Center for Renewable Carbon
The University of Tennessee Institute of Agriculture

UT AgResearch
INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

Developing New Feedstock for the Bioeconomy

T. G. Rials, Professor and Director
The University of Tennessee, Knoxville, Tennessee

A Portfolio of Biomass Sources

- Addresses diverse landowner goals and interests
- Maximizes yield on different sites
- Optimizes ecosystems services (e.g., water and soil quality)
- Reduces risk from disrupted supply
- Enables different technology platforms (thermo- and biochemical)

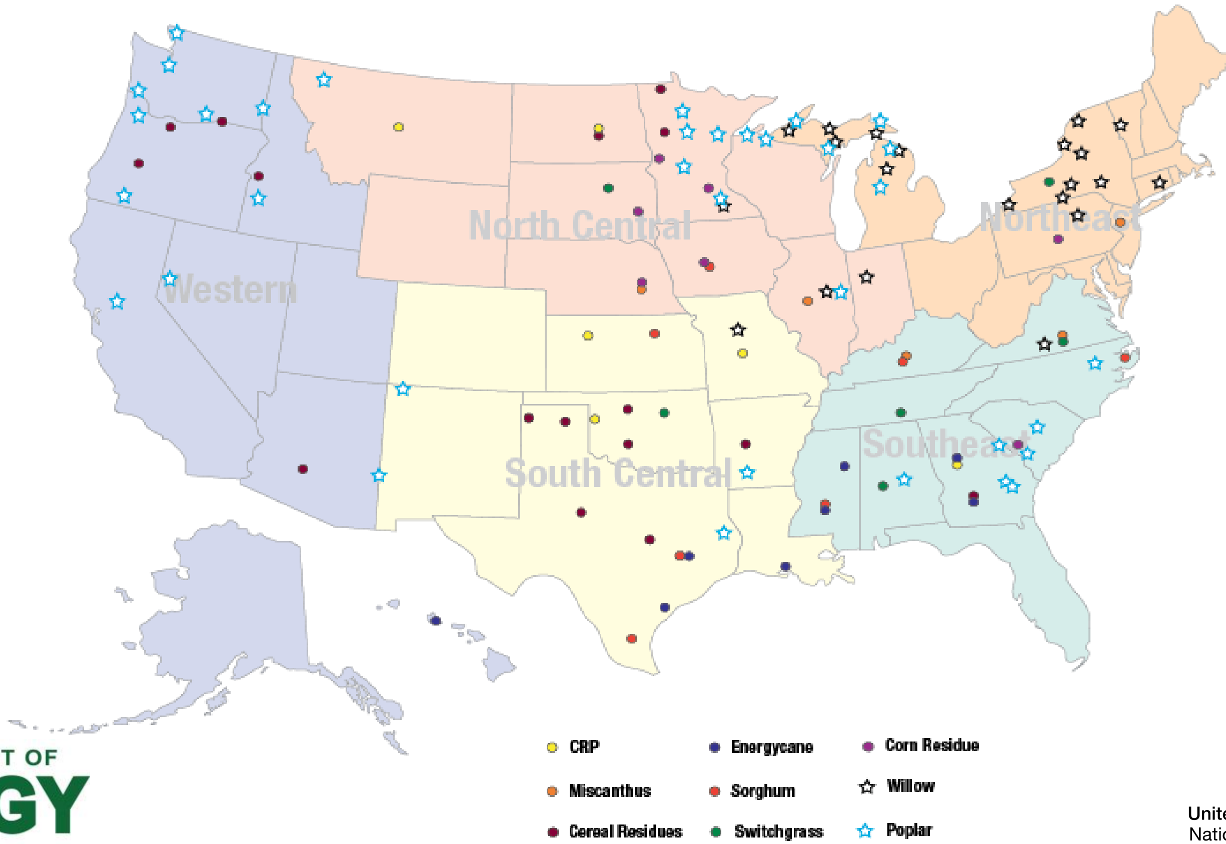
Southern Pine – residue and purpose-grown

Short-Rotation Woody Crops - Hardwood

Perennial Grasses – miscanthus, switchgrass

Annual Crops – biomass sorghum, energy cane

Regional Feedstock Partnership



U.S. DEPARTMENT OF ENERGY

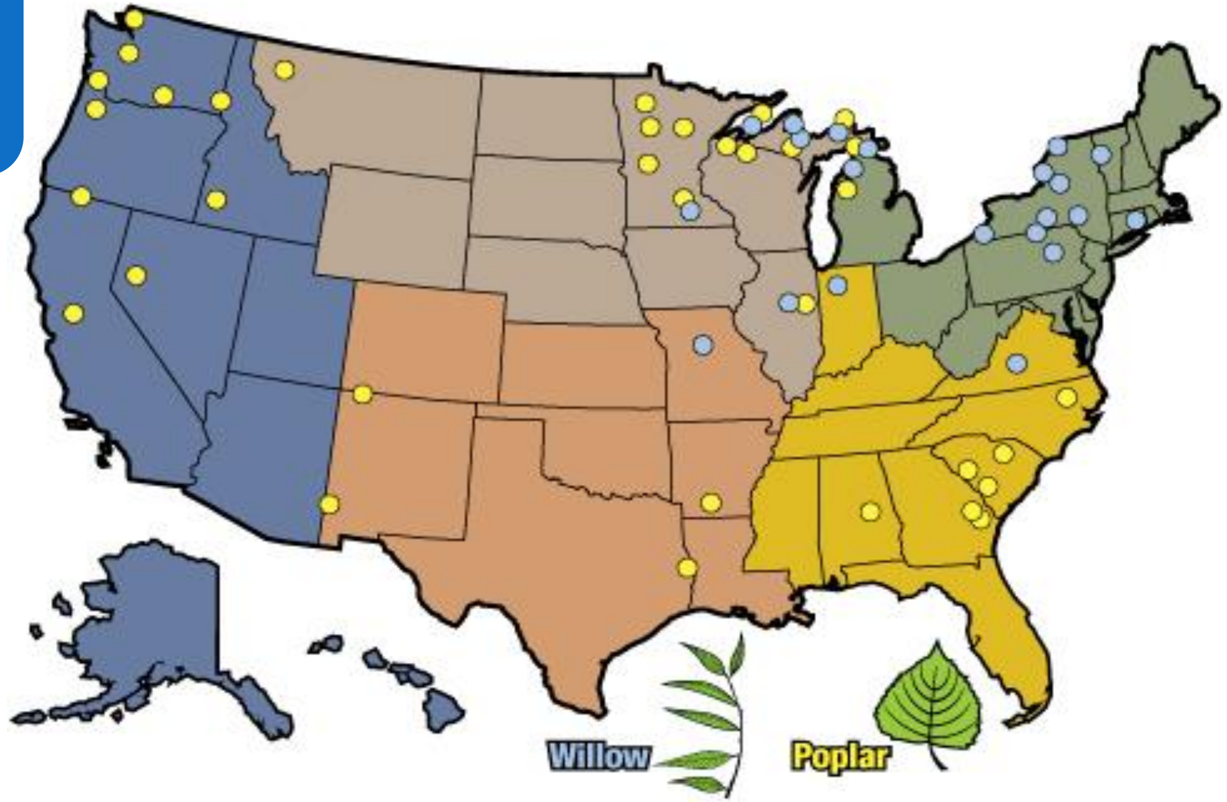
USDA
United States Department of Agriculture
National Institute of Food and Agriculture

