
Agriculture Residues


Flared Gas


Food Processing Waste


Municipal Solid Waste


Pulp Waste


Wet Sludges

ENERGY EVERYWHERE

Modular chemical conversions delivering clean energy

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The Big Idea

Locally transform

the nation's stranded, underutilized, and distributed waste into fuels and chemicals

Waste – National Impact

Waste Sources	Total Resource (barrel of oil/year)
Agricultural and forest waste	600 – 800 million barrels
Animal waste (manures)	350 – 700 million barrels
Food processing	100 – 270 million
Waste water sludge	30 million barrels
Flared gas	50 million barrels
CO_2 (ethanol prod)	Tbd
Municipal and industrial solid waste	400 – 700 million barrels

Impact

1.5-2.5 billion barrels of oil

(2015 imports = 1.7 billion barrels)

New domestic industry

Solves waste disposals challenges

GHG reduction (exceeding 60-80%)

WASTE – NATIONAL IMPACT, LOCALLY DISTRIBUTED

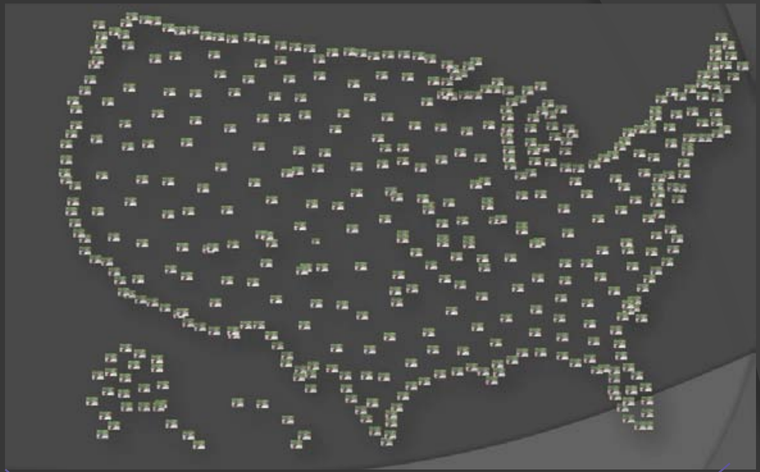
Waste Sources	Total Resource (barrel of oil/year)	Local Size
Agricultural and forest waste	600 – 800 million barrels	2-200 BOE/D
Animal waste (manures)	350 – 700 million barrels	4-150 BOE/D
Food processing	100 – 270 million	2-50 BOE/D
Waste water sludge	30 million barrels	30 BOE/D
Flared gas	50 million barrels	20-200 BOE/D
CO_2 (ethanol prod)	Tbd	10-300 BOE/D
Municipal and industrial solid waste	400 – 700 million barrels	70-1500 BOE/D

Individual unit is small

20-200 barrels per day production

BOE/D= barrels of oil equivalent/day

Right Sized



What will it Take?

US petroleum refinery
125,000 bpd

Gas to liquids*
30,000 bpd

US ethanol†
2,000 bpd

Energy Everywhere
200 bpd

Compact, local systems
Huge national impact

* Typical GTL plant planned for China
† either corn dry mill or BETO 2,000 tonne/day plant

Integrating New Paradigms for Energy Production

Large plants
(> 12GW, 125,000 bpd)

Full heat integration
Optimized use of feed

Steady production ⟷ **Strong fluctuations**

Distributed production
(< 100 MW, 200 bpd)

Heat integration challenging
Not all feed used (e.g., H_2O)

