Thirty years later: Reflections on the past and future of biomass utilization

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Outline

- Biofuel research at ORNL – Why the emphasis on biomass?
- What was happening 30 years ago?
- What are primary feedstock sources and why?
- What are likely future sources of biomass?
- Sustainability issues
  - Discussion
  - Resources for more information
What is Oak Ridge National Laboratory (ORNL)?
U.S. Department of Energy’s Largest Science and Energy Research Center:

- $1.65B budget
- 4,400 employees
- 3,000 research guests annually
- $500M modernization investment
- Nation’s largest materials research portfolio
- Most powerful open scientific computing facility
- World’s most intense neutron source
- World-class research reactor
- Nation’s most diverse energy portfolio
- Managing billion-dollar U.S. ITER project
Deliver scientific discoveries that accelerate the development and deployment of solutions in clean energy and global security, and in doing so, create economic opportunities.
Bioenergy research at ORNL: basic sciences to applications

- **Center for BioEnergy Sustainability**
  - Environmental Socio-economic indicators
  - Integrated land management
  - Management best practices

- **Conversion**
  - Biochemical & thermochemical conversion
  - Catalytic upgrading
  - Materials of construction

- **Carbon Fiber Technology Facility**
  - Materials S&E

- **National Transportation Research Center**
  - Engine evaluation
  - Fuel effects

- **Feedstock Supply Analysis**
  - Terrestrial & algal feedstocks
  - Advanced logistics
  - Supply & price projections

- **Bioproducts**
  - Biopower
  - Biofuels

- **Molecular biology, chemical and structural analysis and characterization, modeling and simulation**

- **Feedstock development**
  - Biomass deconstruction

- **Lighter weight vehicles**

- **Transportation biofuels**

US DOE EERE Bioenergy Technologies Office
ORNL supports Bioenergy Technologies Office (BETO) objectives in several platforms

- **Strategic Analysis & Environmental Sustainability**
  - Defining bioenergy sustainability
  - Improved management practices
  - Address selected global barriers (ILUC)

- **Feedstock Supply & Logistics**
  - Feedstock supply projections
  - Biomass engineering (logistics)

- **Biomass Conversion (Biochemical & Thermochemical)**
  - Catalytic upgrading of ethanol to HC
  - Novel catalyst for bio-oil upgrading
  - Materials compatibility of bio-oils
  - Advanced membranes for separation

- **Demonstration & Market Transformation**
  - High octane renewable super premium fuel
ORNL develops membranes to speed the biomass conversion process

Tunable membranes win R&D 100 Award

- Separations are a common need in both biochemical & thermochemical conversion
  - Oil – water separations
  - Ethanol – water
  - Liquid – vapor phase
- ORNL researchers invented a new class of membranes that can selectively separate molecules in the vapor and liquid phases.
- HiPAS (High Performance Architectured Surface Selective) membranes can be engineered as superhydrophobic or superhydrophilic for use in various stages of the biomass-to-biofuel conversion process.
- These membranes offer an energy-efficient alternative to the distillation process for the biofuels industry.

The same HiPAS membrane can repel water while absorbing ethanol. The tunability of the membrane offers many opportunities for creating greater efficiency, increasing speed, and decreasing costs associated with the production of biofuels. This technology could also benefit the chemical, pharmaceutical, and gas separation industries.

Slide source: Tim Theiss, ORNL
Why biomass for energy?

• Fossil fuel consumption impacts
  – Air quality
  – Sustainable employment
  – Equity today and for future generations and
  – Climate change

• Bioenergy is just one part of equation because it
  – Is dispatchable for power, electricity, heat, mobility and other services
  – Can replace liquid and gaseous fossil fuels in existing systems
  – Stores chemical energy for future use and helps balance other more variable renewable resources
  – Incentives for better land management
Why biomass for energy: Total Global Emissions

Total global emissions: 39.4 ± 3.4 GtCO₂ in 2013, 42% over 1990
Percentage land-use change: 36% in 1960, 19% in 1990, 8% in 2013

Three different methods have been used to estimate land-use change emissions, indicated here by different shades of grey.