SunGrant INITIATIVE
Southeastern Regional Center

National Bioenergy Day
October 21, 2015

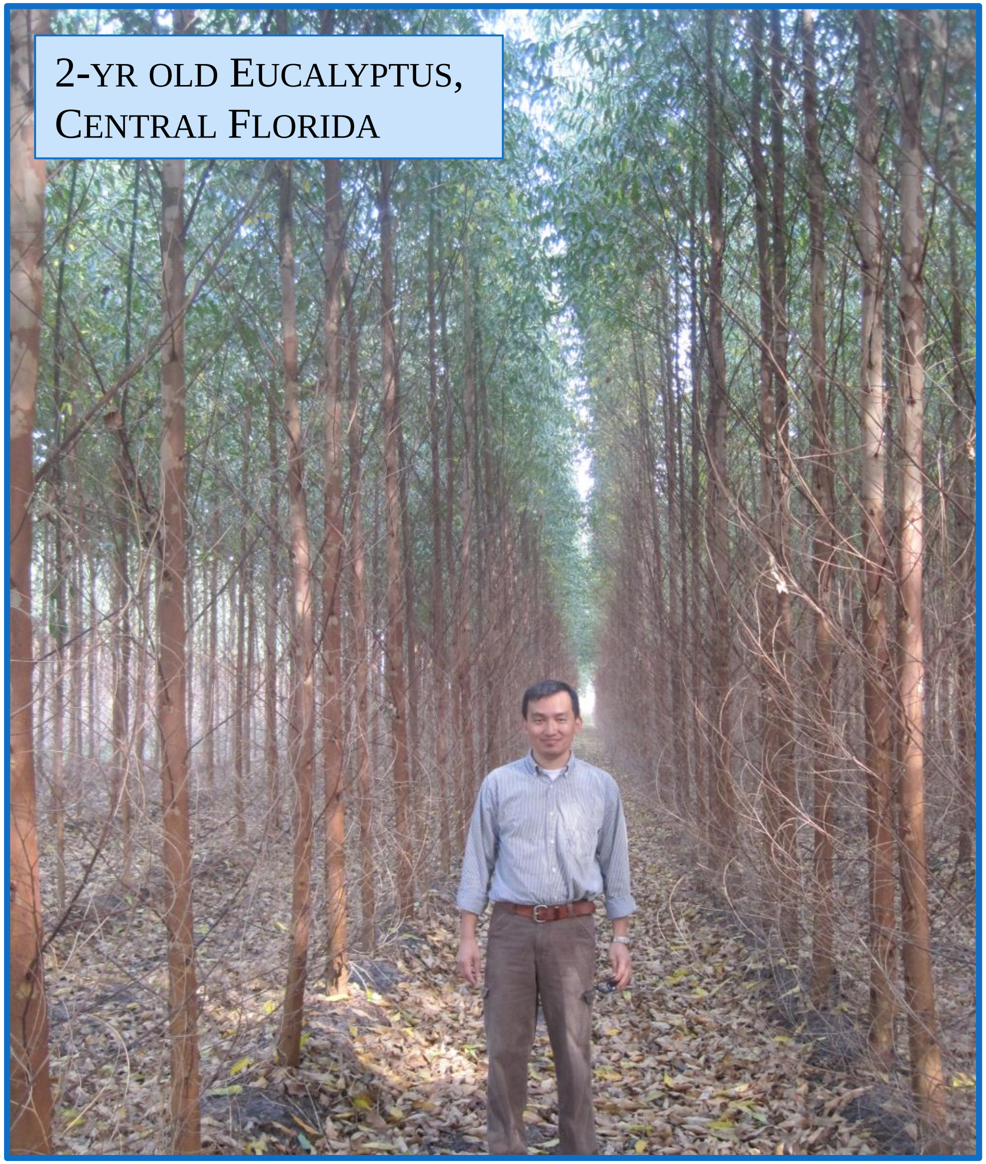
RFP Short-Rotation Woody Crops (SRWC)

- Program included willow *(Tim Volk, Lead)* and hybrid poplar *(Bill Berguson, Lead)*
- Coordinated trial network to assess yield of genetically improved material
- Provided new information on production economics and system sustainability
- Data utilized to create new yield maps (PRISM)
- Biomass provided to *INL Biomass Library*



The IBSS Partnership

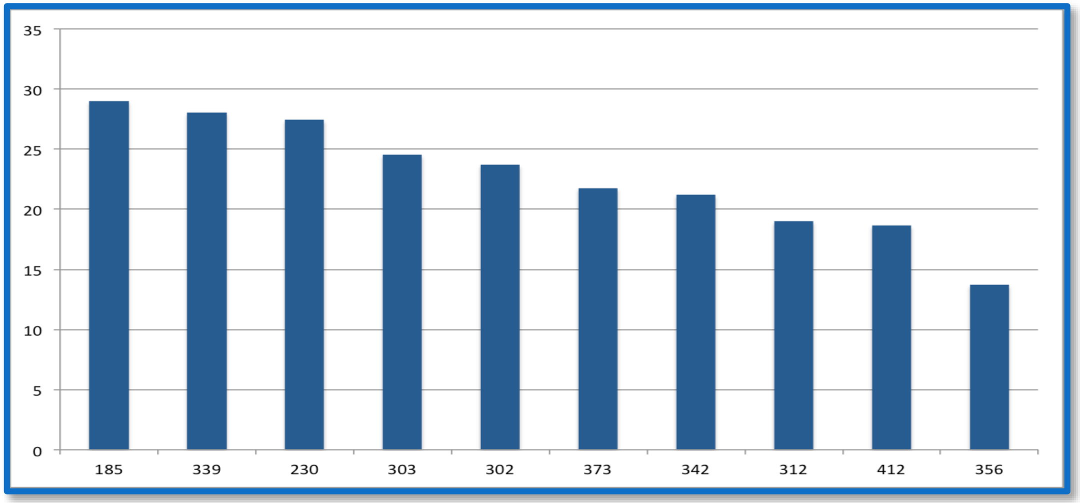
- Reducing barriers to drop-in fuels and chemicals production in the SE
- Biomass production studies include switchgrass, pine, and SRWC's
  - Hybrid Poplar
  - Eucalyptus
- Poplar program coordinated with RFP to assess growth and yield in the region
- Research also considers process-feedstock interaction, (i.e., conversion performance)
- Sustainability is Paramount



