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

For ASTM Committee E48
30th Anniversary Meeting

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U.S. DEPARTMENT OF ENERGY

Oak Ridge National Laboratory
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Outline

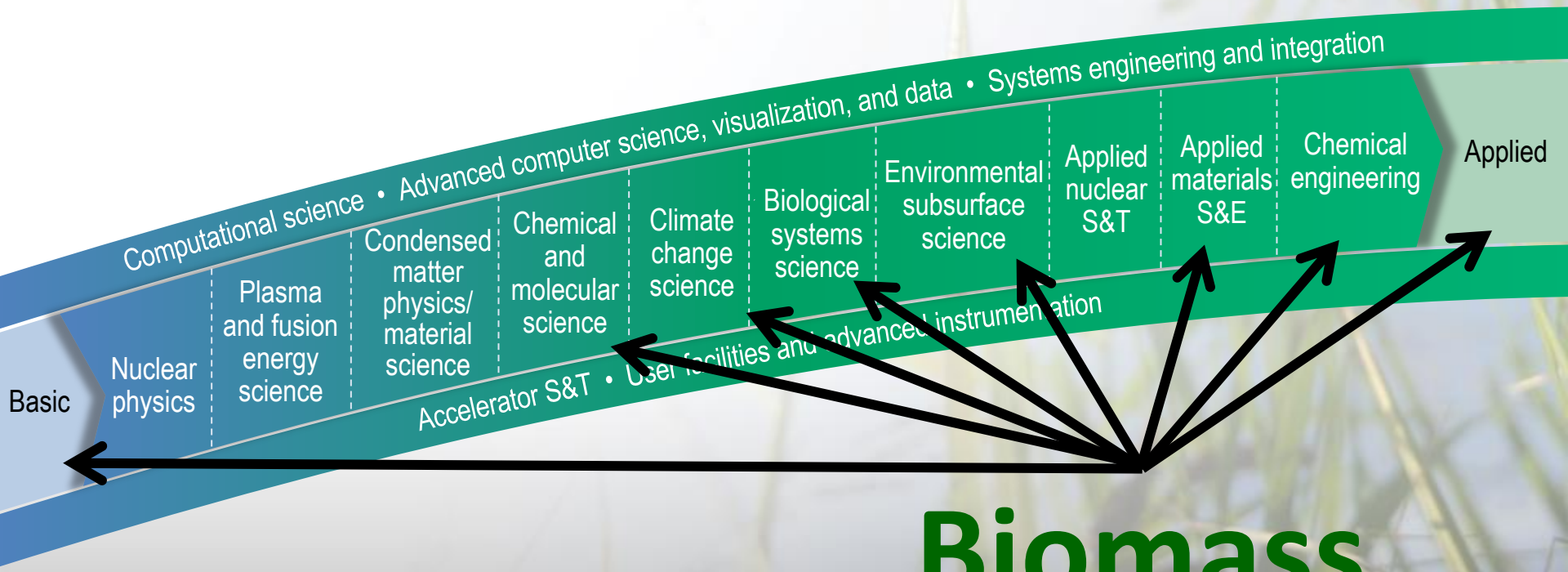
- Biofuel research at ORNL – Why the emphasis on biomass?
- What was happening 30 years ago?
- What are primary feedstock sources and why?
- What are likely future sources of biomass?
- Sustainability issues
  - Discussion
  - Resources for more information

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

ORNL's Mission

Deliver scientific discoveries that accelerate the development and deployment of solutions in clean energy and global security, and in doing so, create economic opportunities



Biomass

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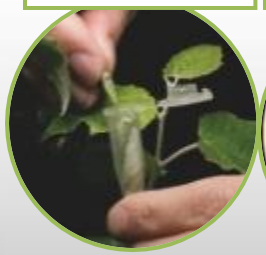
Bioenergy research at ORNL: basic sciences to applications

BESC
BioEnergy Science Center

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

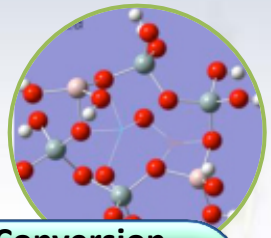
Feedstock development

Biomass deconstruction



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

Feedstock Supply Analysis
Terrestrial & algal feedstocks, Advanced logistics, Supply & price projections

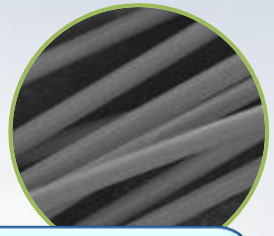


Conversion
Biochemical & thermochemical conversion, Catalytic upgrading, Materials of construction

Bioproducts

Biofuels

Biopower



Carbon Fiber Technology Facility
Materials S&E

Lighter weight vehicles

National Transportation Research Center
Engine evaluation
Fuel effects

Transportation biofuels

FLEX FUEL

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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

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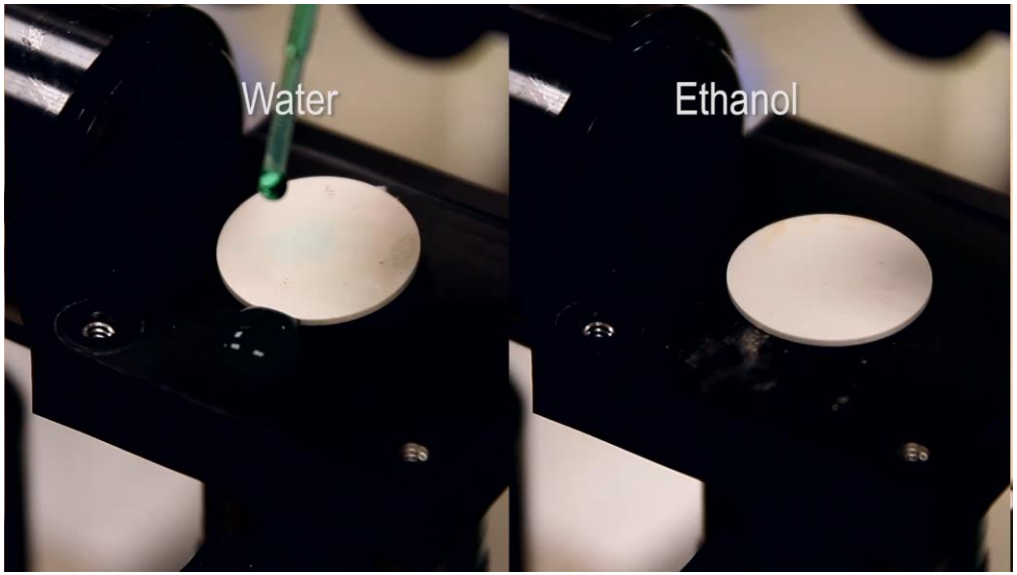
ORNL develops membranes to speed the biomass conversion process

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.

