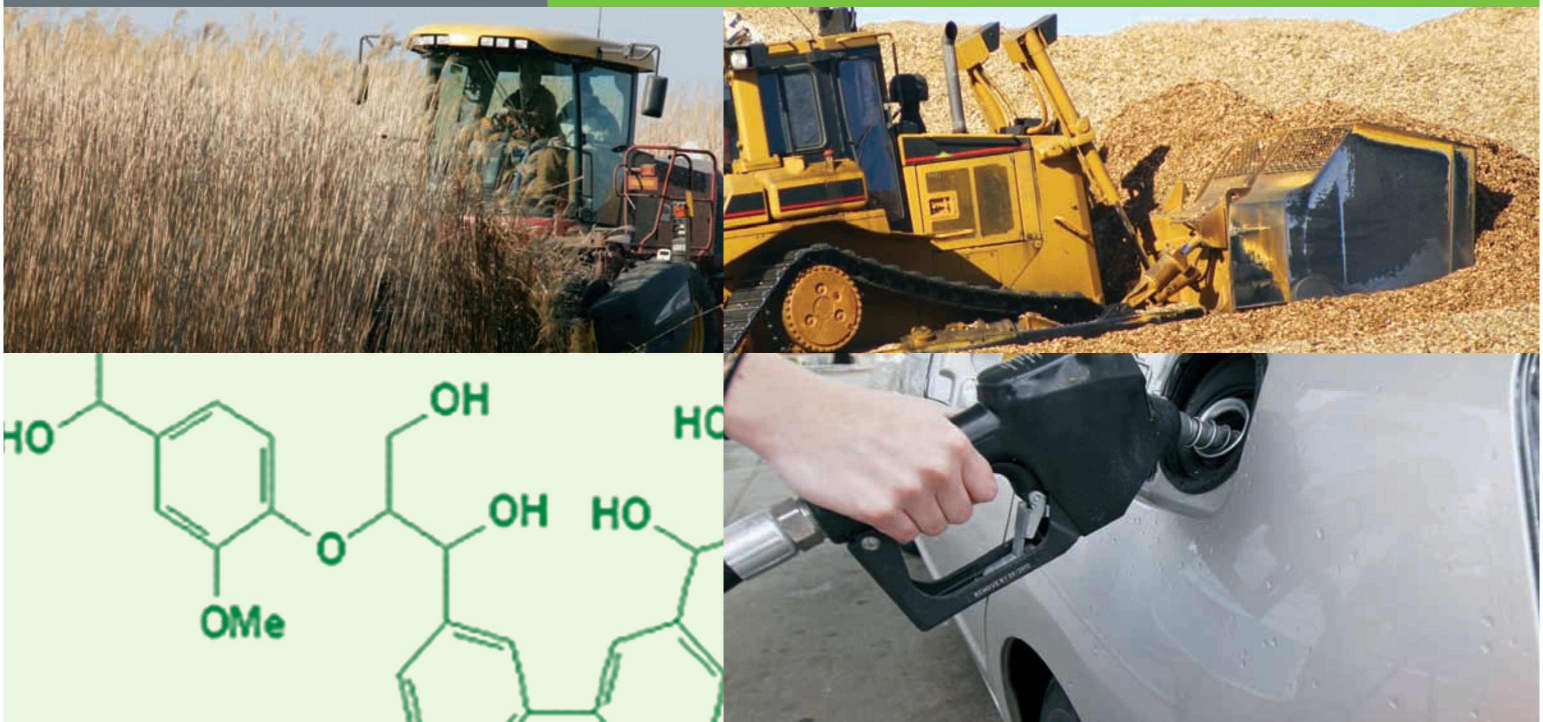


A wide variety of non-food biomass grown across the country can be converted into advanced hydrocarbon fuels using thermochemical processes. *Photos (clockwise from upper left): INL, iStock/3786400, 6090867, Energetics Inc.*

Thermochemical Conversion:
Using Heat and Chemistry to Make Fuels and Bioproducts

The Biomass Program works with industry and other partners to develop economical thermochemical pathways for coverting domestic, non-food biomass into direct substitutes for gasoline, diesel, and other petroleum-based fuels or intermediate products.