Hybrid Poplar In the Southeast

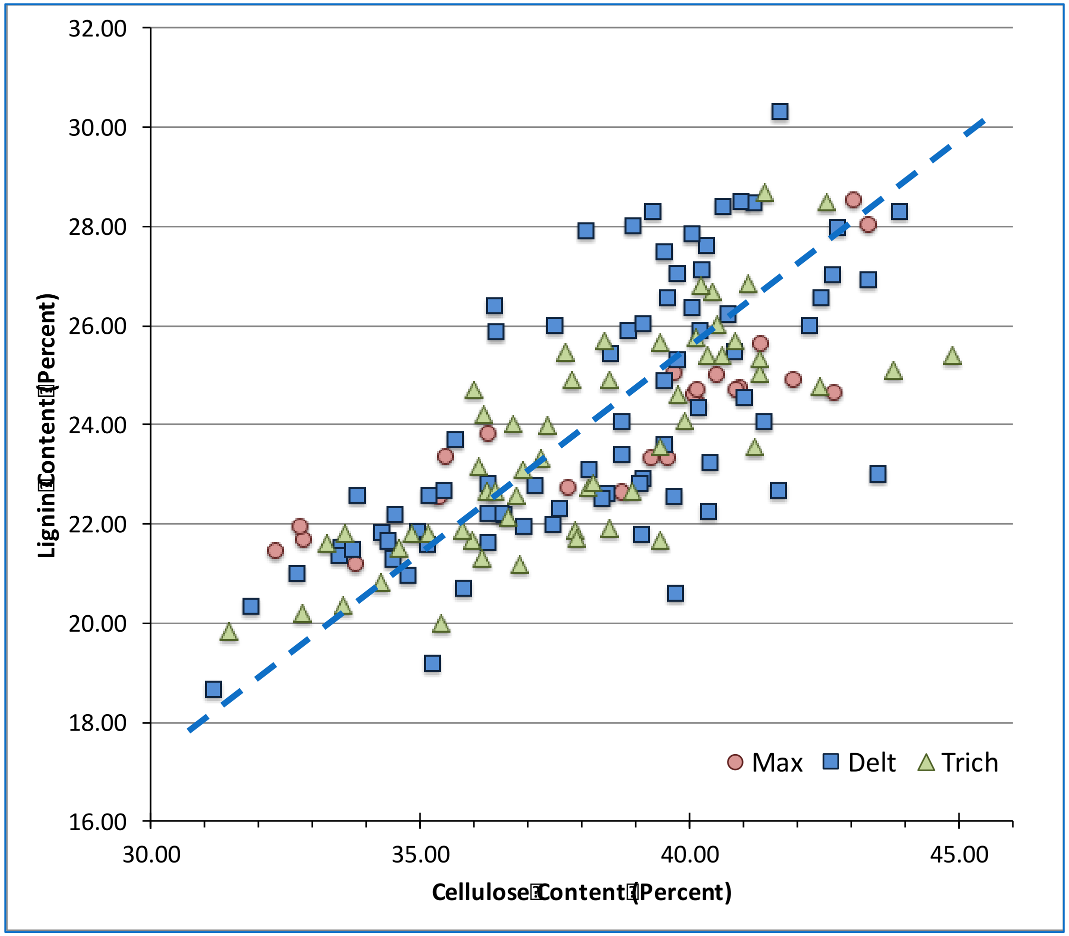
- Complete development chain in place: Clone trials ➟ Yield trials ➟ Demonstration
- Coordinated poplar yield trials in NC, TN, AL (2) and MS.
- Commercial demo in collab-oration with AHB & GWR.
- Wide range in growth & yield between trials.
- Significant variation in yield for different clones
- 7-8 dt/acre for best clones

Hybrid Poplar Production: Height



The Pieces We Want

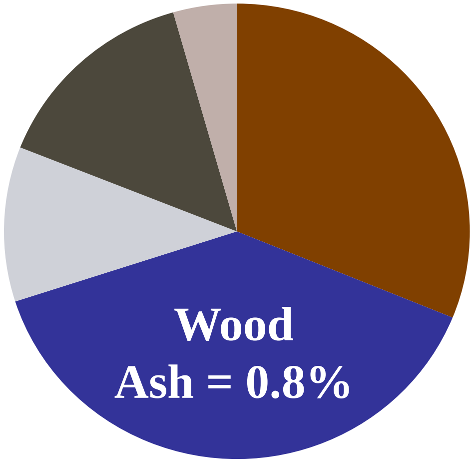
- Sugar availability is key to biochemical processes
- Chemical composition determined near infrared and chemical methods
- Cellulose content ranges from ca. 30% to 45%
- Wide range of lignin content, varying almost 12%
- No clear dependence on genetics or management (trees/acre)
- Highlights the potential for feedstock optimization