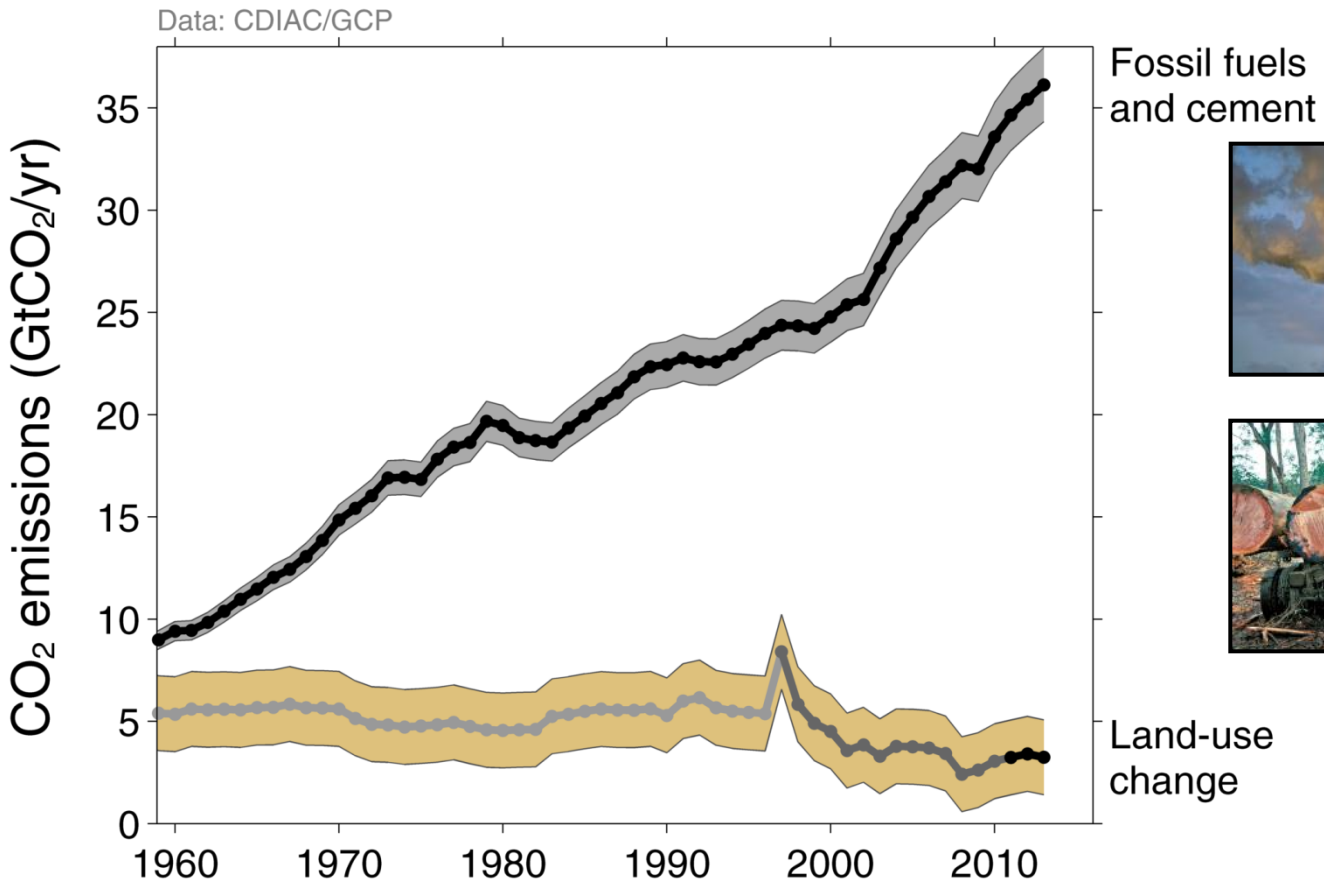
Slide source: Tim Theiss, ORNL

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 $GtCO_2$ in 2013, 42% over 1990
Percentage land-use change: 36% in 1960, 19% in 1990, 8% in 2013

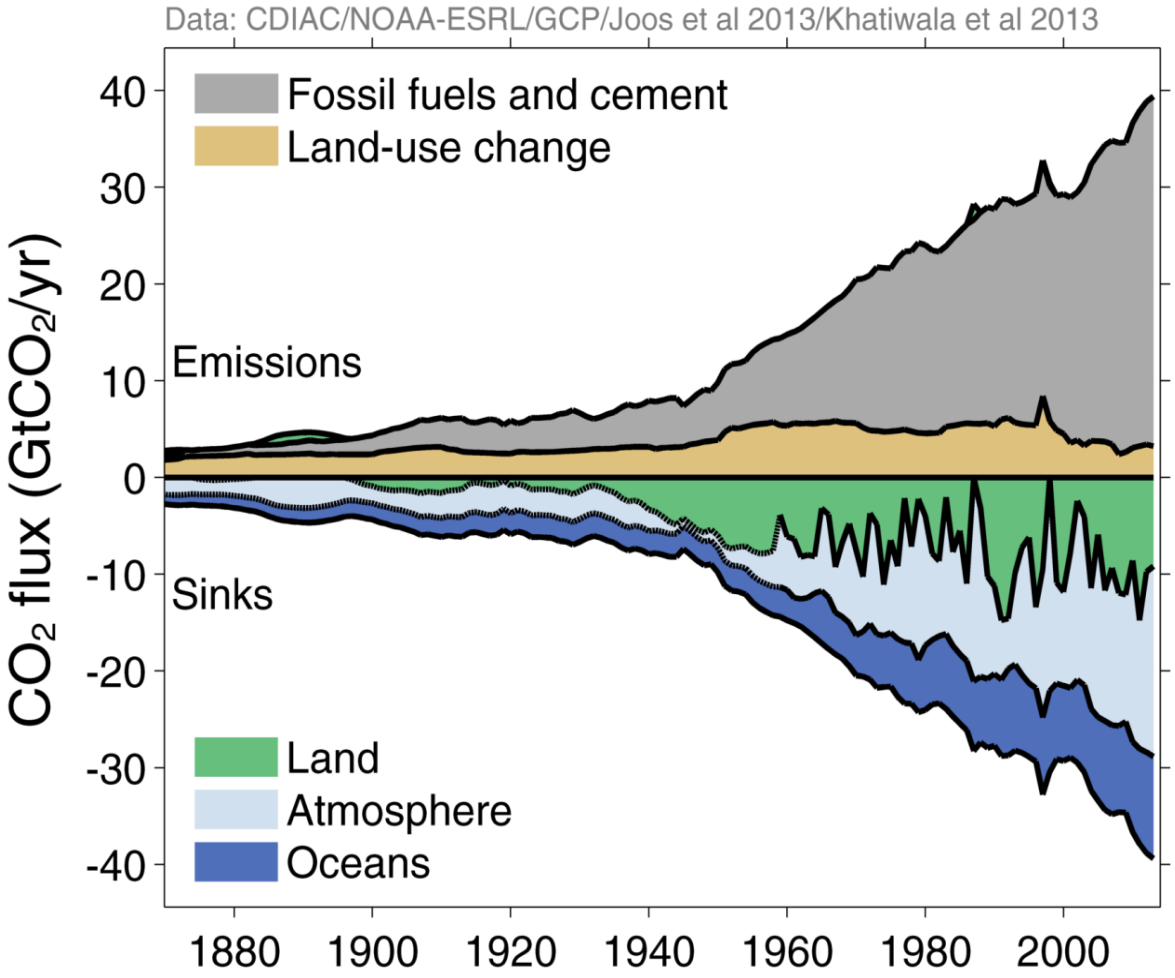


Three different methods have been used to estimate land-use change emissions, indicated here by different shades of grey

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



Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Joos et al 2013; Khatiwala et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014

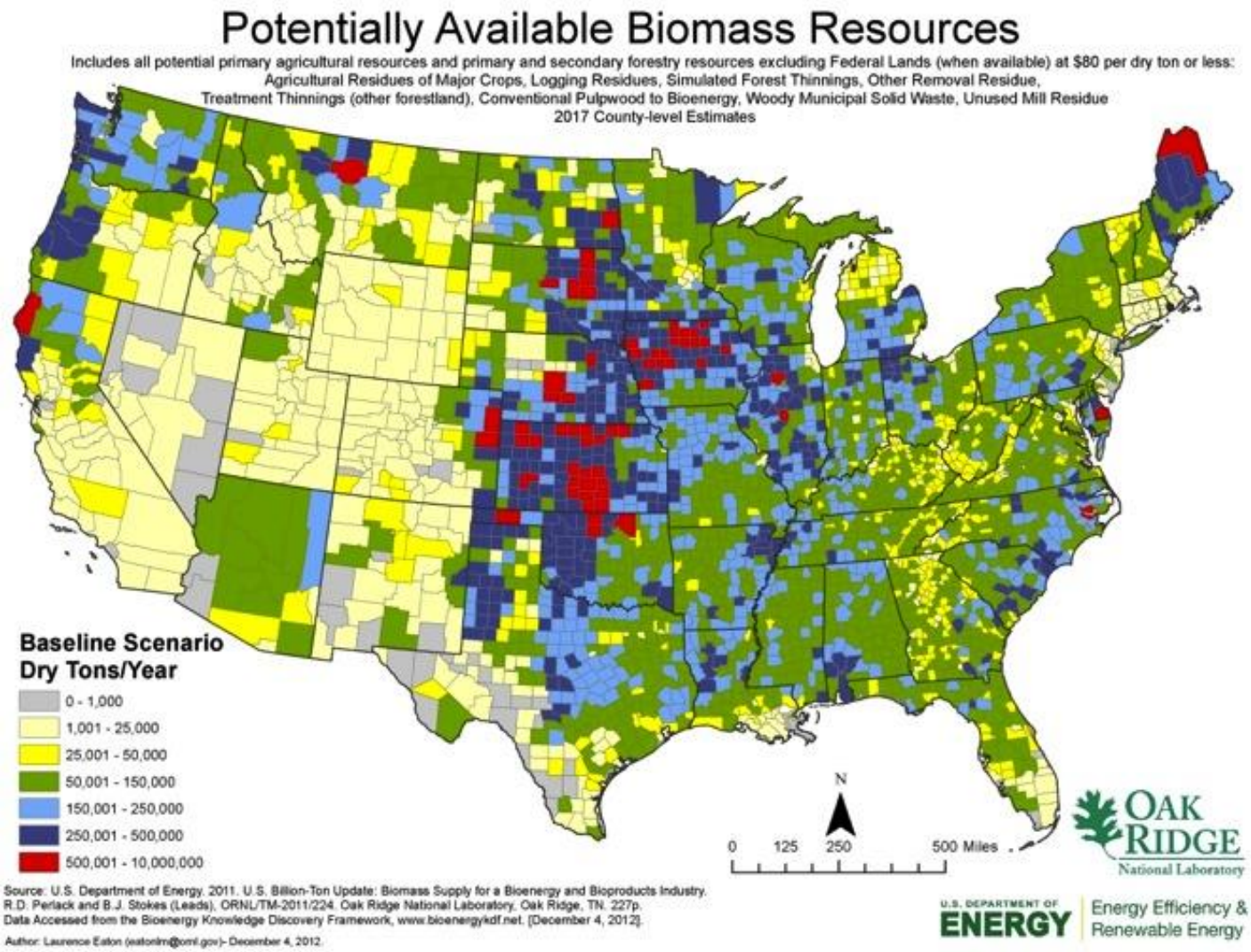
Future resources: US assessment

- 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)

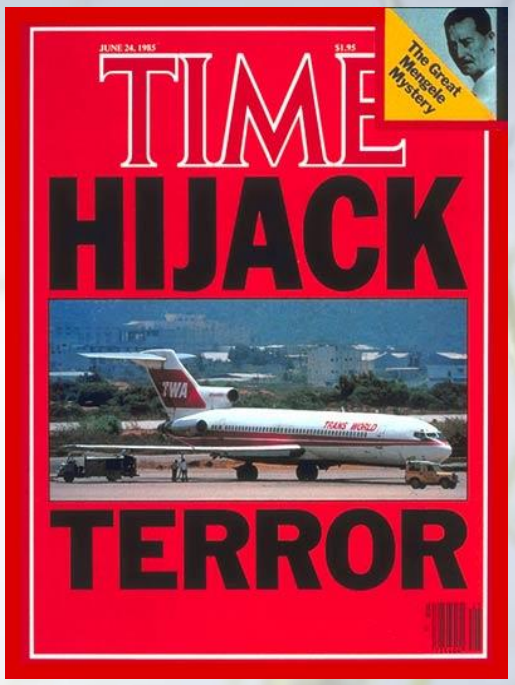
Credit to Matt Langholtz, Laurence Eaton and Billion Ton Update team.

