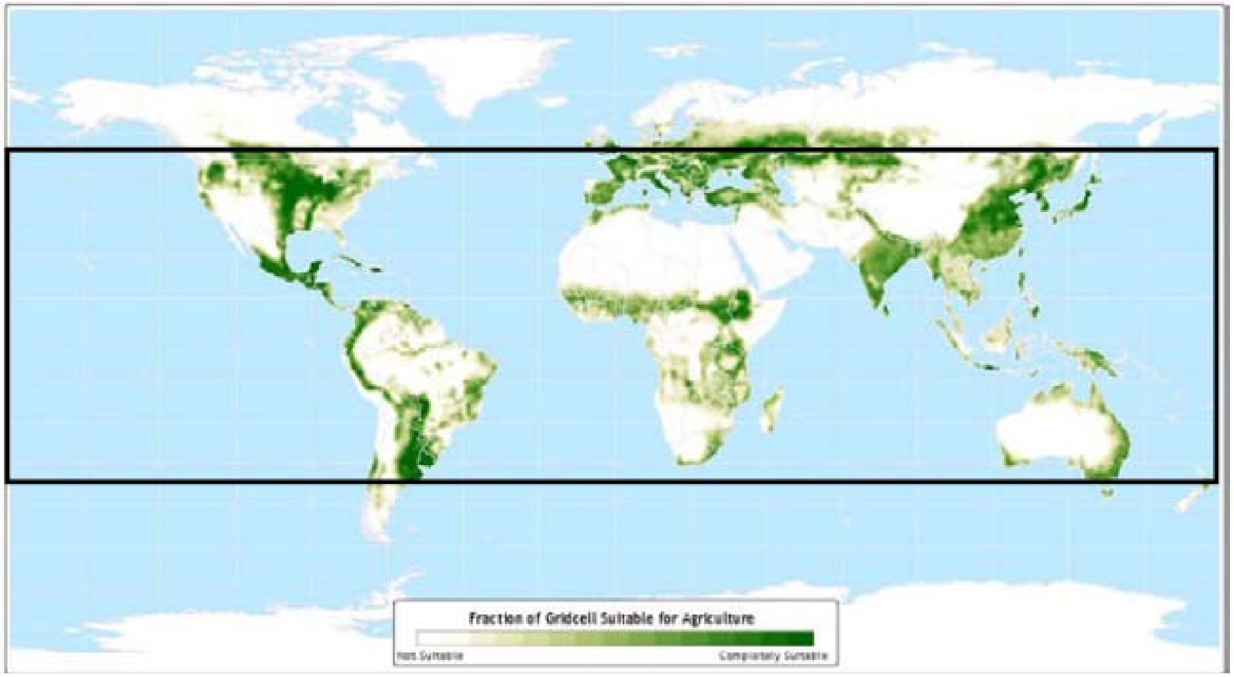
- **Grows well in lowland up to 1000 meters elevation**
- **Grows at rainfall of 300-2380 ml/year**
- **Grows well in porous as well as marginal soil**
- **Required average temperature is 20-28 °C**
- **Requires soil acidity between 5 – 6.5**

- **Yields high quality oil**
- **Yields vary from 220-450 gal/acre/year**
- **Seed quality, cultivation practices and water impact yields**

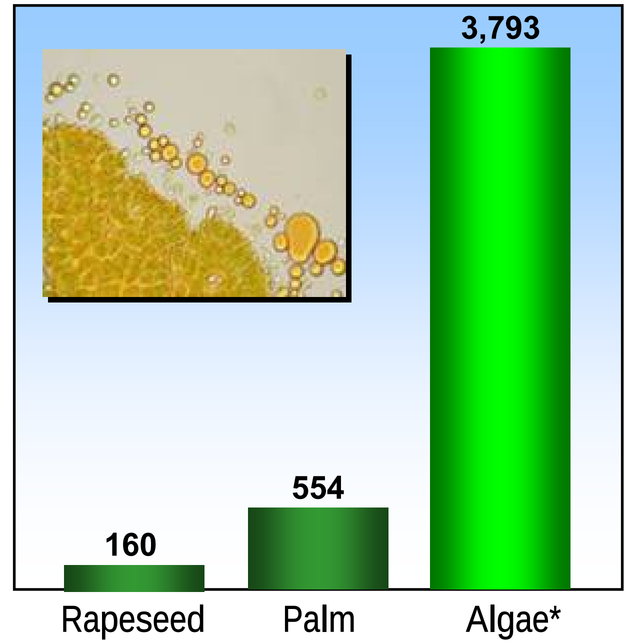
Potential for ~1M BPD of Jatropha based diesel beyond 2015