Source: CDIAC; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014
Why biomass for energy: Global Carbon Budget

Emissions are partitioned between the atmosphere, land, and ocean.

Future resources: US assessment

• Billion-Ton Study of 2005 helped support US renewable fuel volumes
• Billion Ton Update of 2011 included county-level cost & supply projections
• Conclusion: US has ample feedstock to replace up to 1/3 of petroleum with advanced biofuels
• Feedstock is roughly 1/3 cost of fuel: cost reductions and efficiency in feedstock supply are imperative
• Multi-institutional DOE & USDA analysis
  – 20-year projections of economic availability of biomass at county level at any year
  – price, location, scenario
• Primary Resources
  – Forest resources (residues)
  – Ag resources (corn stover)
  – Energy crops (switchgrass)

See: https://bioenergykdf.net/content/billiontonupdate
Example: US county-level Supply Projections
All feedstocks -- Baseline scenario -- $60 dry ton$^{-1}$

155 million DT/yr by 2017 is required to meet EISA targets (85 gal/ton conversion efficiency)

Credit to Matt Langholtz, Laurence Eaton and Billion Ton Update team.
Biomass for bioenergy: Outline

- Biofuel research at ORNL
- What was happening 30 years ago?
- What are primary feedstock sources and why?
- What are likely future sources of biomass?
- Sustainability issues

Photo: Ken Goddard, UT Extension
30 Years Ago…

• Time Cover (June 24, 1985): Hijacked: TWA Flight 847
• Movie release: Cocoon (Ron Howard)
• Top music hit: *Heaven* by Bryan Adams.
• About 75% of primary energy consumption was oil and gas
• *Energy Crisis on horizon: Natural Gas* US reserves were projected to be exhausted by 2025!
• CEQ Optimism (study, under Pres. Jimmy Carter):
  – The US could get 25% of its energy needs from solar sources by 2000
  – and as much as 50% by 2020
• *Based on growth trends, US primary energy demand in 2015 was projected to be 80-130 Quad Btu; it is actually about 100 Quad Btu.*
Total energy consumption grew from 76 to 95 Quad Btu (1985-2012)

Source: U.S. Energy Information Administration, AER Energy Perspectives and MER.
1985: First year US biofuel production was reported by US Energy Information Agency.

Table 10.1  Renewable Energy Production and Consumption by Source
(Trillion Btu)

<table>
<thead>
<tr>
<th>Production</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>Biomass</td>
</tr>
<tr>
<td>Bio-fuels</td>
<td>Total</td>
</tr>
<tr>
<td>1950 Total</td>
<td>NA 1,562</td>
</tr>
<tr>
<td>1955 Total</td>
<td>NA 1,424</td>
</tr>
<tr>
<td>1960 Total</td>
<td>NA 1,320</td>
</tr>
<tr>
<td>1965 Total</td>
<td>NA 1,335</td>
</tr>
<tr>
<td>1970 Total</td>
<td>NA 1,431</td>
</tr>
<tr>
<td>1975 Total</td>
<td>NA 1,499</td>
</tr>
<tr>
<td>1980 Total</td>
<td>NA 2,475</td>
</tr>
<tr>
<td>1985 Total</td>
<td>NA 93</td>
</tr>
<tr>
<td>1990 Total</td>
<td>NA 111</td>
</tr>
<tr>
<td>1995 Total</td>
<td>NA 198</td>
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<tr>
<td>2000 Total</td>
<td>NA 233</td>
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<tr>
<td>2001 Total</td>
<td>NA 254</td>
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<td>2002 Total</td>
<td>NA 308</td>
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<td>2003 Total</td>
<td>NA 402</td>
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<td>2004 Total</td>
<td>NA 487</td>
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<tr>
<td>2005 Total</td>
<td>NA 564</td>
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<tr>
<td>2006 Total</td>
<td>NA 720</td>
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<tr>
<td>2007 Total</td>
<td>NA 978</td>
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<tr>
<td>2008 Total</td>
<td>NA 1,387</td>
</tr>
<tr>
<td>2009 Total</td>
<td>NA 1,584</td>
</tr>
<tr>
<td>2010 Total</td>
<td>NA 1,884</td>
</tr>
<tr>
<td>2011 Total</td>
<td>NA 2,044</td>
</tr>
</tbody>
</table>

2012 total:........... 1942  4419
2013 total:........... 2000  4614
Reflections

• Why has so much of the “biofuel debate” over past decades focused on
  – Feedstock choice?
  – Land use and food security issues?
  – LCA and GHG emissions?