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

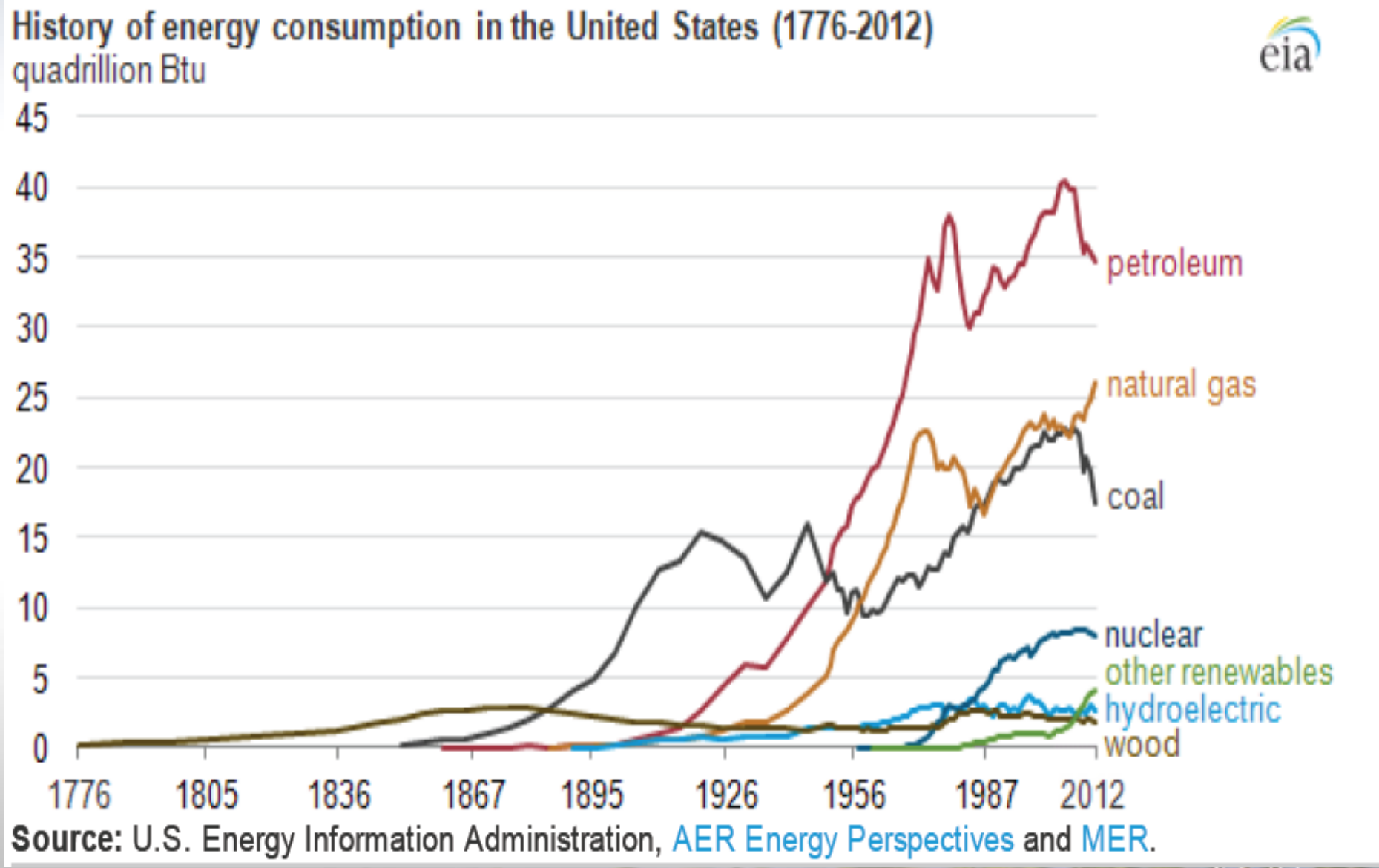
Photo: Ken Goddard, UT Extension

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)



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)

	Production[a]			Consumption								
	Biomass		Total Renewable Energy[d]	Hydroelectric Power[e]	Geothermal[f]	Solar/PV[g]	Wind[h]	Biomass				Total Renewable Energy
	Biofuels[b]	Total[c]						Wood[i]	Waste[j]	Biofuels[k]	Total	
1950 Total	NA	1,562	2,978	1,415	NA	NA	NA	1,562	NA	NA	1,562	2,978
1955 Total	NA	1,424	2,784	1,360	NA	NA	NA	1,424	NA	NA	1,424	2,784
1960 Total	NA	1,320	2,928	1,608	(s)	NA	NA	1,320	NA	NA	1,320	2,928
1965 Total	NA	1,335	3,396	2,059	2	NA	NA	1,335	NA	NA	1,335	3,396
1970 Total	NA	1,431	4,070	2,634	6	NA	NA	1,429	2	NA	1,431	4,070
1975 Total	NA	1,499	4,687	3,155	34	NA	NA	1,497	2	NA	1,499	4,687
1980 Total	NA	2,475	5,428	2,900	53	NA	NA	2,474	2	NA	2,475	5,428
1985 Total	93	3,016	6,084	2,970	97	(s)	(s)	2,687	236	93	3,016	6,084
1990 Total	111	2,735	6,041	3,046	171	59	29	2,216	408	111	2,735	6,041
1995 Total	198	3,099	6,558	3,205	152	69	33	2,370	531	200	3,101	6,560
2000 Total	233	3,006	6,104	2,811	164	66	57	2,262	511	236	3,008	6,106
2001 Total	254	2,624	5,164	2,242	164	64	70	2,006	364	253	2,622	5,163
2002 Total	308	2,705	5,734	2,689	171	63	105	1,995	402	303	2,701	5,729
2003 Total	402	2,805	5,947	2,793	173	62	113	2,002	401	404	2,807	5,948
2004 Total	487	2,998	6,069	2,688	178	63	142	2,121	389	499	3,010	6,081
2005 Total	564	3,104	6,229	2,703	181	63	178	2,137	403	577	3,117	6,242
2006 Total	720	3,216	6,599	2,869	181	68	264	2,099	397	771	3,267	6,649
2007 Total	978	3,480	6,528	2,446	186	76	341	2,089	413	990	3,492	6,541
2008 Total	1,387	3,881	7,219	2,511	192	89	546	2,059	435	1,370	3,865	7,202
2009 Total	1,584	3,967	7,655	2,669	200	98	721	1,931	452	1,568	3,950	7,638
2010 Total	1,884	4,332	8,128	2,539	208	126	923	1,981	468	1,837	4,285	8,081
2011 Total	2,044	4,516	9,170	3,103	212	171	1,168	2,010	462	1,948	4,420	9,074
2012 total:	1942	4419										
2013 total:	2000	4614										

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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)?