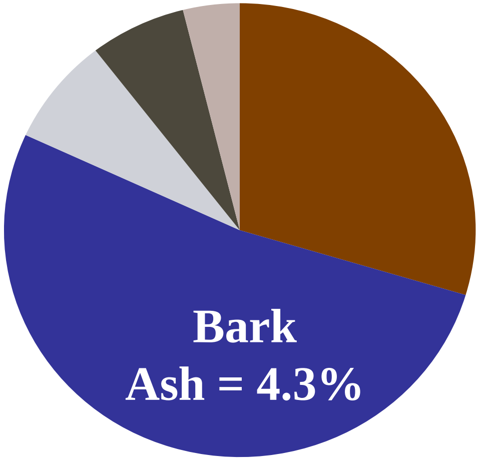


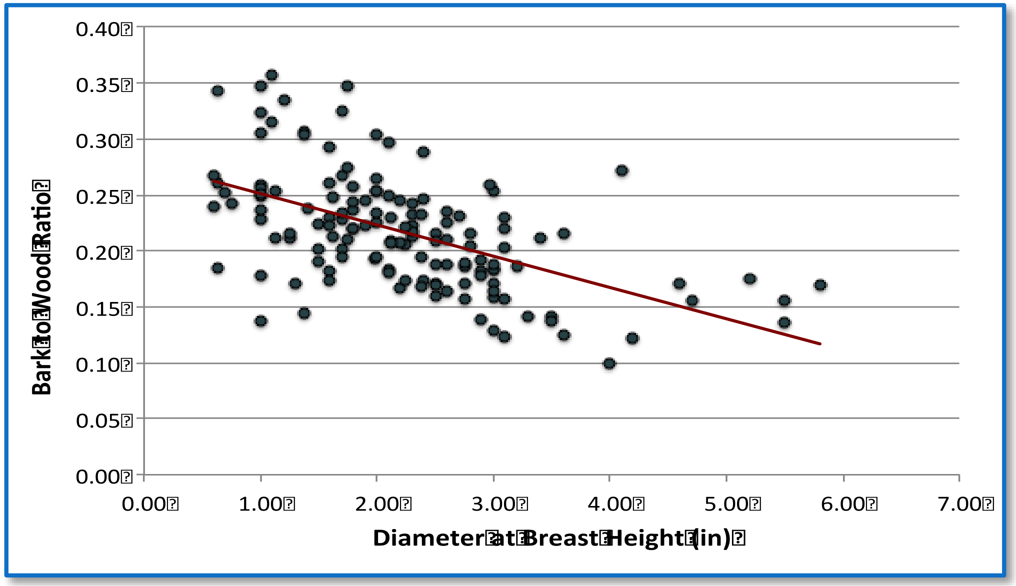
Preliminary results provided by N. Labbe, UT-CRC. Poplar from east Tennessee trial with 11 clones at spacings of 3x10, 4x10 and 7x10.

The Pieces We <u>**Don't**</u> Want

- Any input that is not a part of the product is a problem
  - Extractives, Inorganics
- Inorganics in biomass impact thermochemical processes - catalyst fouling and waste issues
- Bark has much higher levels of inorganics than wood – ca. 5 times in poplar
- For young trees, bark can comprise 30+ percent of the biomass

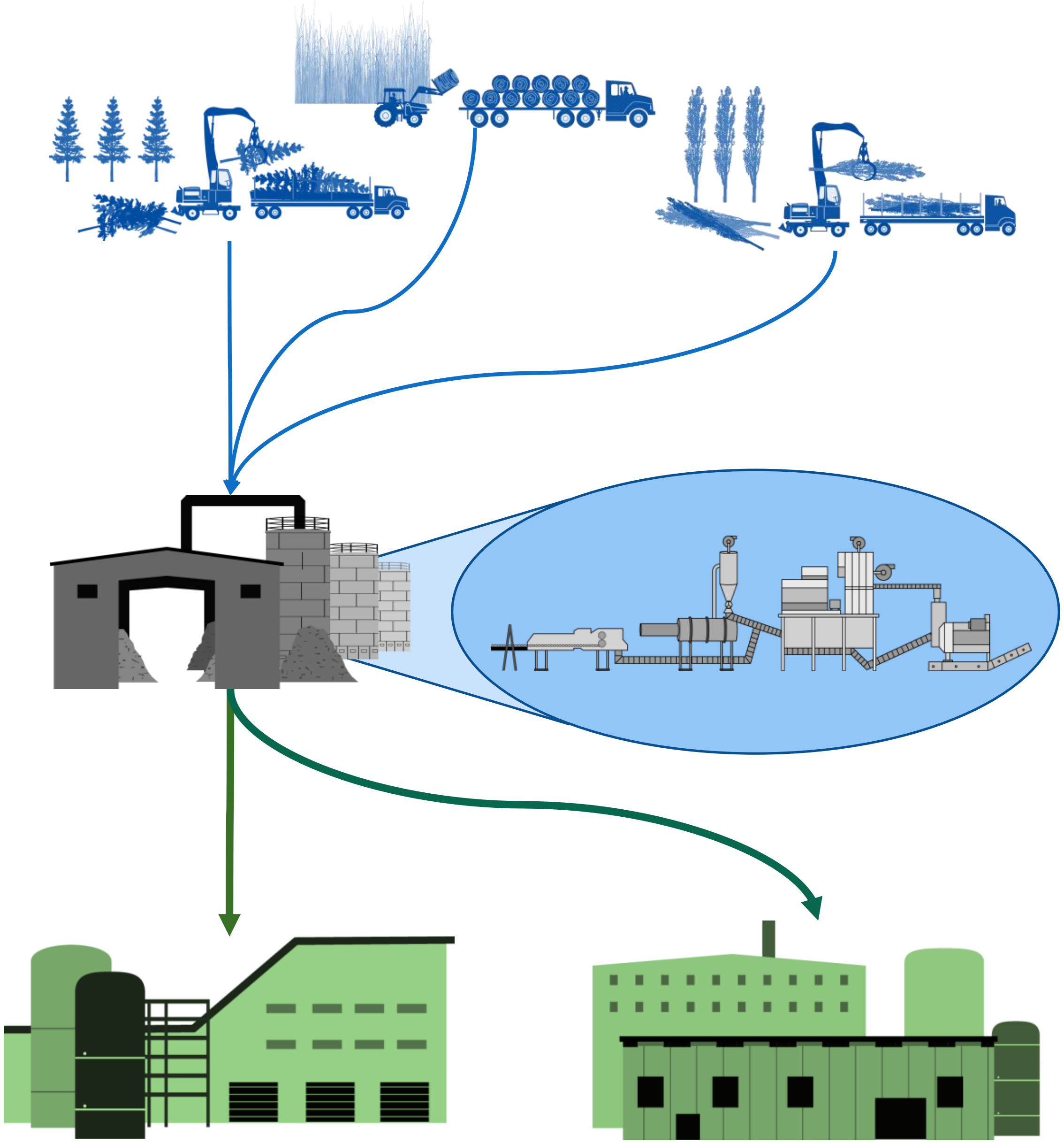






Improved Quality. Reduced Cost.