• What should change over next 30 years? or sooner (5-10 years)?
Biomass for bioenergy: Outline

- Biofuel research at ORNL
- What was happening 30 years ago?
- What are primary feedstock sources and why?
- What are likely future sources of biomass?
- Sustainability issues
Identifying and addressing the challenges for sustainable bioenergy production through field trials, applied research, capacity building, modeling, and analysis.

- **Feedstock production and logistics**
  - Assess and reduce impact on land, water, climate, air quality, biodiversity, and resource use
  - Increase landscape productivity

- **Conversion**
  - Minimize water consumption, GHG footprint, air pollution, and waste
  - Maximize efficiency

- **End use**
  - Evaluate air quality impacts
  - Avoid negative impacts on human health

- **Cross-cutting**
  - Life-cycle analysis of water consumption and GHG emissions
  - Supply chain environmental, economic, and social factors
Future sources depend on costs – Residues play major role for least cost supplies (2012 projection for 2022)

Source: Langholtz et al. 2014 (BioFPR)

See: https://bioenergykdf.net/content/billiontonupdate
Categories for environmental and socioeconomic sustainability

- Greenhouse gas emissions
- Soil quality
- Water quality and quantity
- Air quality
- Productivity
- Biological diversity

Social well being
- Social acceptability
- Resource conservation
- Profitability
- External trade
- Energy security
- Profitability

McBride et al. (2011) *Ecological Indicators* 11:1277-1289


Recognize that measures and interpretations are context specific
Looking at the biofuel supply chain in terms of sustainability indicators

Which biomass crops are preferable?

Preferred biomass production systems –
- Promote improved land management
- Provide other services to society
- Increase efficiency and help minimize or eliminate:
  - fossil fuels
  - “wastes”
- Reduce “climate forcing” (different from GHG emissions – and worthy of a separate talk)
- Can compete in the local market
- Support adaptive management
- Promote continual improvement toward “sustainability”
- EFFICIENTLY PROVIDE INPUTS REQUIRED BY INDUSTRY – that meet defined specifications

What biomass sources are recommended?
- Those that most effectively achieve society goals
U.S. Department of Energy (DOE) Approach to Assessing Bioenergy Sustainability

Select Indicators

Establish baselines and targets

Develop and test best practices

Identify trends and tradeoffs

Evaluate indicator values
Obstacles to developing and deploying more sustainable landscape designs

- Landowner rights
- Traditional practices
- Up front planning required
- Coordination and outreach, stakeholder engagement
- Complexity/level of effort
- Higher initial costs
- Lack of consensus on objectives, priorities

What are current sources of biomass?

Global consumption: traditional, heat


- Fossil fuels: 78.4%
- All Renewables: 19%
- Modern Renewables: 10%
  - Traditional Biomass: 9%
- Hydropower: 3.8%
  - Biomass/geothermal/solar heat: 4.2%
  - Wind/solar/biomass/geothermal power: 1.2%
  - Biofuels: 0.8%
- Nuclear power: 2.6%

A: While traditional biomass represents about 9% of primary global energy use, less than 1% currently comes from liquid biofuels
Current biomass sources: biofuels

Ethanol, Biodiesel, and HVO Global Production, 2000–2013

World Total
116.5 Billion Litres

- Hydrotreated Vegetable Oil (HVO)
- Biodiesel
- Ethanol

Mostly Brazil and USA

Current biomass sources: Large losses = opportunities for future improvement

Biomass Resources and Energy Pathways

- Purpose-grown crops
- Forest
- Agriculture and forest residues
- Food and fibre processing residues
- Municipal wastes*
- Fuel wood, crop residues, dung from harvesting and scavenging

Global annual primary biomass demand: 55.6 EJ

Modern bioenergy
- Heat (sold or used on-site)
- Biofuels
- Electricity

Traditional biomass
- Heat for cooking and heating

* Organic solid and liquid wastes

What are future sources of biomass for bioenergy?
Q: What are future sources of biomass for bioenergy?