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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?
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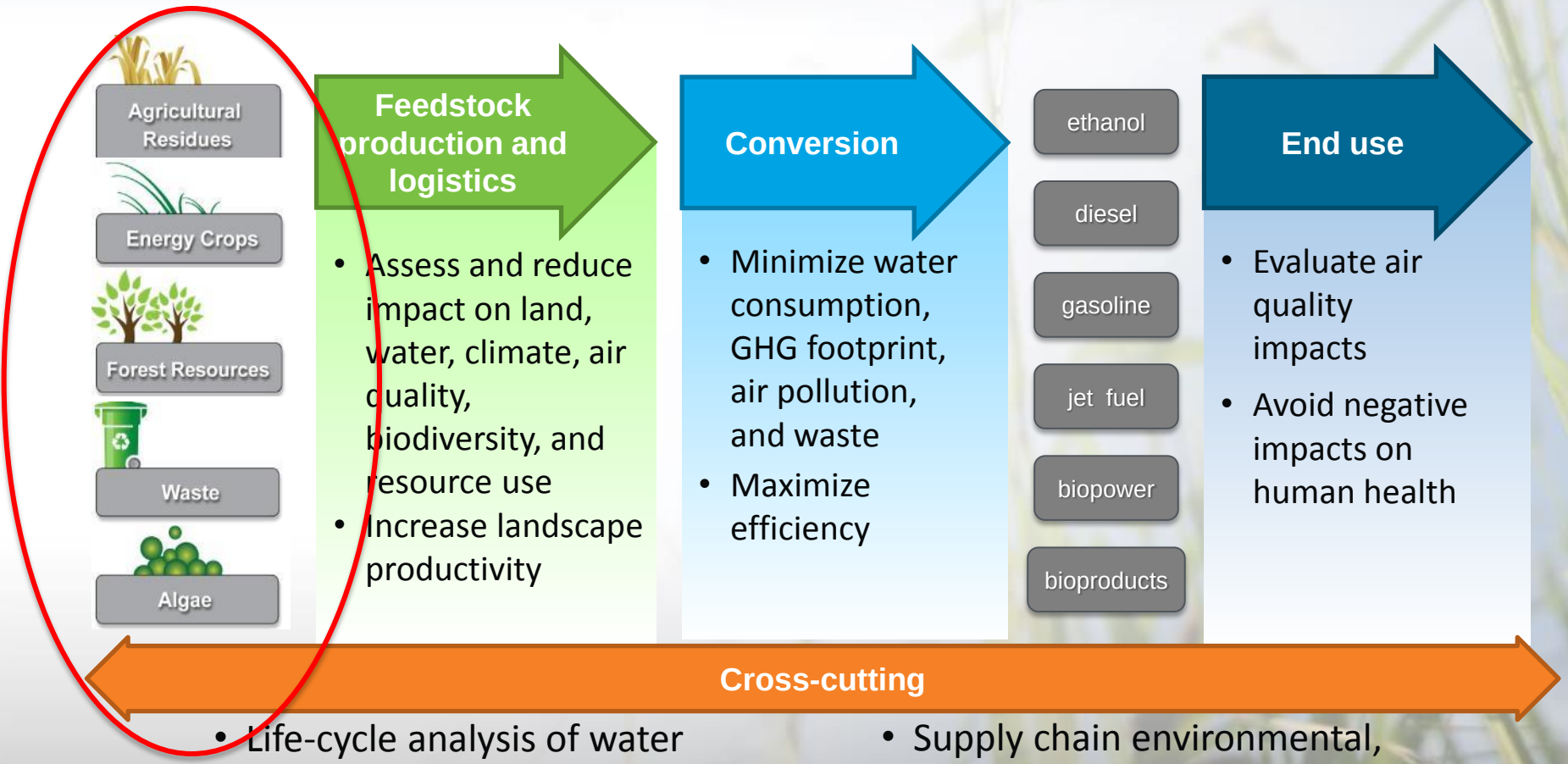
DOE Bioenergy Technology Office's Sustainability Activities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Identifying and addressing the challenges for sustainable bioenergy production through field trials, applied research, capacity building, modeling, and analysis.



- Life-cycle analysis of water consumption and GHG emissions
- Supply chain environmental, economic, and social factors

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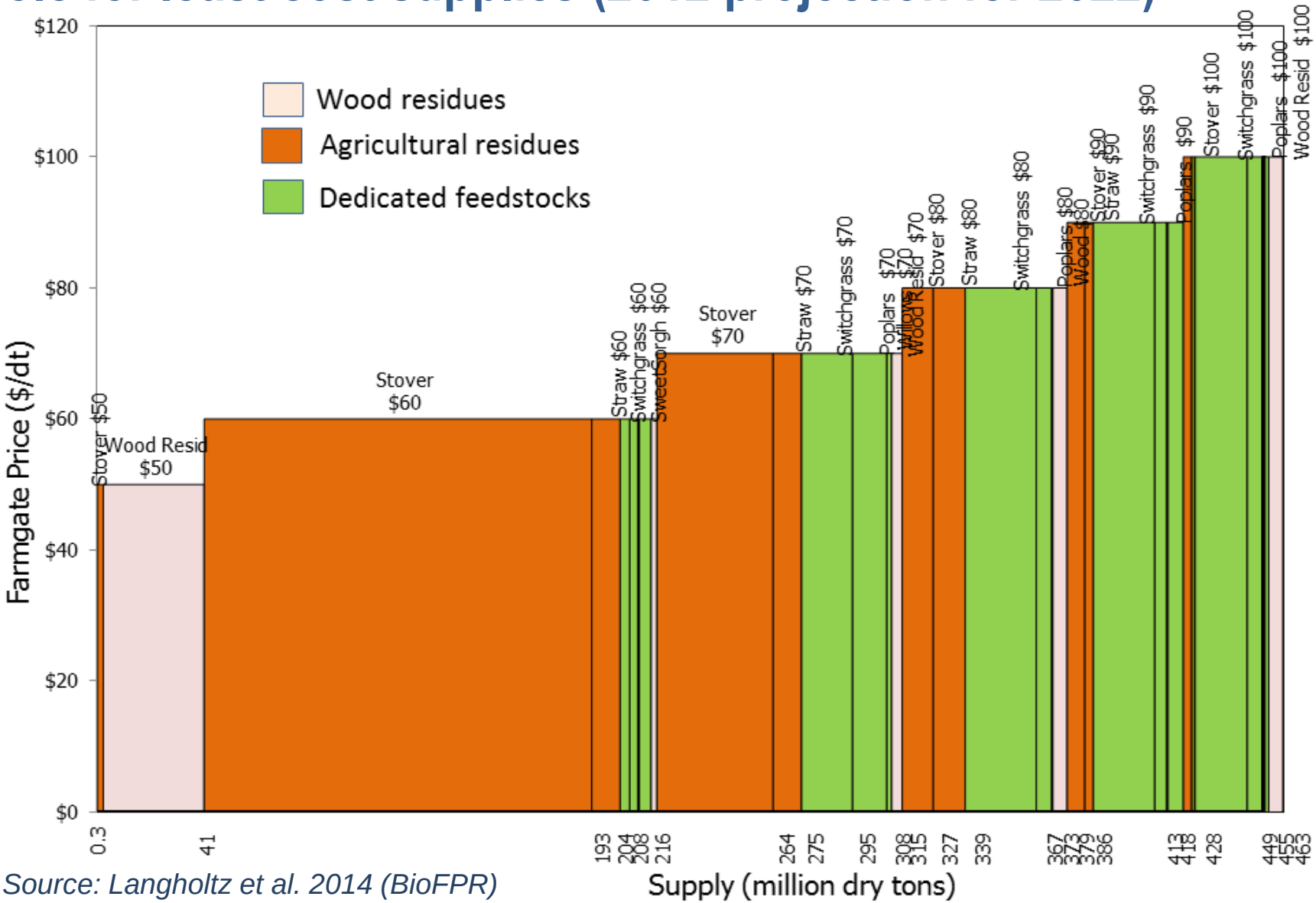
Future sources depend on costs – Residues play major role for least cost supplies (2012 projection for 2022)



Source: Langholtz et al. 2014 (BioFPR)

See: https://bioenergykdf.net/content/billiontonupdate

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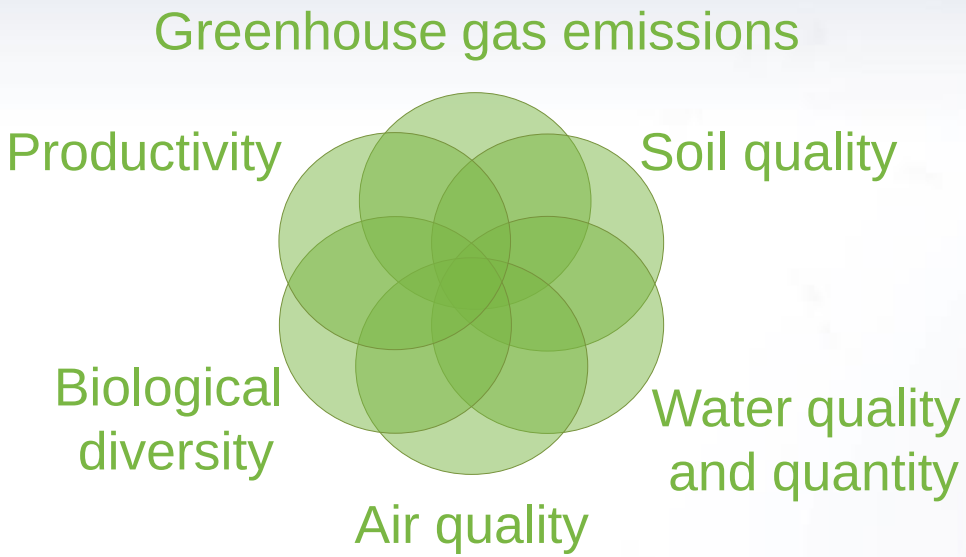
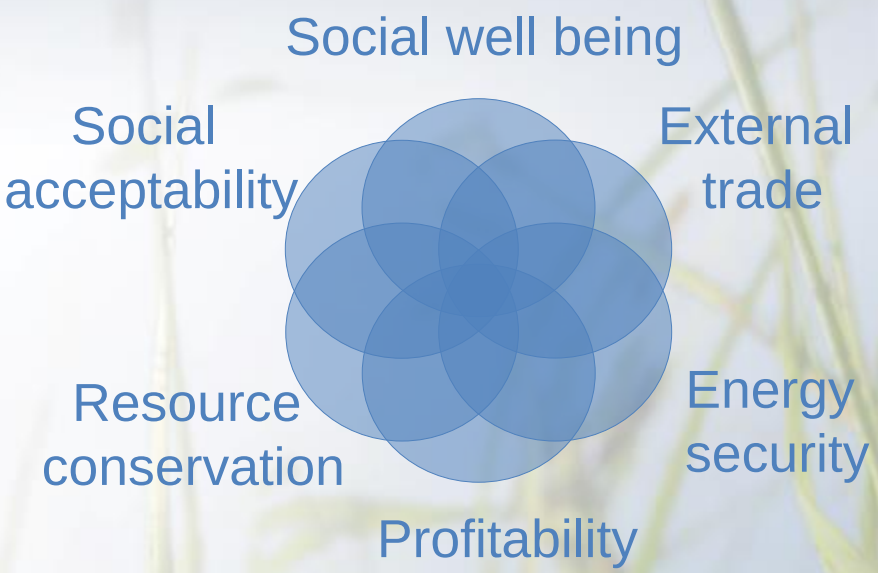
Categories for environmental and socioeconomic sustainability



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



Dale et al. (2013)
Ecological Indicators 26:87-102.