Advanced biofuels are part of America's all-out, all-of-the-above energy strategy to develop all domestic energy resources and win the global race for clean energy technology. Developing a sustainable, commercial-scale U.S. bioindustry will naturally require the flexibility to use a wide variety of domestic biomass resources. Through the application of heat, robust thermochemical processes can efficiently convert a broad range of biomass, including forest and wood residue (known as lignocellulosic biomass), into fuels, power, and other useful products.

In general, thermochemical conversion technologies are less sensitive than biochemical technologies to the type and amount of sugars present in a particular biomass feedstock stream. For this reason, thermochemical conversion efficiencies are also less sensitive to seasonal and regional variations in biomass.

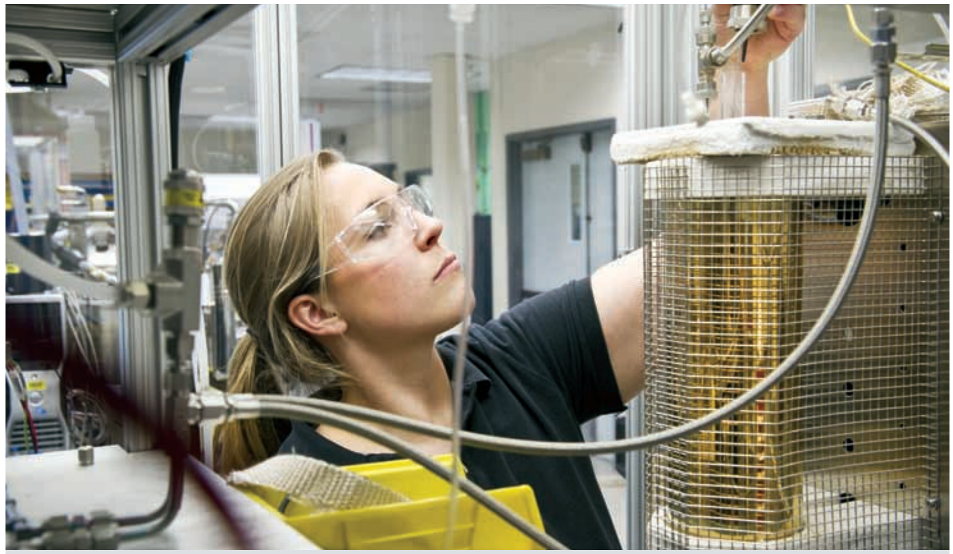
In addition to using a range of biomass feedstocks, thermochemical conversion enables production of many different types of advanced biofuels, including the following:

- Ethanol derived from cellulosic biomass
- Longer-carbon-chain alcohols (such as butanol) that are produced through the conversion of renewable biomass
- Advanced hydrocarbon fuels derived from cellulosic biomass, which can be used as direct replacements for gasoline, diesel, and jet fuel.

> Investing in next-generation biofuels helps boost the competitiveness of the U.S. biofuels industry, supports economic development in rural communities, and creates skilled jobs for American workers.
>
> *—Energy Secretary Steven Chu March 22, 2012*

Expanding Our Biomass Options

The elevated temperatures of thermochemical processes (300-1,000°C) overcome the natural resistance of biomass to conversion, thus expanding the range of feedstocks that can potentially be used by the growing U.S. bio-industry. The Biomass Program works collaboratively with teams from industry, academia, and the National Laboratories to conduct innovative research and development (R&D) to improve the energy efficiency and cost effectiveness of thermochemical conversion technologies. This ongoing work focuses on converting biomass and organic residues into intermediates, fuels, chemicals, or power using pyrolysis, gasification, and other catalytic conversion processes. Two of the most common thermochemical approaches are gasification and pyrolysis:



The National Renewable Energy Laboratory developed a fluidizable tar-reforming catalyst that converts tars (a by-product of gasification) into additional syngas for fuel synthesis. *Photo: NREL/20398*

Gasification

Gasification processes for liquid fuels use heat and may use a limited amount of oxygen to convert biomass into a synthesis gas (syngas), which consists primarily of carbon monoxide and hydrogen. Product-specific catalysts are then used to turn the syngas into liquid transportation fuels.