Algae: Key Attributes

Climatic Zone Suitable for Algal Cultivation



Oil Yield
Gallon/Acre/Year

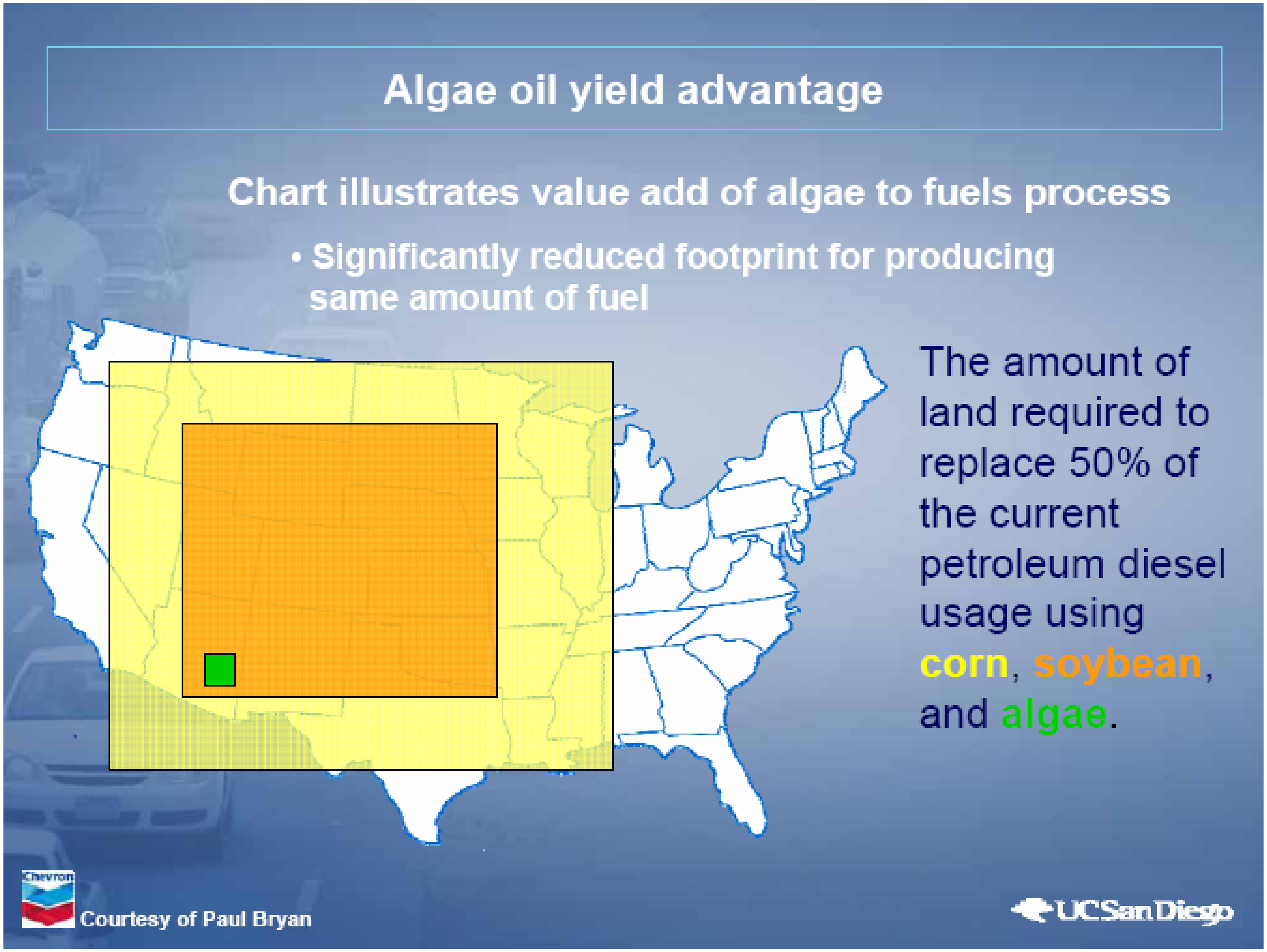


*Yield at 30 $g/m^2/day$, medium irradiation, 30% oil content

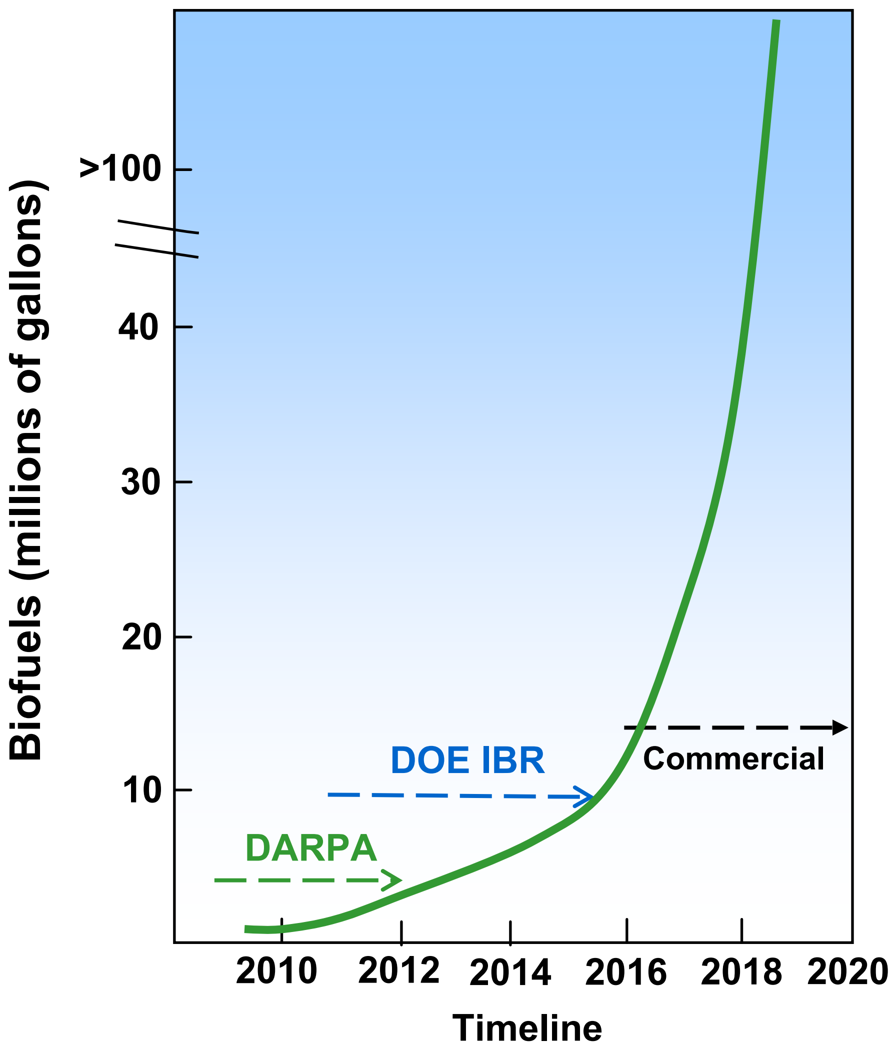
- Temperate & Tropical Zones Avg. temp > 15°C (Optimal = 4-10°C night/10-22°C day)
- Water Resources (hypersaline to fresh)
- Current optimal ~ 1,200 gal/acre/year
- Projected genetic crop enhancement to ~4,000 gal/acre/year

Algae Have Widest Climatic Tolerance and Highest Productivity Of Any Potential Energy Crop

Comparative Land Requirements



Projected Growth in Algal Biofuels



Driving Force for Algal Biofuels:

- **US DARPA Algal Biofuels Program will establish initial pilot production capabilities and oil recovery, purification, and processing capabilities**
- **The US DOE IBR program will promote scale up to commercial size production and refining**
- **Commercial expansion driven by market and regulatory factors**
- **Approximately $200 M in venture funding in 2008 alone**