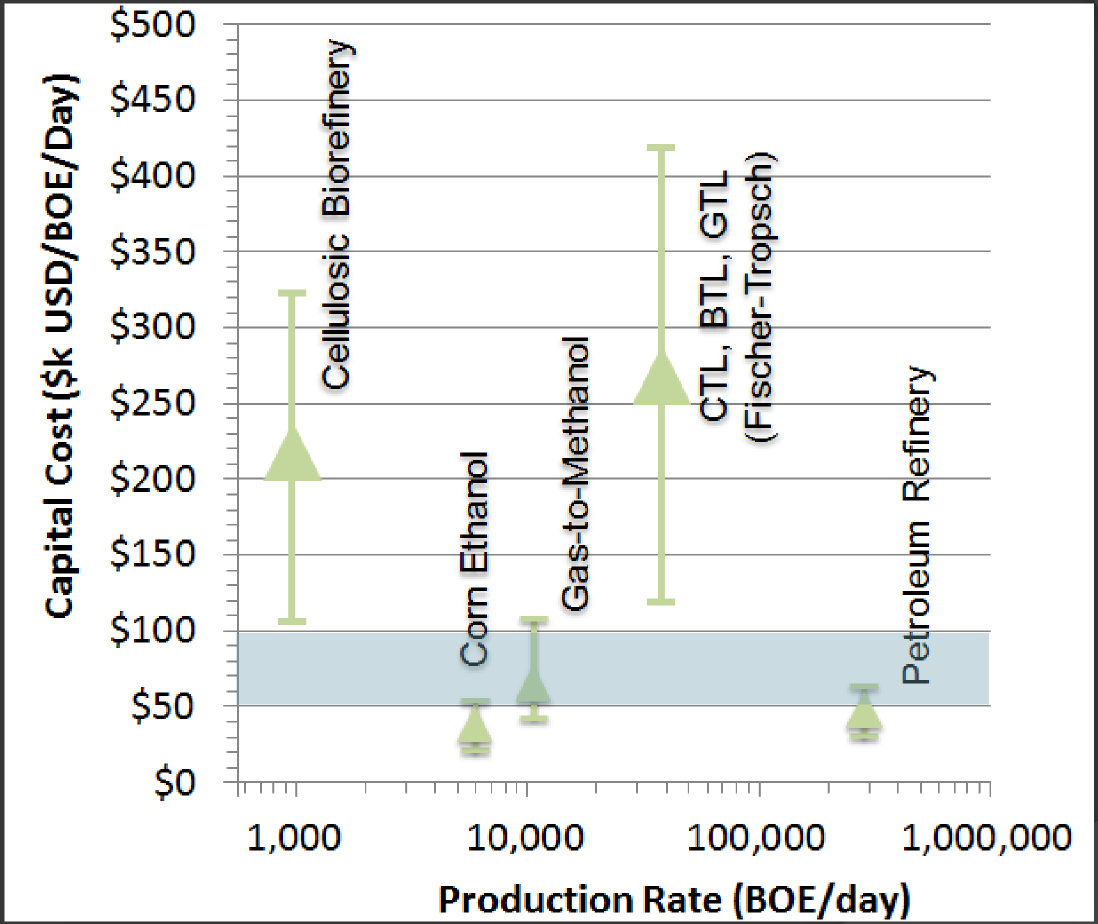
...While Keeping Capital Cost Low

Goal

Capital at $50k per (BOE/day)

Impact

Reduced risk at small scale



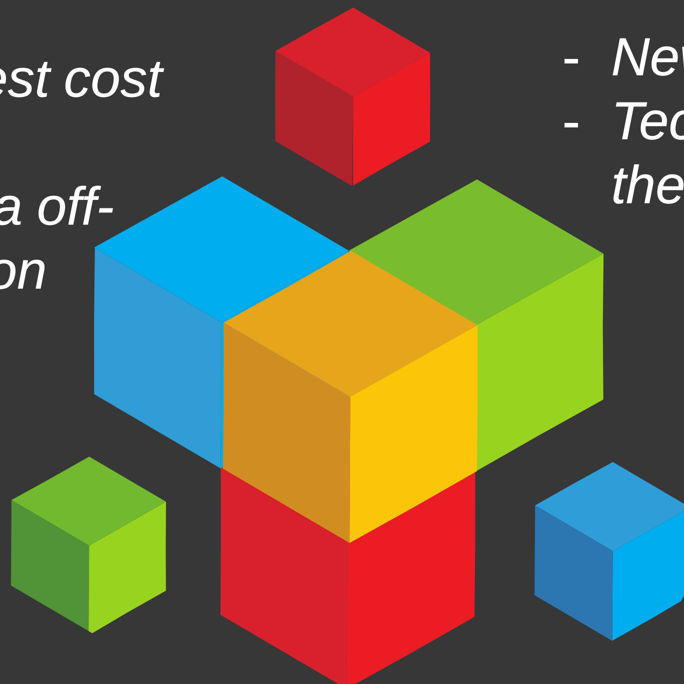
Economic Enablers

Small scale

- *Reduces risk*
- *Enables use of lowest cost feedstock*
- *Provides benefits via off-site plant construction*

New technologies

- *New scientific advances*
- *Technologies that avoid the 2/3 power scaling law*



Mass production

- *Modular design flexibility*
- *Flexible product production*
- *Learning curve 3x greater*