A: more of the same?
Why do global biomass potential estimates vary so much?

• “Technical Potential”
  750-1500 EJ per year \( (\text{Smeets et al. 2007}) \)

• “Sustainable potential”
  300-500 EJ per year
  - Dornburg et al. 2010

• “Conservative potential”
  – “impossible that bioenergy could physically provide more than 250 EJ /yr in 2050”
  - Haberl et al. 2013 (Environ. Res. Lett. 8)

**Assumptions** about land available without impacting food security are key to estimates.
Many options exist that can contribute to enhanced food AND energy security.
Future biomass for bioenergy sources must address real and perceived obstacles

- Economics and markets
- Food security and land concerns
- Land management effects on biodiversity, carbon cycle/stocks, water
- Distribution of benefits and costs
- Need for integrated policy across agriculture, forestry, waste management, urban planning, environment, energy...
- Sector- and nation-specific challenges: e.g., policies, “blend wall,” distribution infrastructure

Source: Kline presentation to “Pathways to Climate Solutions: Assessing Energy Technology and Policy Innovation” Workshop organized by the Aspen Global Change Institute; 24-28 February, 2014. Aspen CO.
IPCC Special Report Renewable Energy
To achieve climate mitigation scenarios – BIOENERGY has important role relative to other potential renewable energy sources.

So we should figure out how to do it right!
(more sustainably)

-IPCC 2012 Special Report on Renewables and Climate Change Mitigation
SCOPE (2015): There is no shortage of biomass
Different places, contexts, needs and goals require unique solutions.

We need to
• Learn from experiences
• Build partnerships
• Develop and apply a suite of metrics that reflect local stakeholder priorities for “sustainability”
Recommended practices

• Consider management goals and options within the broader context

• Attention to site selection and effects in the
  – location and specification of feedstock
  – handling and transfer of feedstock
  – refinery processing
  – Distribution and use of bioenergy

• Monitoring and public reporting of key measures of sustainability

• Attention to what is “doable”

• Stakeholder engagement throughout process

Biomass for bioenergy – Outline

- ORNL and DOE programs
- Feedstock supply analysis
- Sustainability
- Landscape design
- Discussion

“You can’t know where you’re headed if you don’t know where you’ve been”

And it helps to understand where you are right now.

“Prediction is very difficult, especially about the future”

-Niels Bohr, Danish physicist.
Negative impacts of bioenergy can be avoided or reduced by attention to three principles:

1. Identify and conserve priority ecosystem and social services
2. Consider local context, trends, and stakeholders
3. Monitor effects of concern and adjust plans to improve performance over time

Sustainability reflects current needs, issues and stakeholder VALUES.
Framework for Selecting Indicators

1. Define goals
2. Define context
3. Identify & consult stakeholders

4. Identify & assess necessary tradeoffs
5. Determine objectives for analysis

6. Determine selection criteria for indicators
7. Identify & rank indicators that meet criteria

8. Identify gaps in ability to address goals & objectives
9. Determine whether objectives are achieved

No

Yes

10. Assess lessons learned & identify good practices

Information as determined by:
- Available data
- Resources needed to collect & assemble required data

Thank you

Center for Bioenergy Sustainability
http://www.ornl.gov/sci/ees/cbes/

See CBES website for
• Reports
• Forums on current topics
• Recent publications

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The views in this presentation are those of the author/presenter who is responsible for any errors or omissions.
Further reading on bioenergy and sustainability:


- USDoe State of Technology updates: http://www1.eere.energy.gov/bioenergy/key_publications.html


- IPCC 2012 Special Report on Renewables and Climate Change Mitigation.


Bibliography and references (continued)


• Economic Research Service, Amber Waves, 10(2 (June)), 2012.