Exxon Mobil's $600M investment into Algae R&D validates this sector

UOP/ENI Ecofining™ Green Diesel

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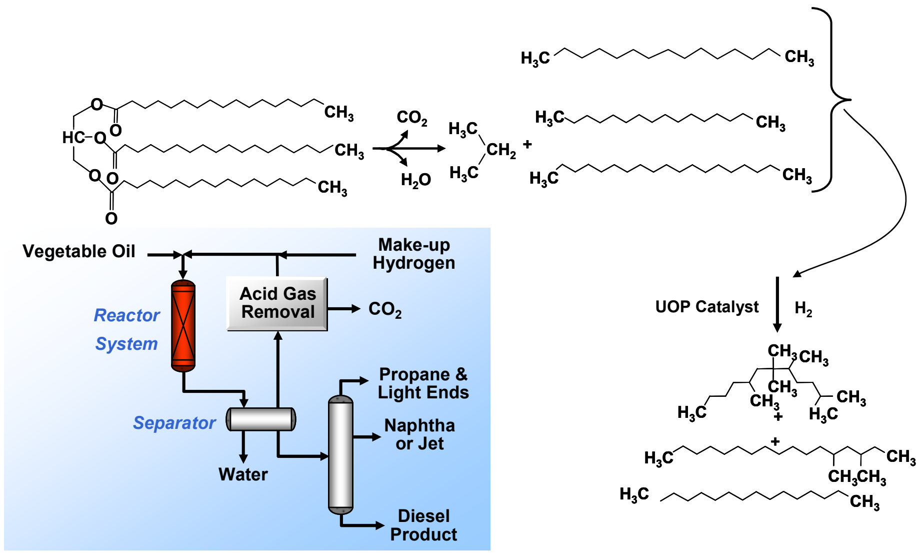
Ecofing Process Chemistry and Flow Scheme



Process Comparison vs. Biodiesel

Natural Oil/ Grease + Methanol → **Biodiesel (FAME)** **+ Glycerol**

Natural Oil/ Grease + Hydrogen → **Green Diesel** **+ nC3 & Naphtha**

- **Technology that produces a fully fungible hydrocarbon product**
- **Uses existing refining infrastructure, can be transported via pipeline, and can be used in existing automotive fleet**
- **Two units licensed in Europe with first commercial start-up in 2010**
- **Excellent blending component, allowing refiners to expand diesel pool by mixing in “bottoms”**
- **Can be used as an approach to increase refinery diesel output**

Performance Comparison

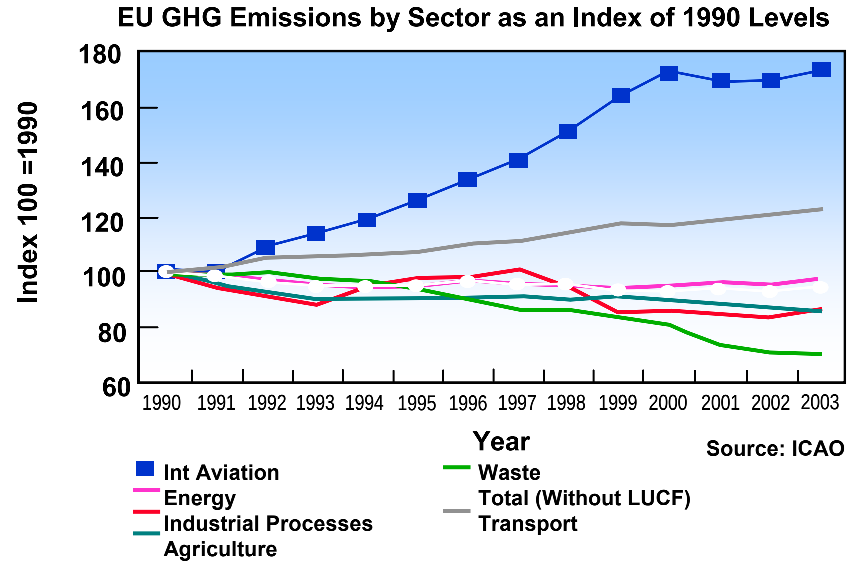
	Petrodiesel	*Biodiesel*	*Green Diesel*
NOx	Baseline	+10	Baseline or better
Cetane	40-55	50-65	75-90
Cold Flow Properties	Baseline	Needs Additives	Baseline or better
Oxidative Stability	Baseline	Needs Additives	Baseline or better