Standardized platforms

- *Reduce operating cost with sensor and controls*
- *Support innovation with plug and play approach*

New Technologies

- *Avoiding the 2/3 power scaling law*
- *Operating at low temperatures*
- *Replacing high capital processes*
- *Deploying low-energy separations technologies*

R&D focus

- *Linear throughput scaling e.g., electrochemical or photochemical activated*
- *10,000 fold increase in activity (e.g., catalyst)*
- *No high pressure H_2 gas use*
- *Non-thermal separations rather than distillations*

Focus on technologies designed for small scale

Standardized platforms

- *Employing separations and conversion modules*
- *Using "Chemical lumping"*
- *Reducing operating cost with sensor and controls*

R&D focus

- *Understanding thermodynamics of multi-component liquids*
- Estimating or measuring fast intrinsic reaction rates
- Developing relationships to represent transport behavior

Support innovations with plug and play approach

Mass production

- *Modular design*
- *Prefabrication (off-site)*
- *Flexible product options*

R&D focus

- *Determining common platforms (size, throughput)*
- Understanding the role of additive manufacturing
- Determining materials of construction requirements

Take advantage of a learning curve 3x greater

Small scale processing of waste

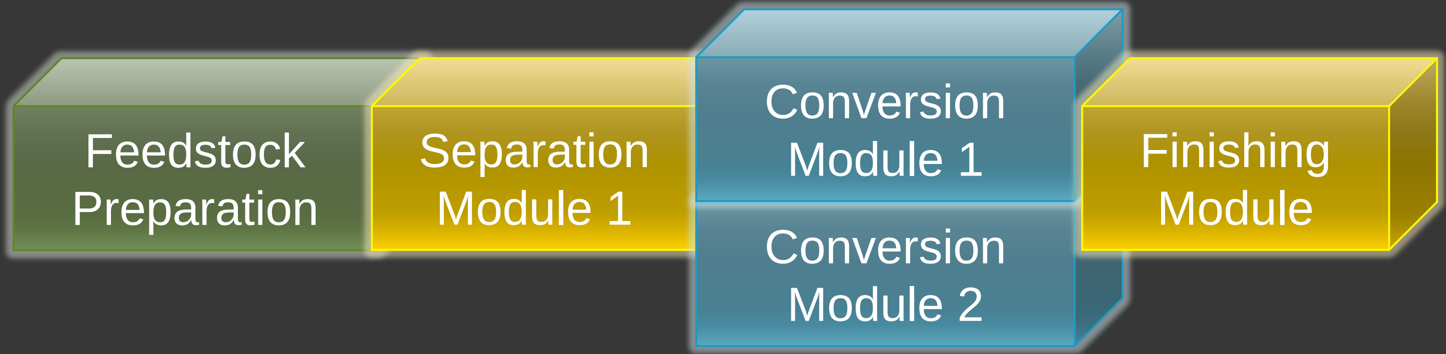
- *Enables use of lowest cost feedstock*
- *Requires non-technical risks be mitigated*

R&D focus (other)

- *Addressing codes and standards*
- *Completing markets studies*
- *Understanding local and national regulatory environment*

Reduce risk and promote innovation through low capital opportunities

Distributed Production Modules



Handling feedstock variability and intermittency

Produce common intermediate using simple technologies able to handle complexity

Directing output to conversion modules

Upgrade to products for local use (fuels, chemicals, minerals, clean water) or that feed into current energy infrastructure