References Used in the Global Carbon Project Analysis


### Categories of environmental sustainability indicators

<table>
<thead>
<tr>
<th>Environment</th>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil quality</td>
<td>1. Total organic carbon (TOC)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>2. Total nitrogen (N)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>3. Extractable phosphorus (P)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>4. Bulk density</td>
<td>g/cm³</td>
</tr>
<tr>
<td>Water quality and quantity</td>
<td>5. Nitrate concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>6. Total phosphorus (P) concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>7. Suspended sediment concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>8. Herbicide concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>9. storm flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>10. Minimum base flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>11. Consumptive water use (incorporates base flow)</td>
<td>feedstock production: m³/ha/day; biorefinery: m³/day</td>
</tr>
<tr>
<td>Greenhouse gases</td>
<td>12. CO₂ equivalent emissions (CO₂ and N₂O)</td>
<td>kgC&lt;sub&gt;eq&lt;/sub&gt;/GJ</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>13. Presence of taxa of special concern</td>
<td>Presence</td>
</tr>
<tr>
<td></td>
<td>14. Habitat area of taxa of special concern</td>
<td>ha</td>
</tr>
<tr>
<td>Air quality</td>
<td>15. Tropospheric ozone</td>
<td>ppb</td>
</tr>
<tr>
<td></td>
<td>16. Carbon monoxide</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>17. Total particulate matter less than 2.5μm diameter (PM&lt;sub&gt;2.5&lt;/sub&gt;)</td>
<td>µg/m³</td>
</tr>
<tr>
<td></td>
<td>18. Total particulate matter less than 10μm diameter (PM&lt;sub&gt;10&lt;/sub&gt;)</td>
<td>µg/m³</td>
</tr>
<tr>
<td>Productivity</td>
<td>19. Aboveground net primary productivity (ANPP) / Yield</td>
<td>gC/m²/year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social well-being</td>
<td>Employment</td>
<td>Number of full time equivalent (FTE) jobs</td>
</tr>
<tr>
<td></td>
<td>Household income</td>
<td>Dollars per day</td>
</tr>
<tr>
<td></td>
<td>Work days lost due to injury</td>
<td>Average number of work days lost per worker per year</td>
</tr>
<tr>
<td></td>
<td>Food security</td>
<td>Percent change in food price volatility</td>
</tr>
<tr>
<td>Energy security</td>
<td>Energy security premium</td>
<td>Dollars /gallon biofuel</td>
</tr>
<tr>
<td></td>
<td>Fuel price volatility</td>
<td>Standard deviation of monthly percentage price changes over one year</td>
</tr>
<tr>
<td>External trade</td>
<td>Terms of trade</td>
<td>Ratio (price of exports/price of imports)</td>
</tr>
<tr>
<td></td>
<td>Trade volume</td>
<td>Dollars (net exports or balance of payments)</td>
</tr>
<tr>
<td>Profitability</td>
<td>Return on investment (ROI)</td>
<td>Percent (net investment/initial investment)</td>
</tr>
<tr>
<td></td>
<td>Net present value (NPV)²</td>
<td>Dollars (present value of benefits minus present value of costs)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Resource conservation</td>
<td>Depletion of non-renewable energy resources</td>
<td>MT (amount of petroleum extracted per year)</td>
</tr>
<tr>
<td></td>
<td>Fossil Energy Return on Investment (fossil EROI)</td>
<td>MJ (ratio of amount of fossil energy inputs to amount of useful energy outputt)</td>
</tr>
<tr>
<td>Social acceptability</td>
<td>Public opinion</td>
<td>Percent favorable opinion</td>
</tr>
<tr>
<td></td>
<td>Transparency</td>
<td>Percent of indicators for which timely and relevant performance data are reported</td>
</tr>
<tr>
<td></td>
<td>Effective stakeholder participation</td>
<td>Number of documented responses to stakeholder concerns and suggestions reported on an annual basis</td>
</tr>
<tr>
<td></td>
<td>Risk of catastrophe</td>
<td>Annual probability of catastrophic event</td>
</tr>
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</table>

Thank you!

http://www.ornl.gov/sci/ees/cbes/