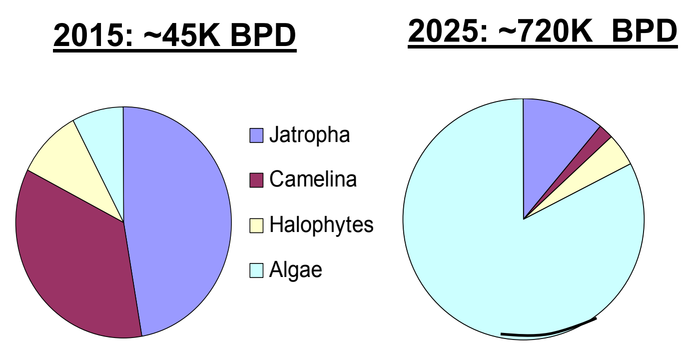
Aviation Fuels: Principal Market Drivers

- **EU 27-Emission Trading Scheme (ETS):**
  - Central pillar of EU Climate Policy
  - Applicable since January 1, 2005
  - Covers around 2B MT of CO_2 emissions – ~50% of EU's total emissions
  - Cap & Trade System
  - ETS extended to aviation emissions in October'2008
  - Total emissions will be capped in 2012 at 97% of 2004-2006 average
  - Cap will decrease in 2013 to 95% of historical emissions

- **US Military:**
  - National Security & Green Vision driven
  - Consumes ~300K BPD aviation fuel
  - Goal set to have 50% of its needs met by alternative fuels primarily biojet by 2020

- **Green Jet: Production Potential:**
  - In the near term feedstock supply key determinant
    - **Camelina - ~200M gpy by 2012 & ramping up**
    - **Jatropha - ~3B gpy by 2015**
  - Longer term:
    - **Algae will be primary feedstock**
    - **Commercial scale production, 7-10 years out**
  - Acceleration of certification





Feedstock shift towards Algae

OEM Led Market Development & Supported by Legislation

UOP Renewable Jet Process

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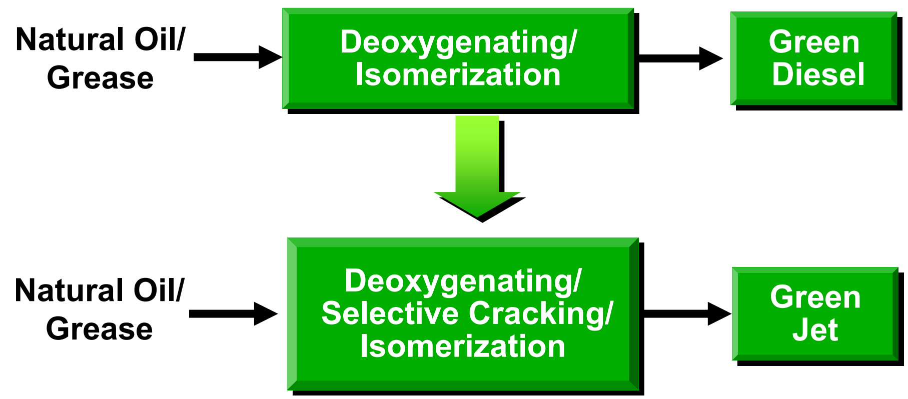
- Initially a DARPA-funded project to develop process technology to produce military jet fuel (JP-8) from renewable sources
- Targets maximum Green Jet production
- Green Jet Fuel can meet all the key properties of petroleum derived aviation fuel, flash point, cold temperature performance, stability
- Certification of Green Jet as a 50% blending component in progress

Built on Ecofining Technology



DARPA Project Partners

Southwest Research Institute
Sandia National Laboratories
DARPA
Cargill
UOP A Honeywell Company
Honeywell