Producing on-site

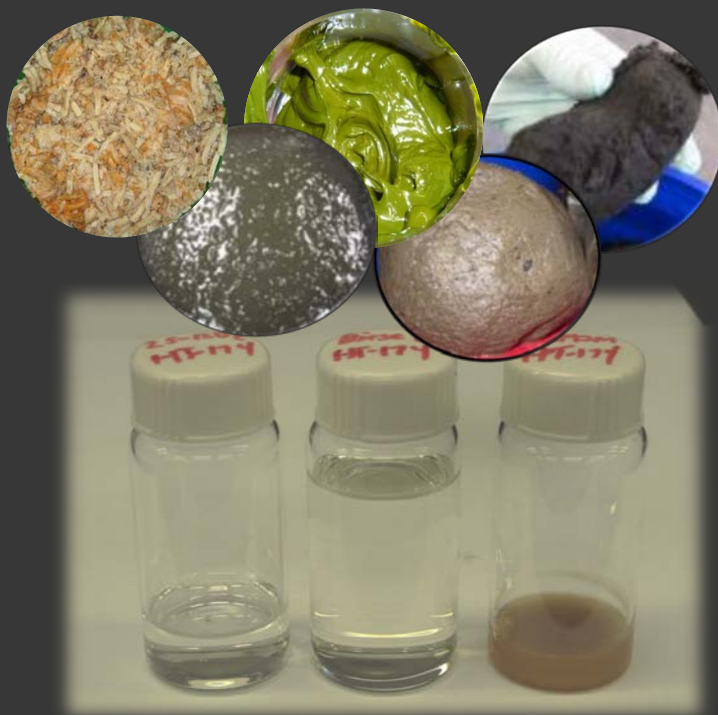
transport only usable product

Where Do We Start?

Waste Sources	Total Resource (barrel of oil/year)	Local Size	
Agricultural and forest waste	600 – 800 million barrels	2-200 BOE/D	
Animal waste (manures)	350 – 700 million barrels	4-150 BOE/D	Focus: Wet waste (high moisture)
Food processing	100 – 270 million	2-50 BOE/D	
Waste water sludge	30 million barrels	30 BOE/D	
Flared gas	50 million barrels	20-200 BOE/D	Focus: Gas waste
CO_2 (ethanol prod)	Tbd	10-300 BOE/D	
Municipal and industrial solid waste	400 – 700 million barrels	70-1500 BOE/D	

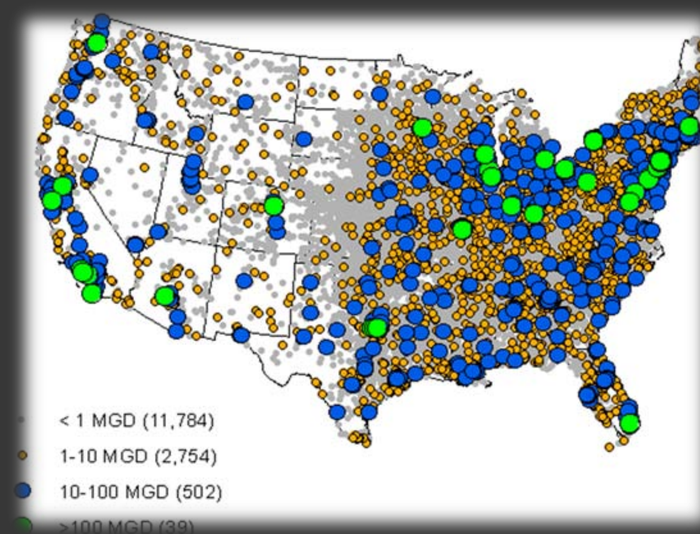
Where Are We at Today?

Demonstrated high quality diesel fuel from wet sludges



- Waste water sludge
- Food processing waste
- Algal bodies
- Mixed waste

Feedstock-infrastructure analysis underway



- Understand true availability
- Place in context of infrastructure (electrical transmission lines, gas pipelines, roads, rail, ports, refineries, renewable electrons)

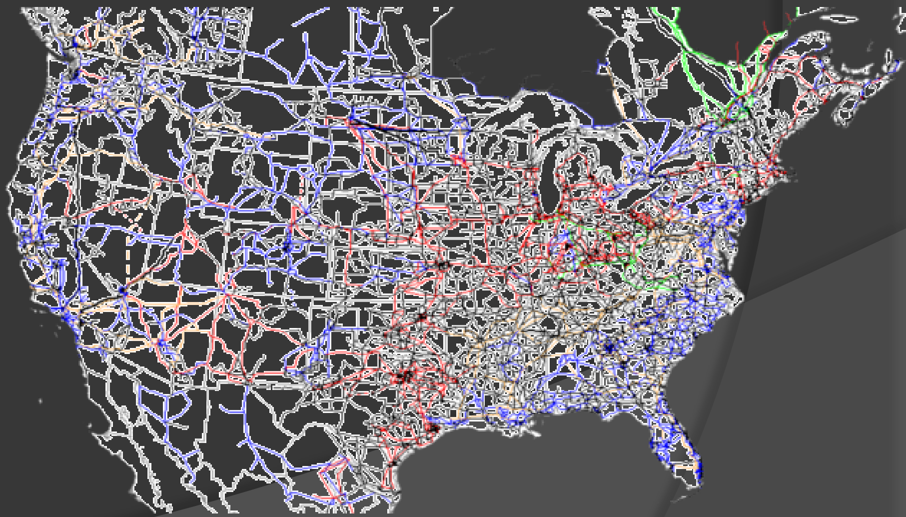
WHAT IS NEXT?