Key Challenges:

- Demonstrating reliable reactor operation
- Developing improved catalysts for liquid fuel production
- Refining efficient gas cleaning technologies

Pyrolysis/Liquefaction

Pyrolosis is a thermochemical process during which biomass feedstocks are broken down using heat in the absence of oxygen. This process produces a bio-oil that can be further refined to create renewable hydrocarbon transportation fuels. The decomposition occurs at lower temperatures than gasificaton processess and produces a liquid oil instead of a synthesis gas. This bio-oil varies in oxygen content and viscosity depending upon the processing conditions and the presence of a catalyst. A specific type of processing called "fast pyrolysis" involves rapidly heating the biomass in a reactor to approximately 500° for less than two seconds.

Key Challenges:

- Removing oxygen
- Cleaning and stabilizing the bio-oils
- Improving catalysts for upgrading bio-oils into finished fuels

Thermochemical Conversion via Pyrolysis

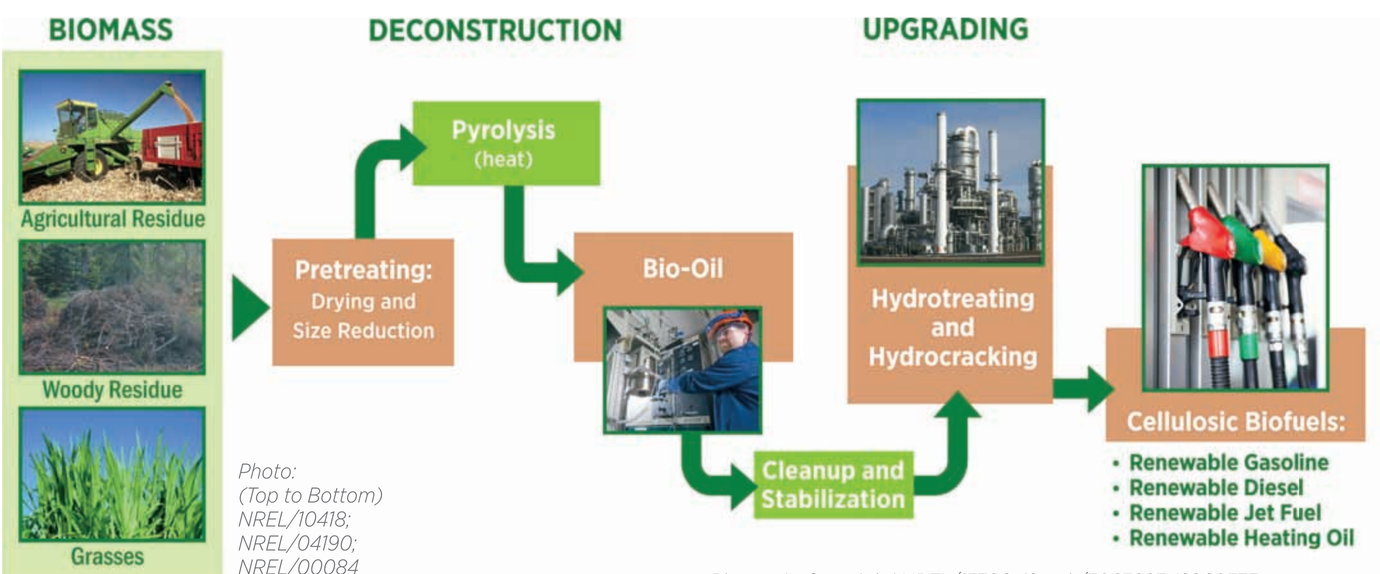


Photo: (Top to Bottom) NREL/10418; NREL/04190; NREL/00084

Photo: (Left to right)NREL/15700; iStock/3067027, 12902533

Pathway to Diverse Biofuels and Benefits

The flexibility of thermochemical processing provides the opportunity to develop cost-effective methods for producing advanced biofuels that deliver diverse benefits. The specific level and mix of benefits vary by biofuel, providing a range of product choices to meet market needs and priorities. These benefits include the following:

- **Climate Change:** On a life-cycle basis, advanced biofuels produced via thermochemical conversion processes could reduce greenhouse gas emissions by 50% or more.
- **Infrastructure Compatibility**: Many advanced biofuels are compatible with the existing fuel delivery infrastructure (pipelines, tanks, pumps, blending facilities, vehicles, etc.), facilitating rapid commercial introduction of these renewable fuels.

Program research in thermochemical conversion is helping to define feedstock criteria for reliable processing in pressurized systems.
Photo: iStock/4373820

Demonstrating Thermochemical Processes

The Biomass Program is working in partnership with private industry and others to develop and scale up technologies for efficiently producing biofuels and bioproducts. Current projects are focused on enabling biorefineries to efficiently convert woody or ligno-cellulosic biomass into biofuels at demonstration and commercial scales.

The Program is working to better understand the physical properties, reactivities, and compatabilities of biofuel intermediates for finishing in traditional petroleum refineries.
Photo: Microsoft/MP900185095

Examples of Thermochemical Processes for Biofuel Production

Conversion Steps	Feedstock	DOE Projects	Stage	Product
• Gasification of biomass to syngas • Synthesis into mixed alcohols • Distillation into pure ethanol	Agricultural residue (e.g., corn stover) and short-rotation woody crops	Address issues with syngas cleanup and conditioning and mixed alcohol synthesis technology	Commercial-scale demonstration	Ethanol for use in gasoline engines or blending in gasoline
• Gasification of biomass to syngas • Catalytic conversion into hydrocarbon fuels • Refining into “clean diesel” and naphtha fractions	Wood, agricultural residue, switchgrasss	Address issues with syngas cleanup and conditioning and Fischer-Tropsch liquids synthesis technology	Demonstration scale	Fischer-Tropsch liquids (synthetic hydrocarbons) for use in diesel and jet engines
• Pyrolysis of biomass to bio-oil • Stabilization of bio-oil • Upgrading to gasoline/diesel fuels	Wood, agricultural residue, switchgrasss	Develop conversion and upgrading technologies	Research and demonstration	Renewable gasoline and diesel for use in gasoline, diesel, and jet engines Renewable fuel oil for heat and power

Potential Biomass Feedstocks for Thermochemical Conversion

Advances in thermochemical conversion technology will enable productive use of a wide spectrum of existing and emerging feedstocks:

Short rotation woody crops:

These biomass crops consist of fast-growing tree species, which are often harvested within 3 to 10 years of planting.

Herbaceous crops:

These crops typically include perennial grasses (such as switchgrass, which is native to many regions across North America).

Agricultural residues:

Waste products from agricultural activities (e.g., plant parts left in the field after harvest) and secondary residues, such as manure and food processing wastes, can be useful feedstocks.

Municipal urban residues:

Clean waste from residential, commercial, and industrial activities are included (e.g., grass clippings, unusable pallets, and municipal sorted waste).

Forestry residues:

This category includes logging residues from conventional harvest operations, forest management, and land clearing; secondary residues include mill wastes.

Oils:

This category includes bio-oils (for conversion to biodiesel or for hydro-treating into green diesel), vegetable oil (e.g., from soybeans), used fryer oil, and tallow (animal fats). Algae and jatropha also show promise as new oil feedstocks.

Photos:(left column-top to bottom) USDA/d1253-1, INL, NREL/04190
(right column-top to bottom) USDA/k11202-1, NREL/0081, Vorticom

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