Recognize that measures and interpretations are <u>context</u> specific
Efroymson et al. (2013) *Environmental Management* 51:291-306.

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Looking at the biofuel supply chain in terms of sustainability indicators

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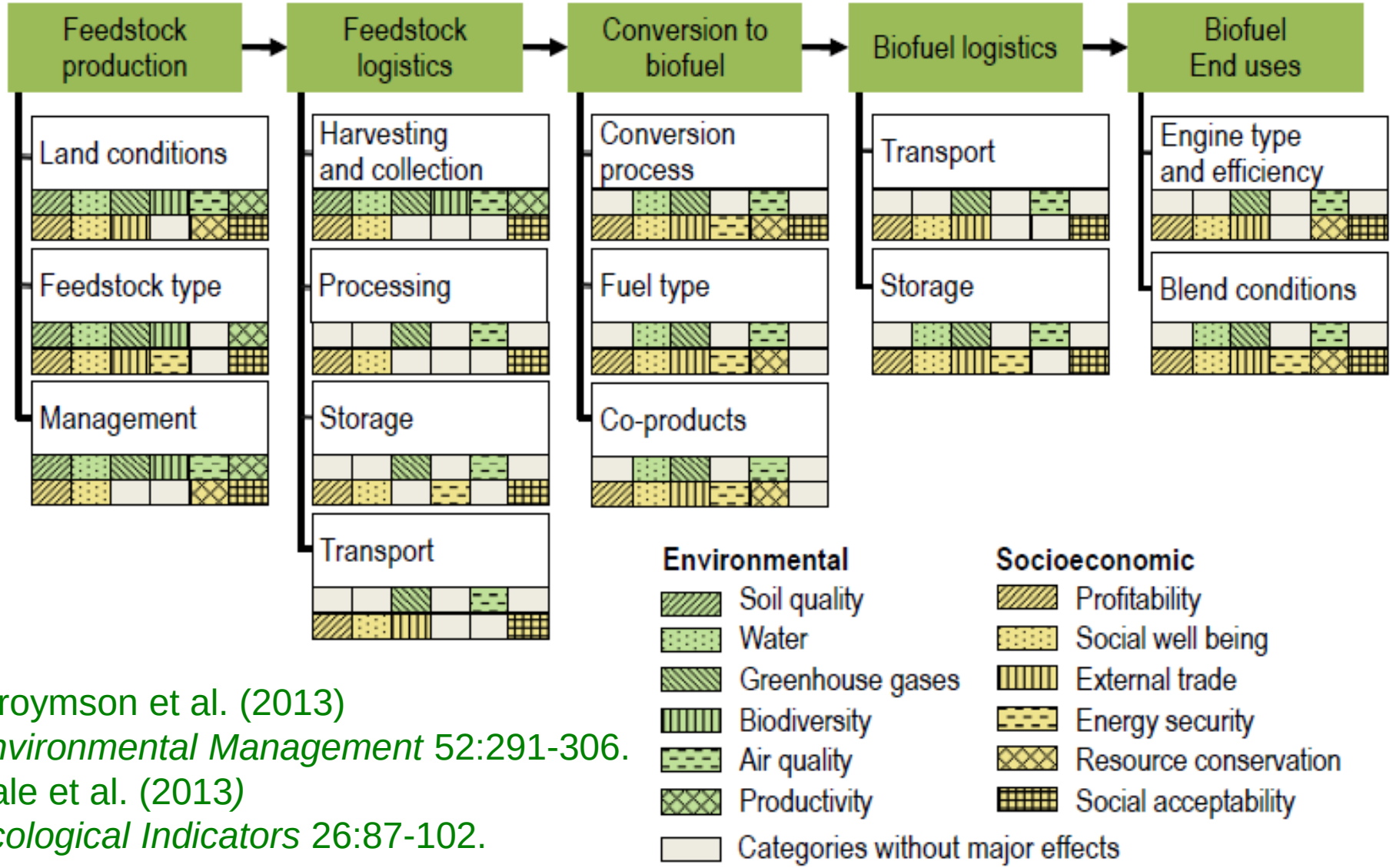

Efroymson et al. (2013)
Environmental Management 52:291-306.
Dale et al. (2013)
Ecological Indicators 26:87-102.

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

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U.S. Department of Energy (DOE) Approach to Assessing Bioenergy Sustainability

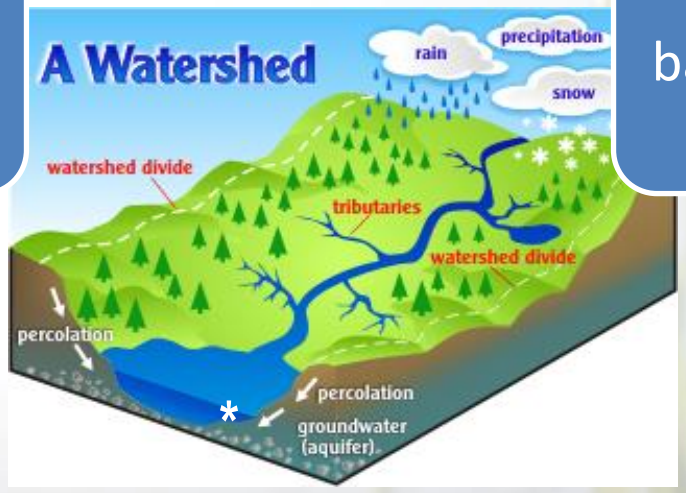
Select Indicators

Establish baselines and targets

Evaluate indicator values

Identify trends and tradeoffs

Develop and test best practices



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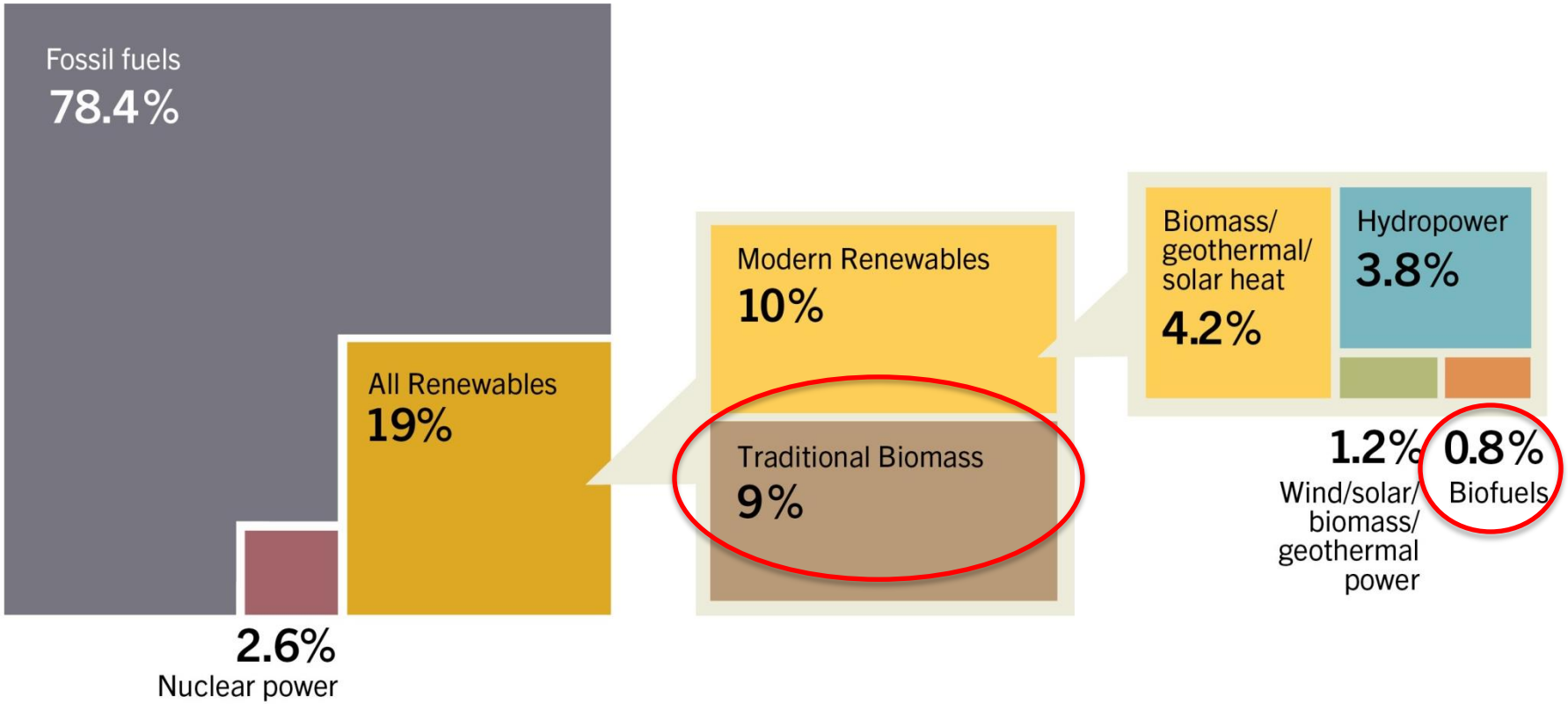
Obstacles to developing and deploying more sustainable landscape designs