IN FIVE YEARS

- Demonstrate market feasibility with a functioning prototype

IN 10 TO 15 YEARS

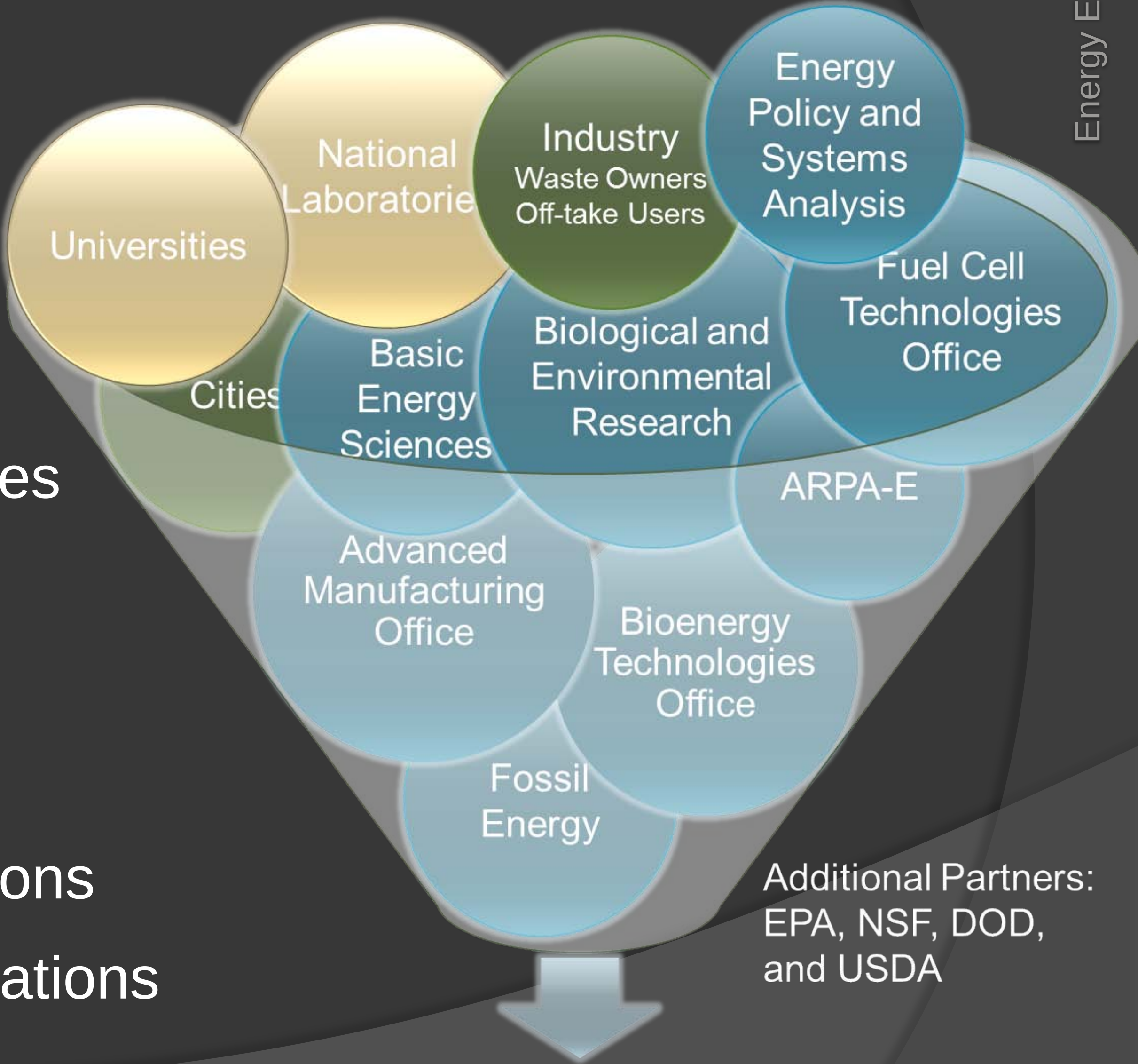
- Create regional networks of modular processing systems



Bringing the Pieces Together

Developing Roadmap

- Early targets
- Cross-office activities
- S&T research plan
- Early adopters
- Policy implications
- Industry collaborations
- Regional demonstrations