Available for License Q3 2009

Completed Flight Demonstrations

- Successful ANZ Flight
  Demo Date: Dec. 30 2008

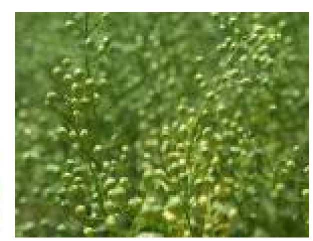
Feedstock: Jatropha oil

- Successful CAL Flight
  Demo Date: Jan. 7 2009

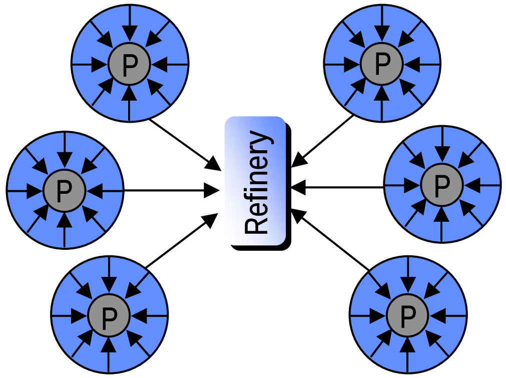
Feedstock: Jatropha and algal oil

- Successful JAL Flight Demo
  Date: Jan. 30 2009

Feedstock: Camelina, Jatropha and algal oil



Pyrolysis Oil to Energy & Fuels



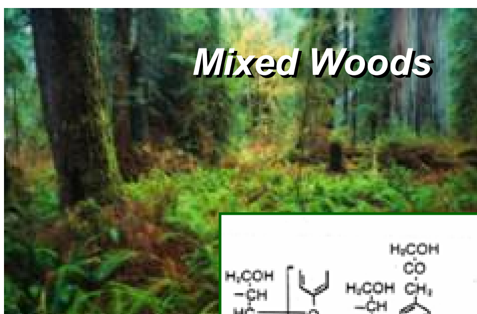
Biomass → **Fast Pyrolysis RTP Process** → Pyrolysis Oil

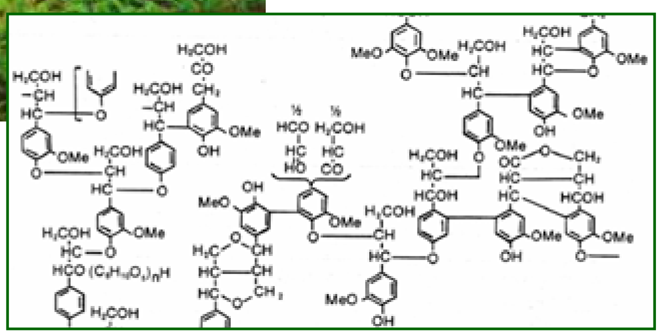
- **Electricity Production**
- **Fuel Oil Substitution**