- 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

[Building from Seuring and Muller (2008) Journal of Cleaner Production 16:1699-1710]

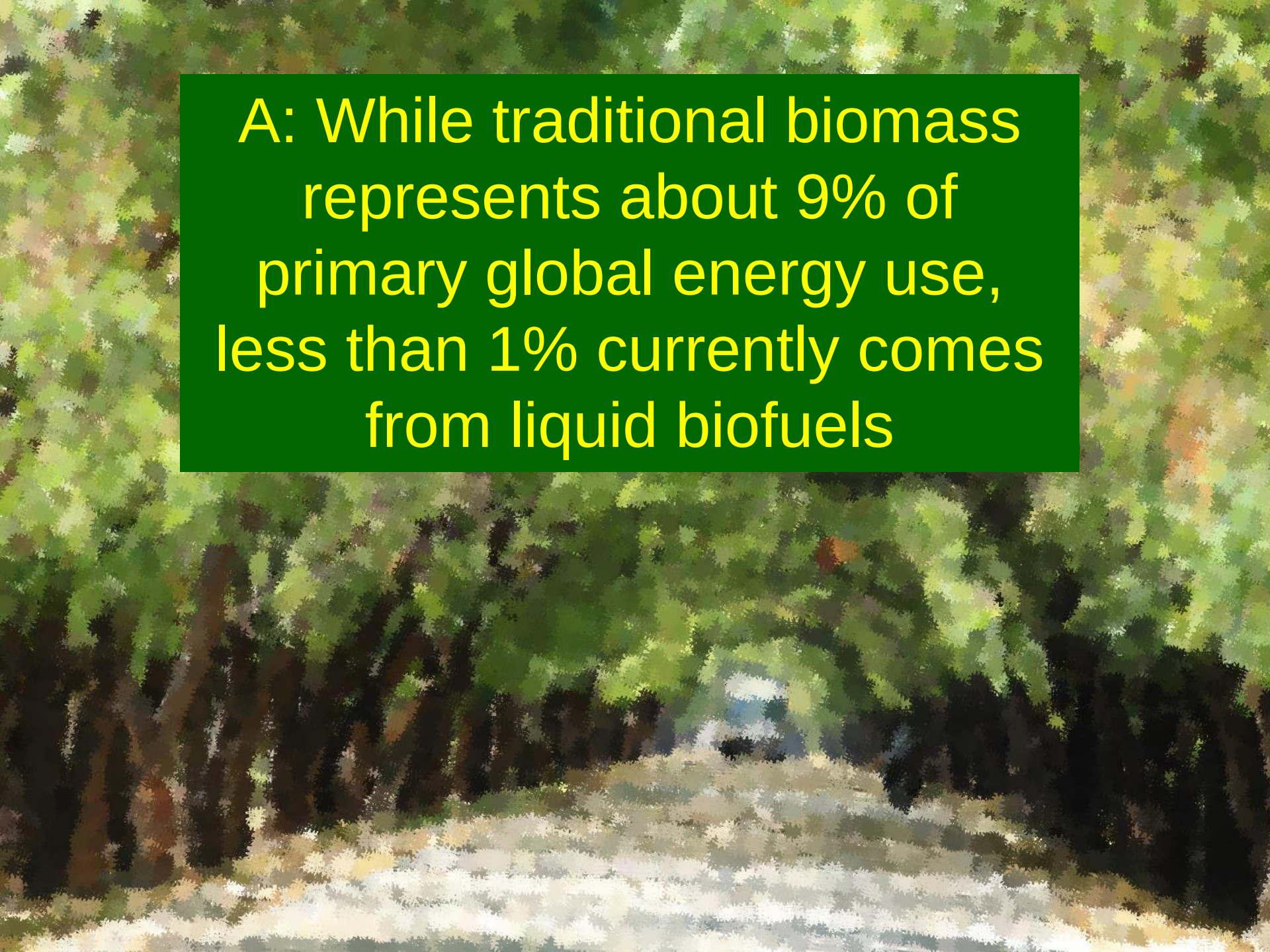
What are current sources of biomass? Global consumption: traditional, heat

Estimated Renewable Energy Share of Global Final Energy Consumption, 2012



REN21. 2014. *Renewables 2014 Global Status Report* (Paris: REN21 Secretariat).

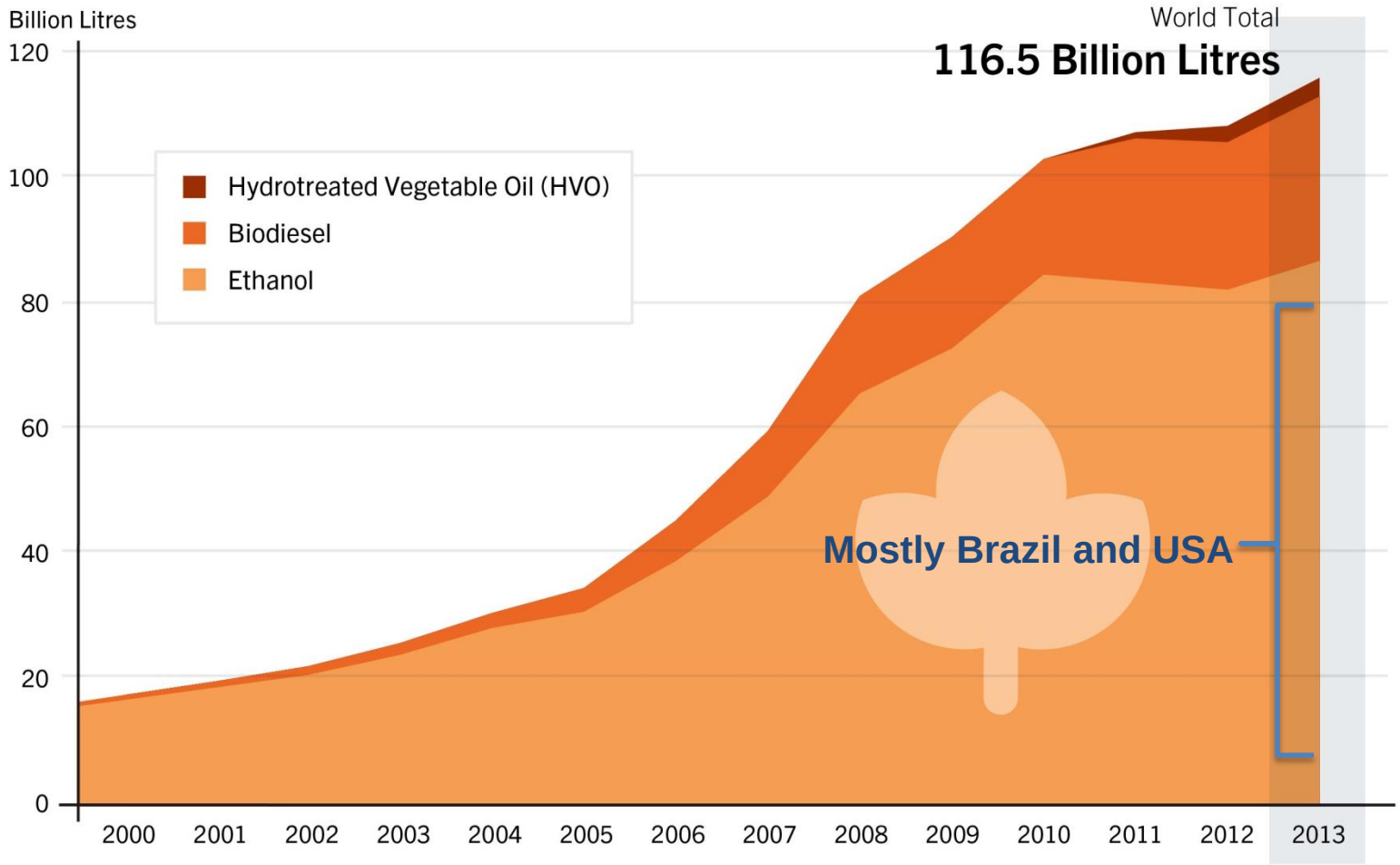
REN21 Renewable Energy Policy Network for the 21st Century