- New Project with DOE BETO regarding improved logistics (Logistics for Enhanced-Attribute Feedstock)
- Introducing SPC with new sensor technology for process monitoring and improvement
- Advancing formulated blends to reduce variation and lower costs along the supply chain of multiple, high-impact biomass sources (pine and switchgrass)
- University of TN, Auburn University, Genera Energy, Herty, INL, John Deere, NC State University, PerkinElmer



Closing Remarks

- Energy crops will play an important role in the bioeconomy
- The potential for engineered feedstocks will impact process efficiency
- Woody crops provide unique characteristics to enhance supply
- Significant progress has been made in the last 10 years to introduce this technology to supplement advanced biomass sources

Thermochemical conversion of biomass to fuels and other products

Stephen C. Chmely
Research Assistant Professor
Center for Renewable Carbon
University of Tennessee

October 21, 2015

National Bioenergy Day
Celebrating Nature's Energy Source

Gasification & pyrolysis

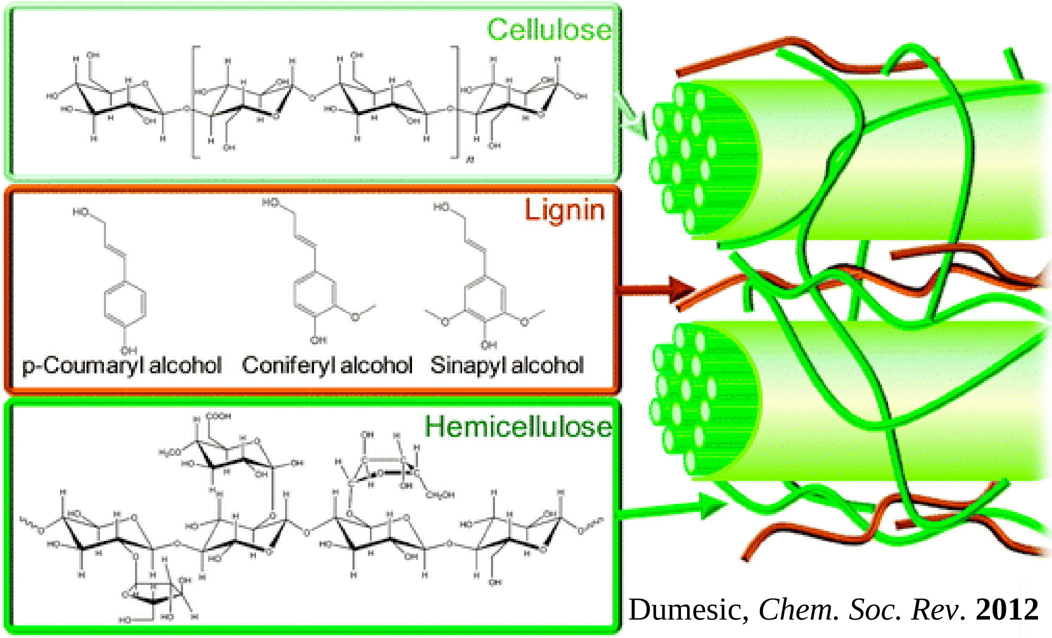
GASIFICATION

- Complex series of chemical reactions >700 °C
  - **Dehydration**, **pyrolysis**, **combustion**, and **gasification**
- Product is a gas (syngas, $CO + H_2$)
  - Can be used in FT-synthesis or can be combusted to generate heat

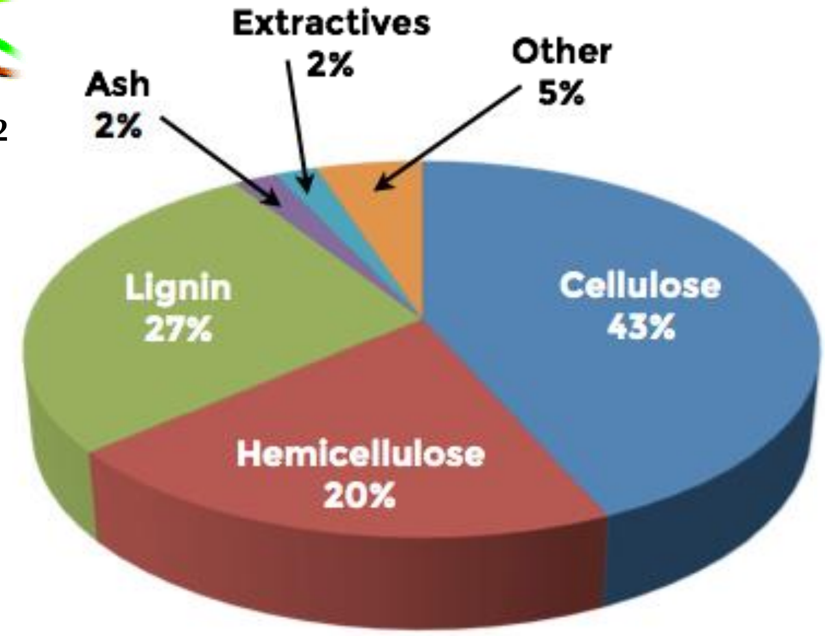
PYROLYSIS

- Thermochemical decomposition **in absence of oxygen** 400-600 °C
  - **Is not combustion**
- Products are a liquid (bio-oil) and a solid (bio-char)
  - Can be used as direct replacement for petroleum and all fuels and chemicals derived from it