Available Today

- **Transport Fuels (Gasoline, Jet Diesel)**
- **Chemicals (Resins, BTX)**

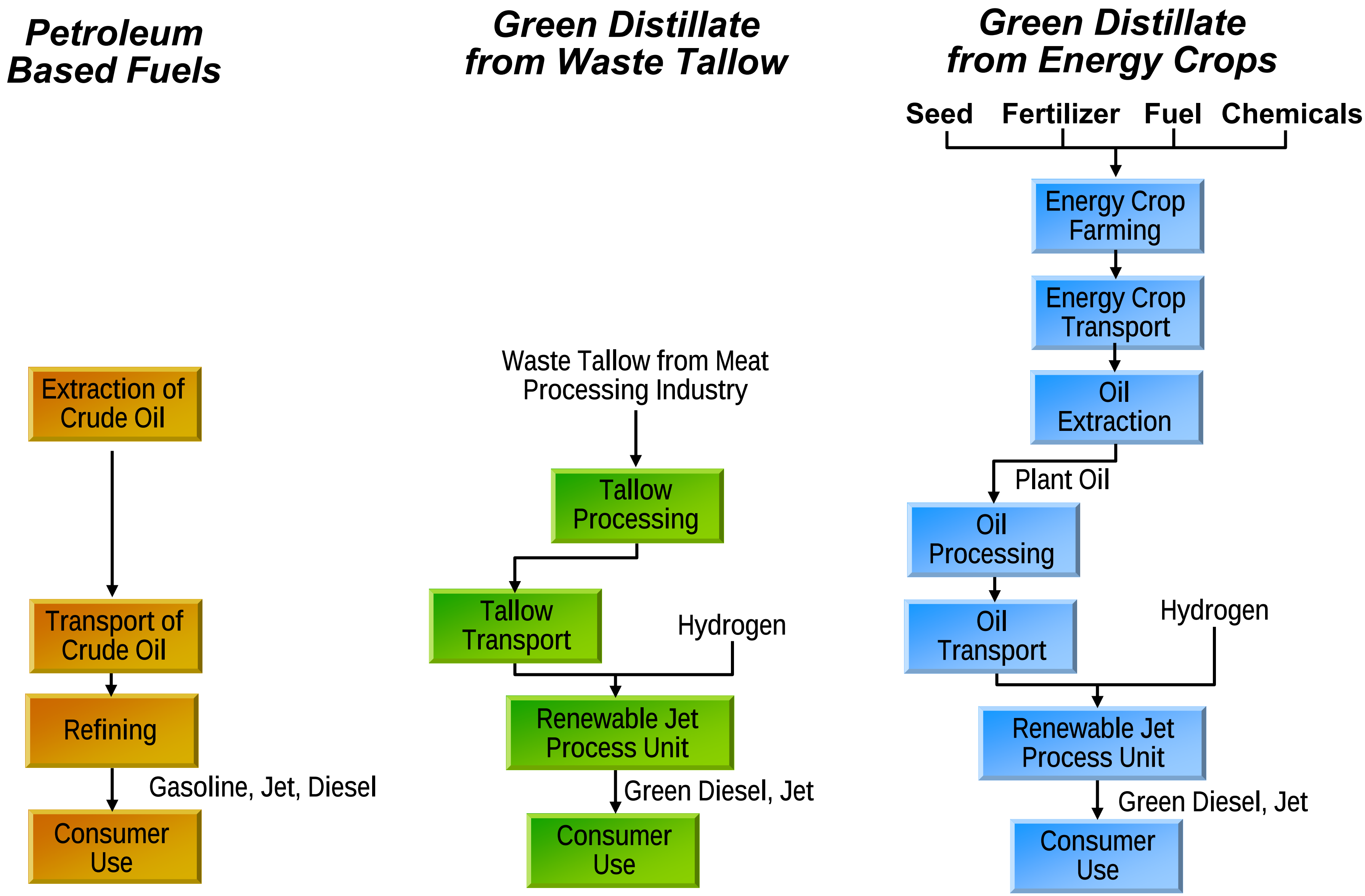
3 Years to complete R&D





Conversion to Transport Fuels Demonstrated in Lab
Collaboration with DOE, USDA, PNNL, NREL