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

Current biomass sources: biofuels

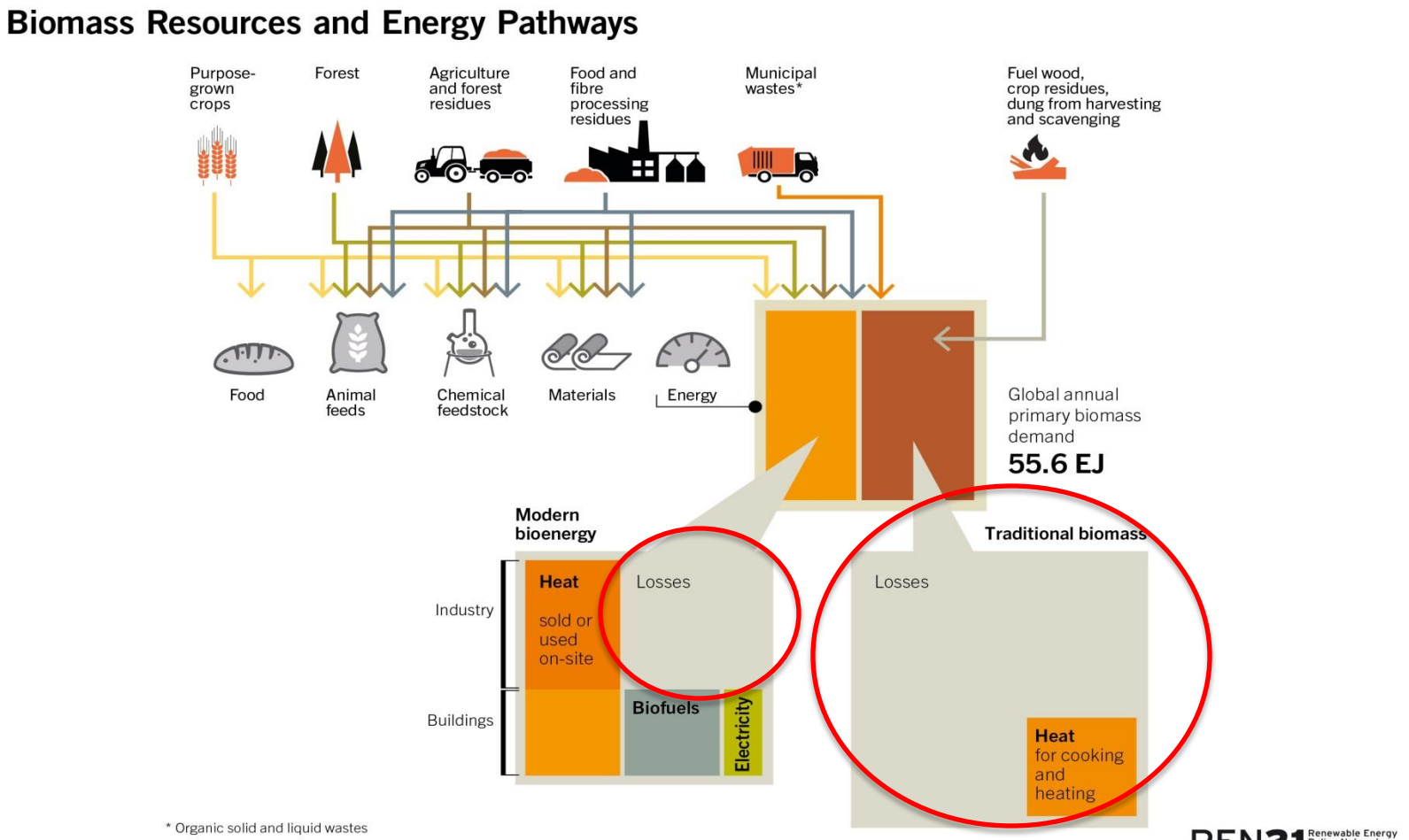
Ethanol, Biodiesel, and HVO Global Production, 2000–2013



REN21. 2014. *Renewables 2014 Global Status Report* (Paris: REN21 Secretariat).

REN21 Renewable Energy Policy Network for the 21st Century

Current biomass sources: Large losses = opportunities for future improvement



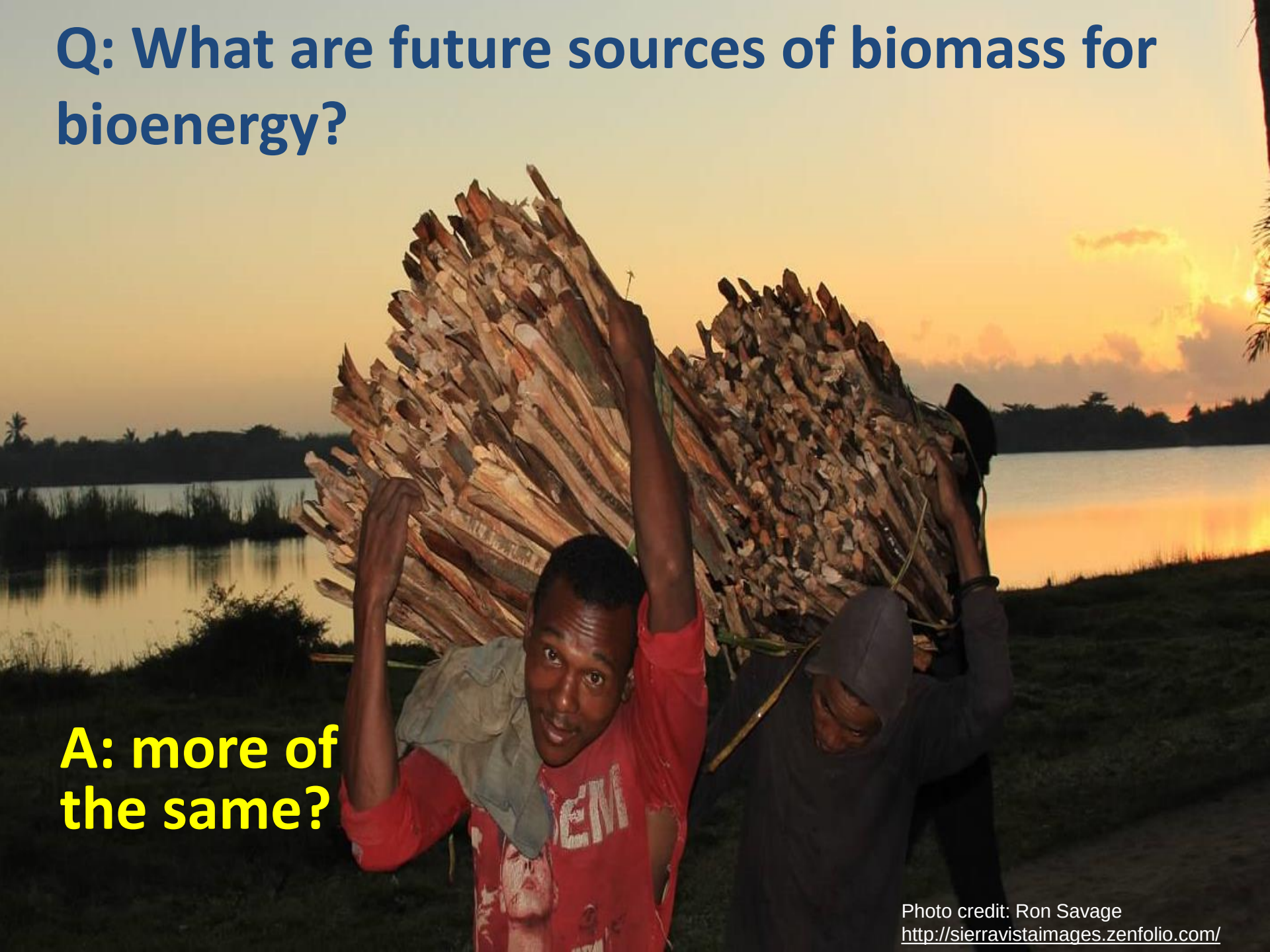
REN21. 2014. *Renewables 2014 Global Status Report* (Paris: REN21 Secretariat).

What are future sources of biomass for bioenergy?

Photo credit: Ron Savage http://sierravistaimages.zenfolio.com/

National Laboratory

Q: What are future sources of biomass for bioenergy?

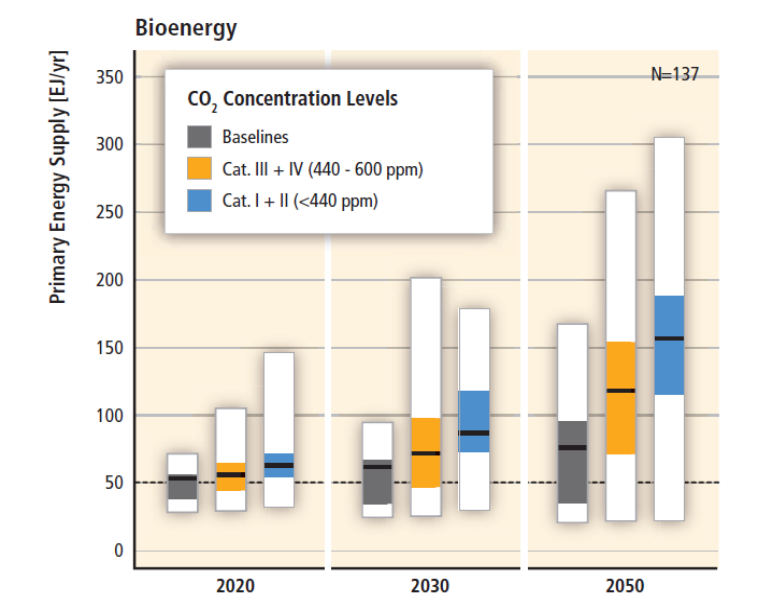


A: more of the same?

Photo credit: Ron Savage
http://sierravistaimages.zenfolio.com/

Why do global biomass potential estimates vary so much?