Additional Partners: EPA, NSF, DOD, and USDA

Locally Transform Waste

WASTE CARBON

- Food, animal, agricultural, forest waste
- Municipal and industrial waste

ENERGY

- Renewable sources (water, wind, light)
- Off-peak energy from power plants

INNOVATIVE ENGINEERING

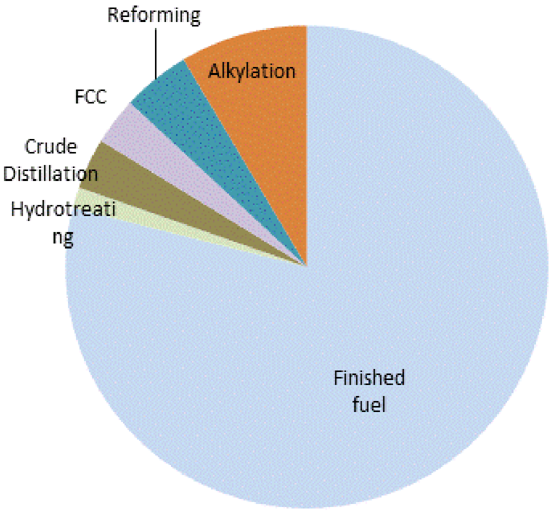
- Sized to local waste carbon sources (20-200 BOE/day)
- Modular and mass produced

Clean Energy Mission Innovation

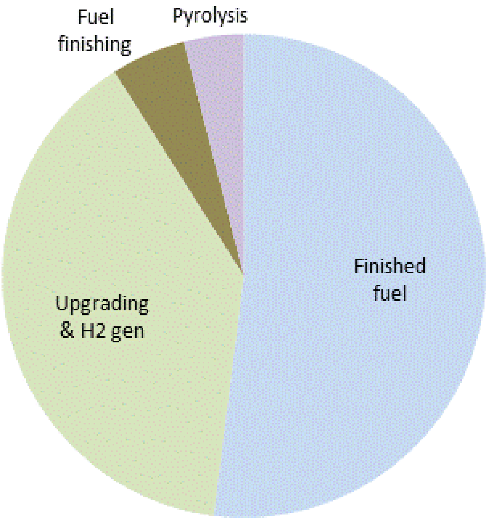
Back Up Material

Cost of Hydrotreating

Energy Distributions (pyrolysis oil):

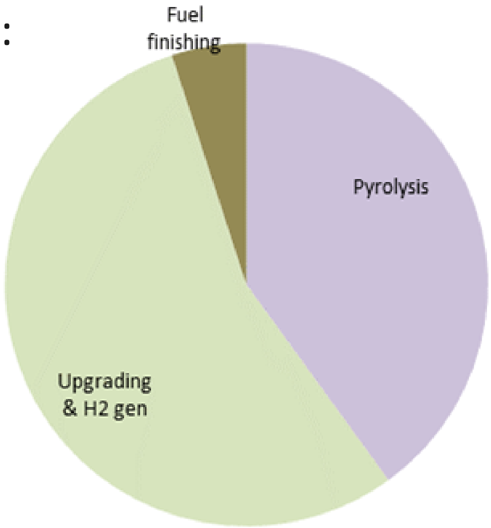


Typical petroleum refinery



Biorefinery – pyrolysis of wood

CAPEX distribution (pyrolysis oil):



Biorefinery – pyrolysis of wood

Petroleum hydrodesulfurization				Petroleum hydrocracking			Pyrolysis oil	HTL biocrude
Naptha HDS	Kerosene HDS	ATM resid HDS	Gas oil HDS	Mild HCK	Single STG HCK	Resid HCK	HDO	HDO
45	555	460	422	358	1150	660	~3400	~1800

H_2 chemical consumption, scf/bbl fd (standard cubic feet/barrel feed))

COST OF HYDROTREATING

Process	Pyrolysis & Oil Upgrading	Hydrothermal Liquefaction & Upgrading
Biomass	Wood	Algae (med lipid)
Plant Scale, US ton/day	2000	1340
Naphtha & Diesel, bbl/d product	4000	4000
Capex, mm$ (2011)	700	470
% of Hydrotreating related Capex	55%	23%
Total Capex $/bbl/d product	180,000	120,000
HT Capex $/bbl/d product	99,000	27,600
% of Hydrotreating related Opex	81%	86%

80% of OPEX and up to 55% of CAPEX