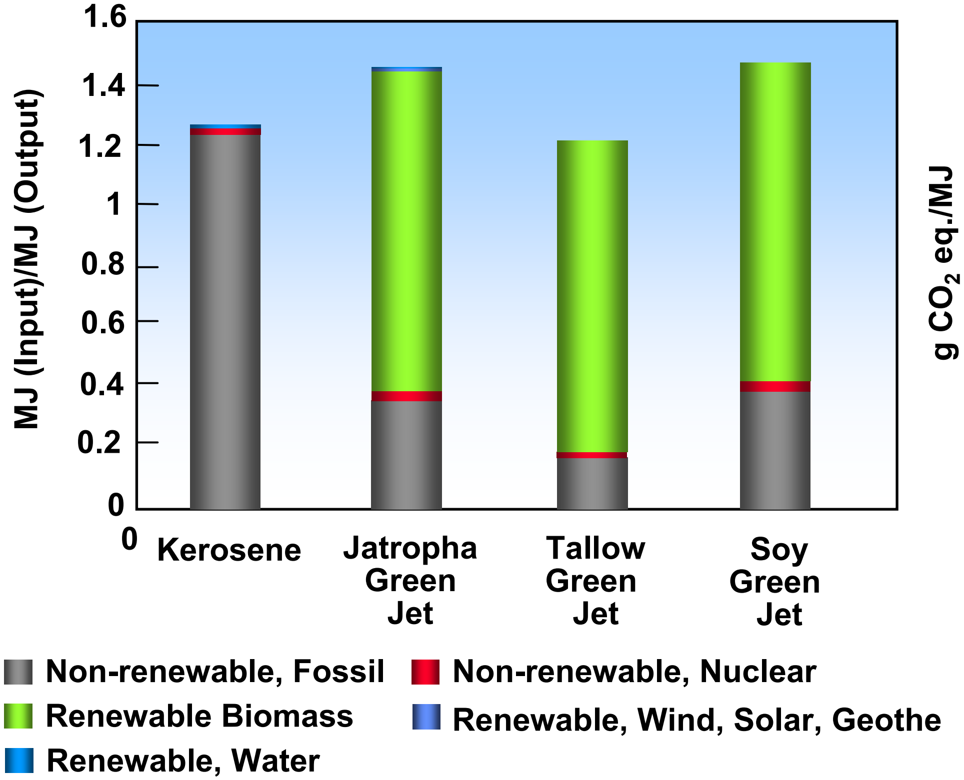
Scope of WTW* LCA



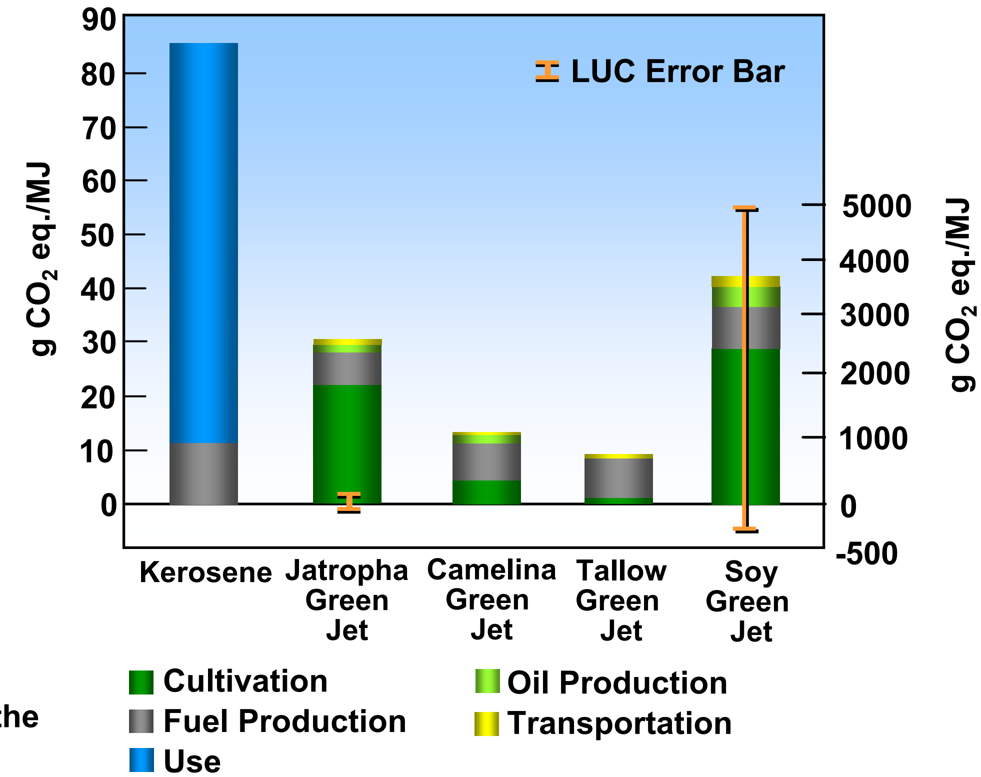
***WTW is either “well-to-wheels” or “well-to-wings”**

Life Cycle Analysis for Renewable Jet Fuel

Cumulative Energy Demand



Greenhouse Gases



Significant GHG Reduction Potential

Basic Data for Jatropha Production and Use. **Reinhardt, Guido et al.** IFEU June 2008
Biodiesel from Tallow. **Judd, Barry.** s.l. : Prepared for Energy Efficiency and Conservation Authority, 2002.
Environmental Life-Cycle Inventory of Detergent-Grade Surfactant Sourcing and Production. **Pittinger, Charles et al.** 1, Prarie Village, Ka : Journal of the American Oil Chemists' Society, 1993, Vol. 70.

Summary

- Renewables are going to make up an increasing share of the energy pool
  - Fungible biofuels enable industry expansion
  - Essential to overlay sustainability criteria
- Feedstock availability is an important enabler
  - First generation biofuels, though raw material limited, are an important first step to creating a biofuels infrastructure. Bridging feedstocks are key
  - Second generation feedstocks, cellulosic waste and algal oils, are on the horizon
  - Diverse feedstock initiatives are enabling regional sustainable solutions
- Important to promote technology neutral and performance based standards and directives to avoid standardization on old technology.
- Meeting legislation in the most cost effective manner will require a combination of solutions