- "Technical Potential"
  750-1500 EJ per year(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)



IPCC 2012 Special Report on Renewables and CC Mitigation

Assumptions **about land available without impacting food security are key to estimates.**

Slide adapted from 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.

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Many options exist that can contribute to enhanced food AND energy security

Photo credit: Ron Savage
http://sierravistaimages.zenfolio.com/

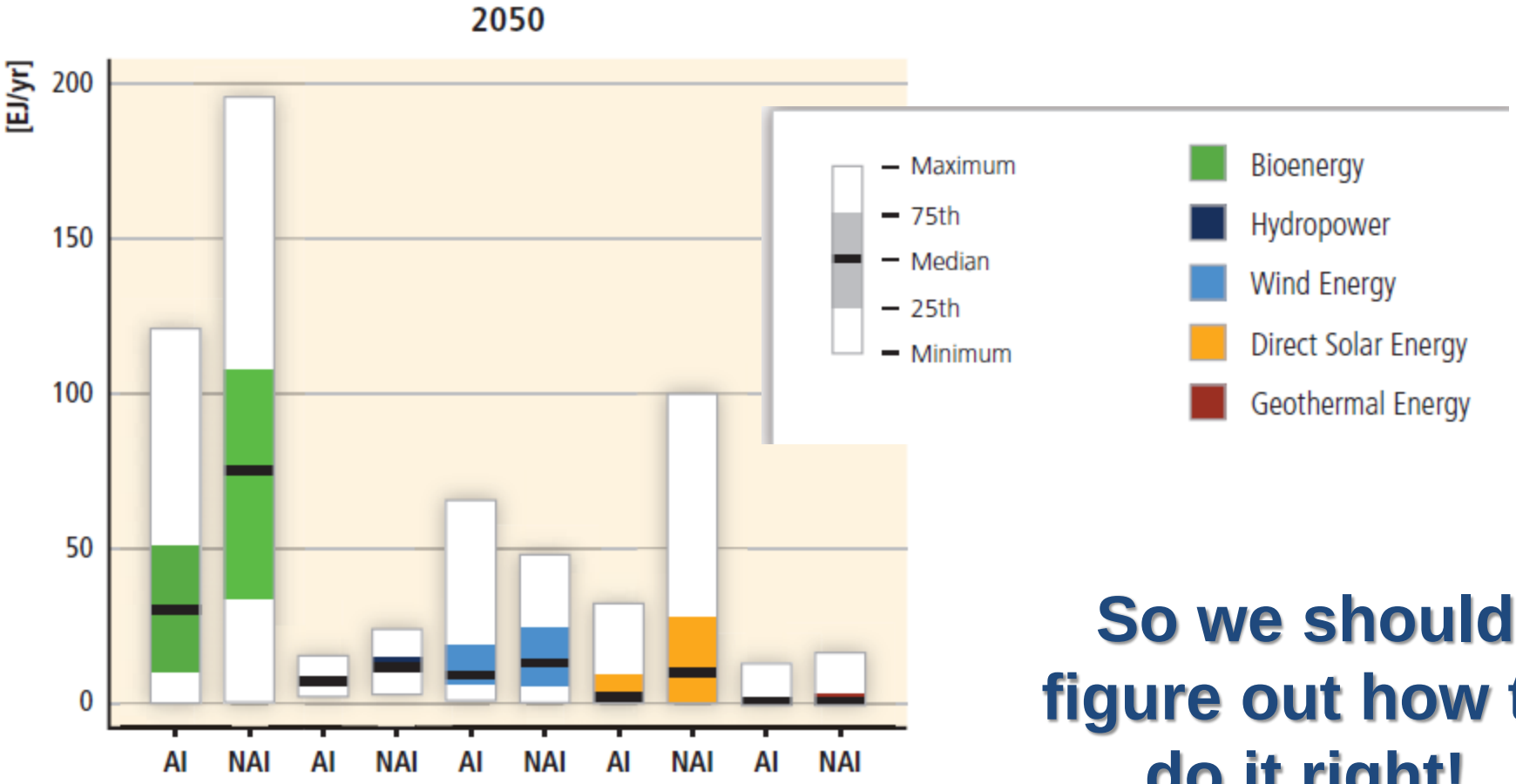
Future biomass for bioenergy sources must address real and perceived obstacles

- 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.



-IPCC 2012 Special Report on Renewables and Climate Change Mitigation

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

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

McBride et al. (2011) Ecological Indicators 11:1277-1289.
Dale et al. (2013) Ecological Indicators 26:87-102.

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.

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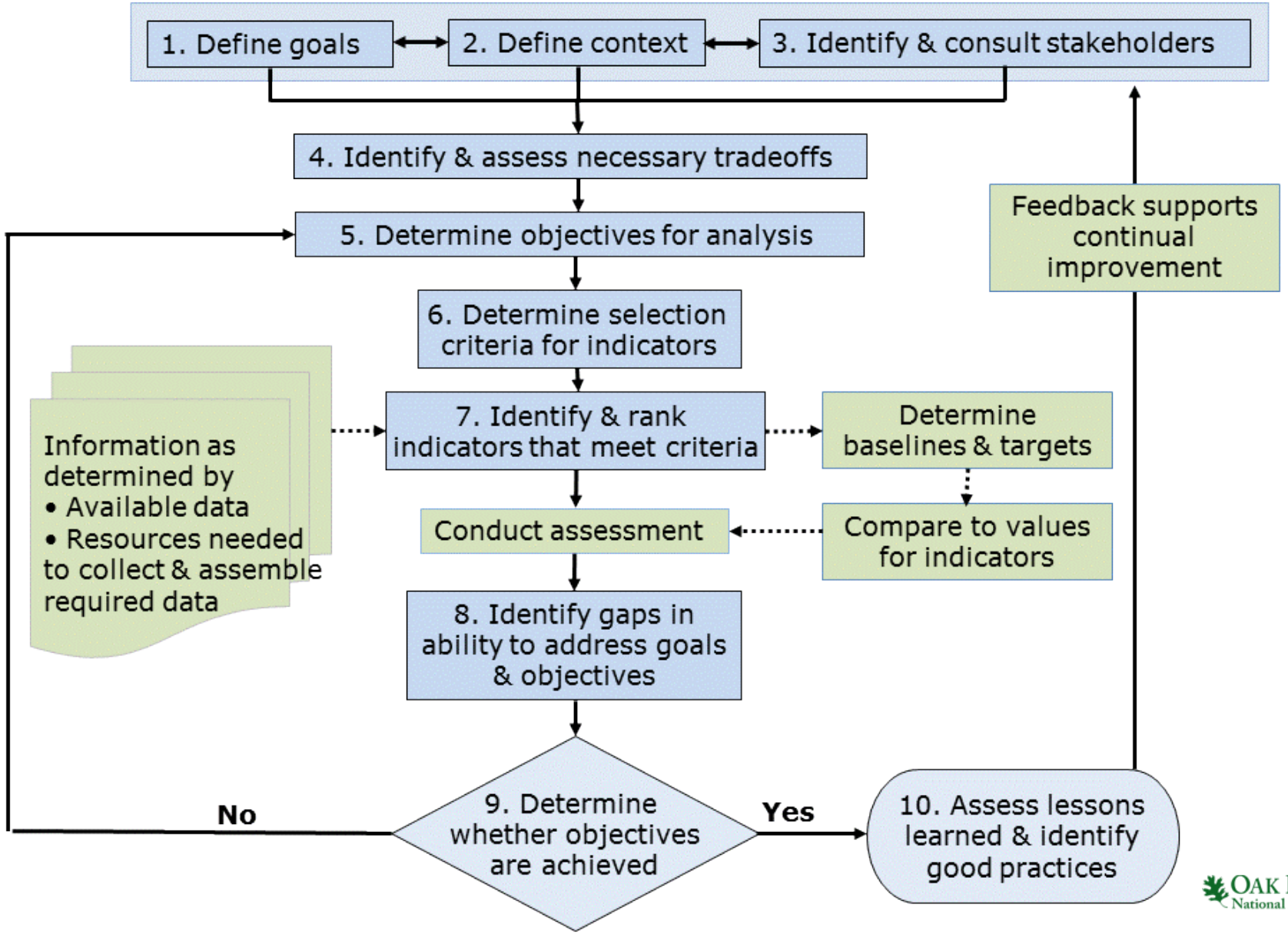
Negative impacts of bioenergy can be avoided or reduced by attention to three principles:

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



Dale, Efroymson, Kline, Davitt (2015) A framework for selecting indicators of bioenergy sustainability. Biofuels, Bioproducts & Biorefining. DOI: 10.1002/bbb.1562

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.

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Categories of environmental sustainability indicators

Environment	Indicator	Units
Soil quality	1. Total organic carbon (TOC)	Mg/ha
	2. Total nitrogen (N)	Mg/ha
	3. Extractable phosphorus (P)	Mg/ha
	4. Bulk density	g/cm^3
Water quality and quantity	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	9. storm flow	L/s
	10. Minimum base flow	L/s
	11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

Environment	Indicator	Units
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter less than 2.5µm diameter ($PM_{2.5}$)	$\mu g/m^3$
	18. Total particulate matter less than 10µm diameter (PM_{10})	$\mu g/m^3$
Productivity	19. Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year

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Categories of socioeconomic sustainability indicators

Ten minimum practical measures

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

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

Dale et al. (2013*) Ecological Indicators* 26:87-102.

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Thank you!

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