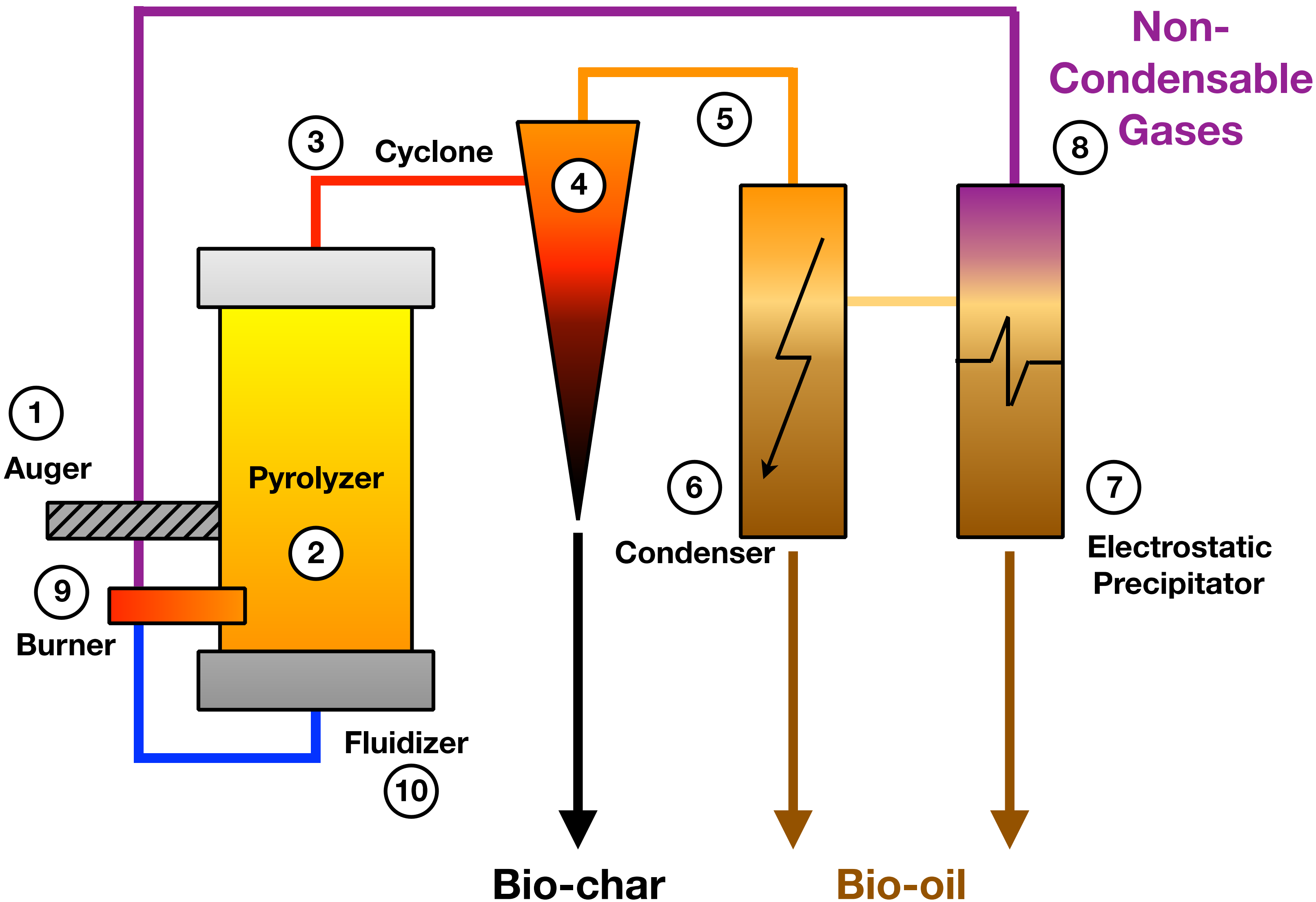
Biomass chemical composition



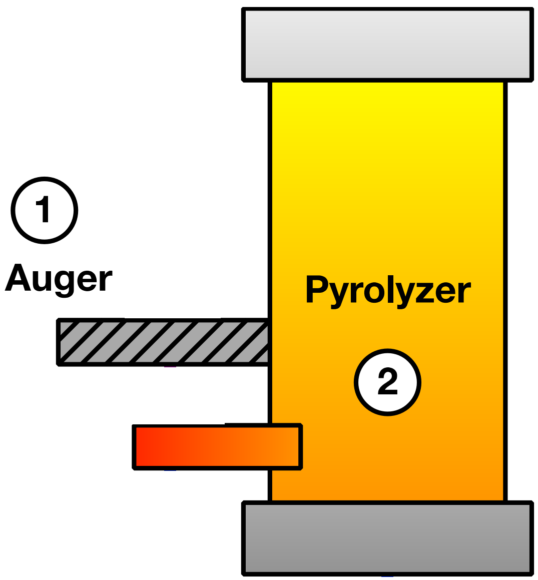
Dumesic, *Chem. Soc. Rev.* **2012**

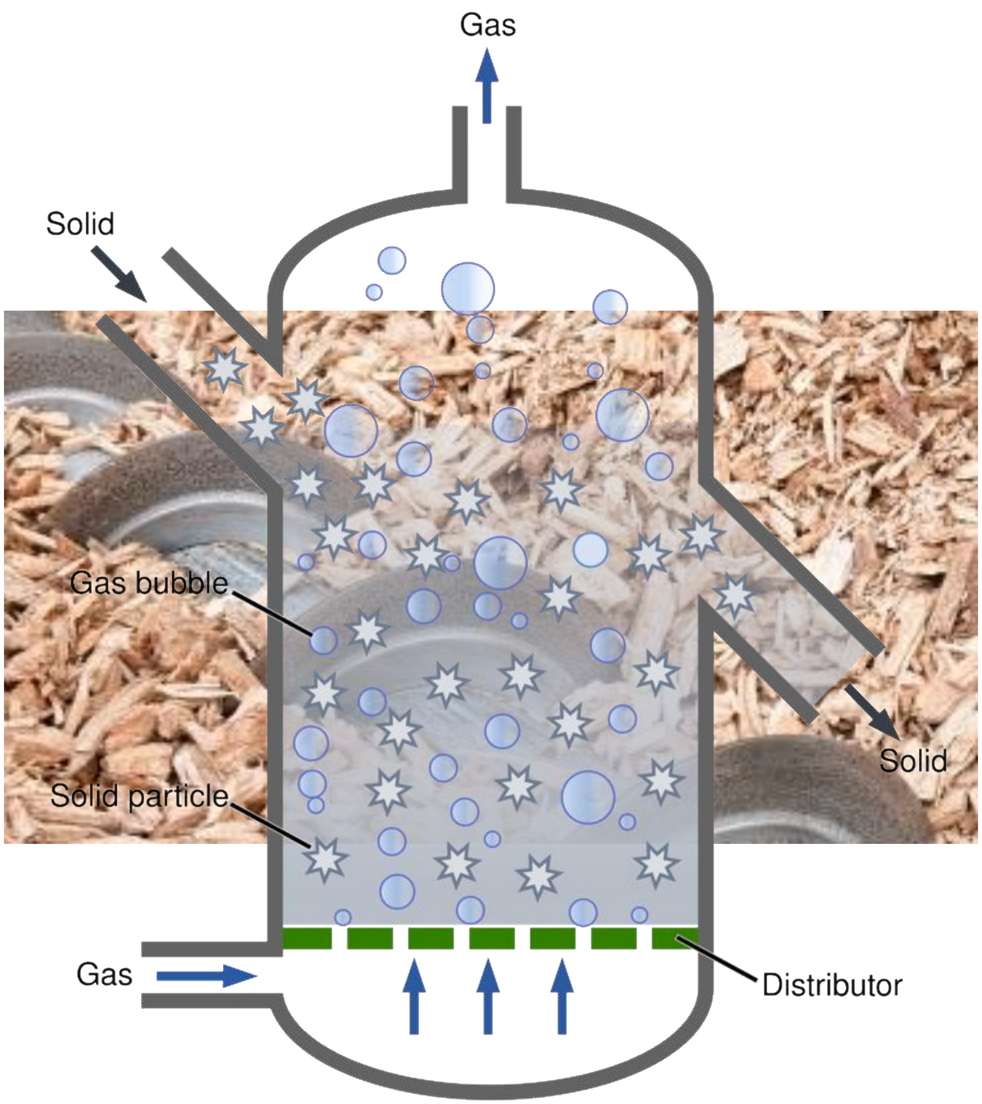


Schematic of fast pyrolysis



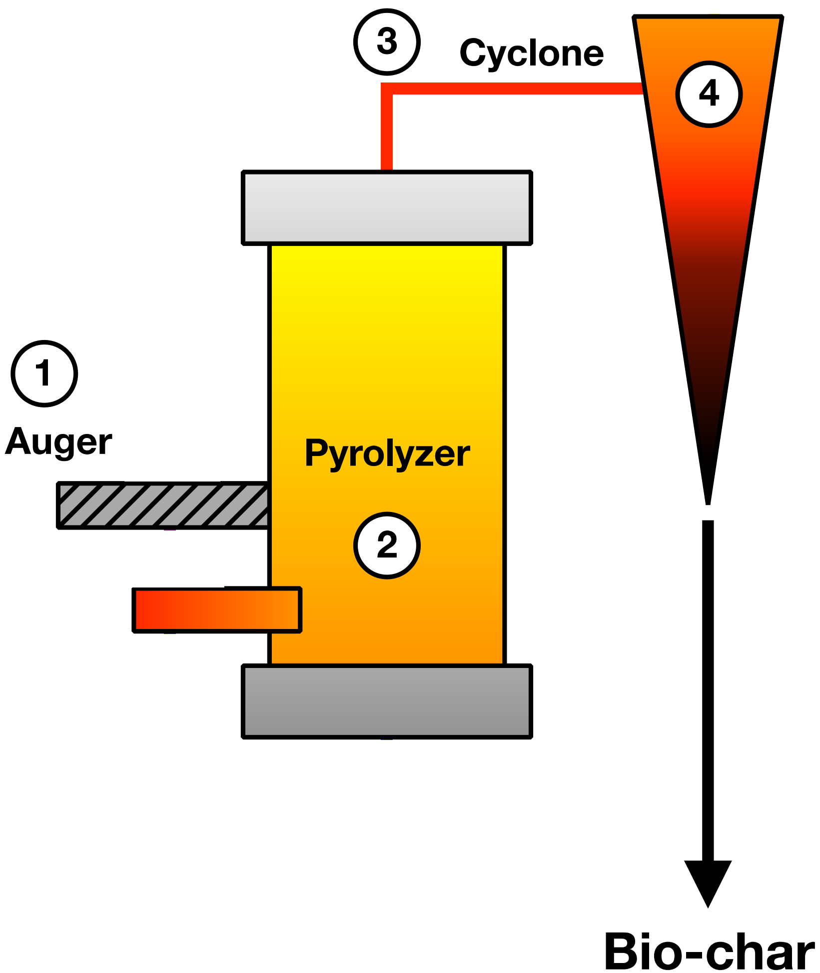
Fast pyrolysis front end

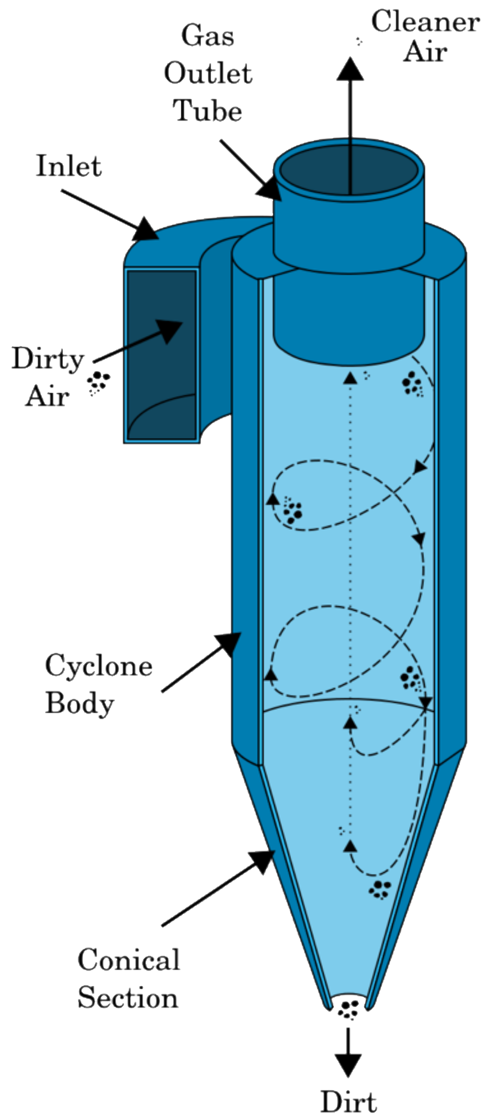




https://en.wikipedia.org/wiki/Fluidized_bed_reactor

The first product



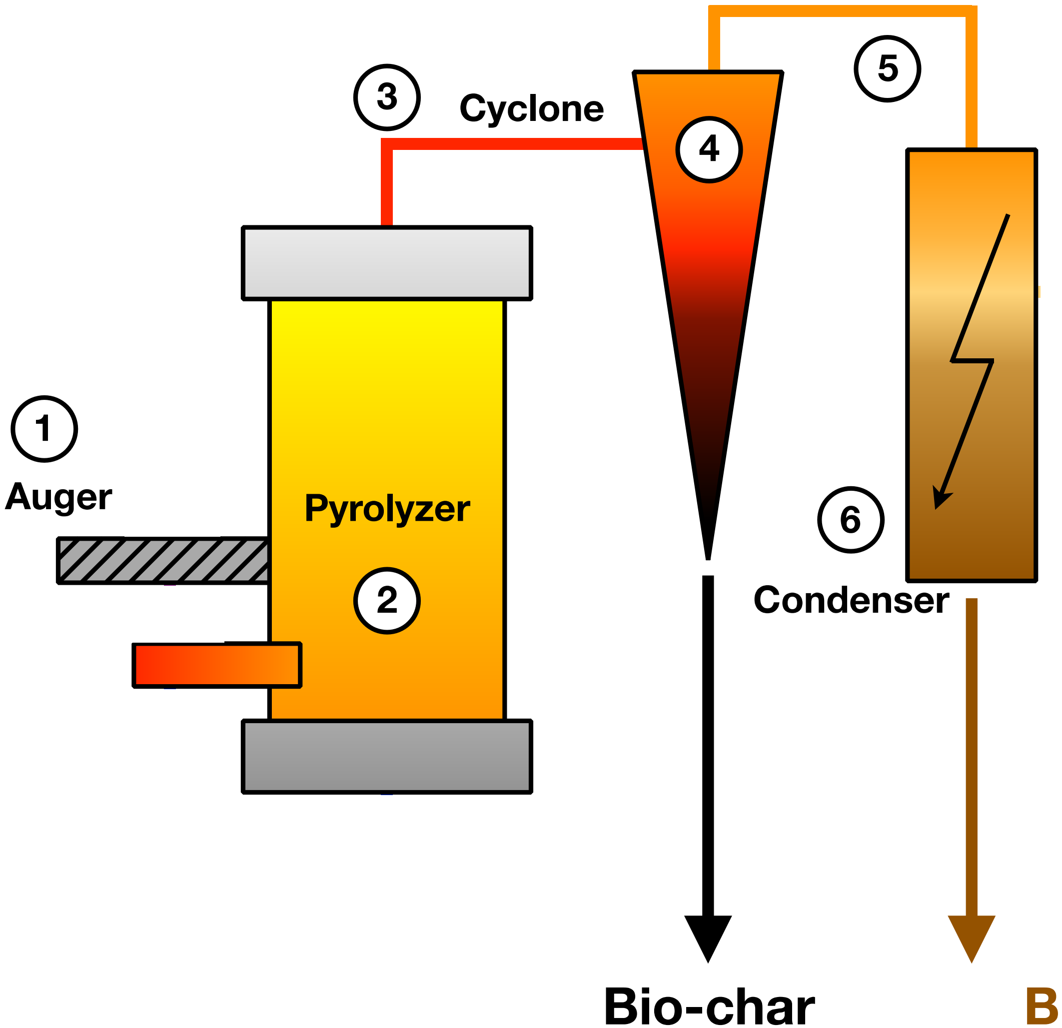


https://en.wikipedia.org/wiki/Cyclonic_separation

More on bio-char

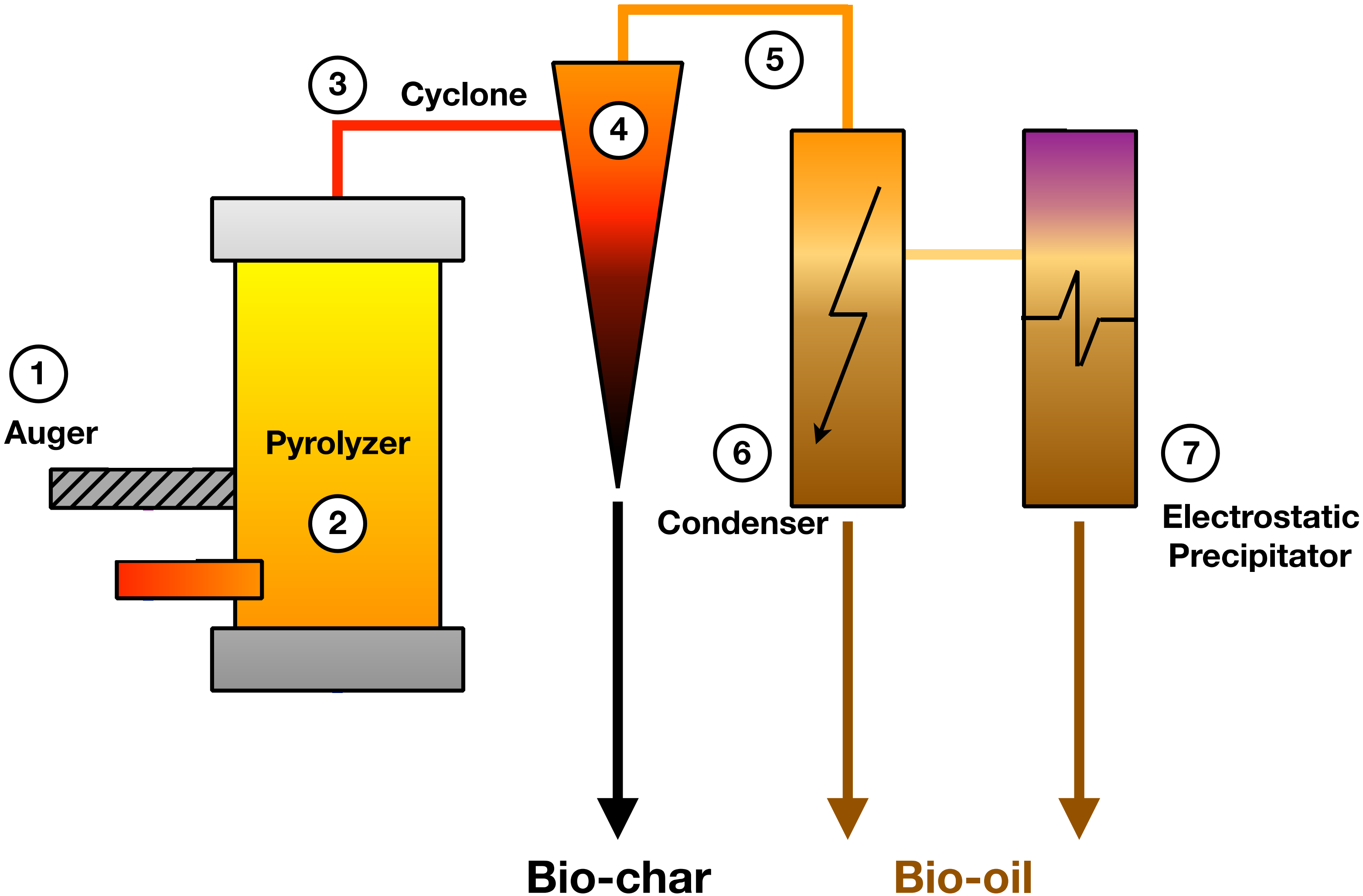
- Comprised of mostly carbon, can also contain inorganic ash
- Highly porous material
- Useful as a soil amendment
    - Can absorb water
    - Contains beneficial inorganic nutrients
    - Can house beneficial soil micro organisms
- *Recalcitrant* carbon

Collection of bio-oil: condensation



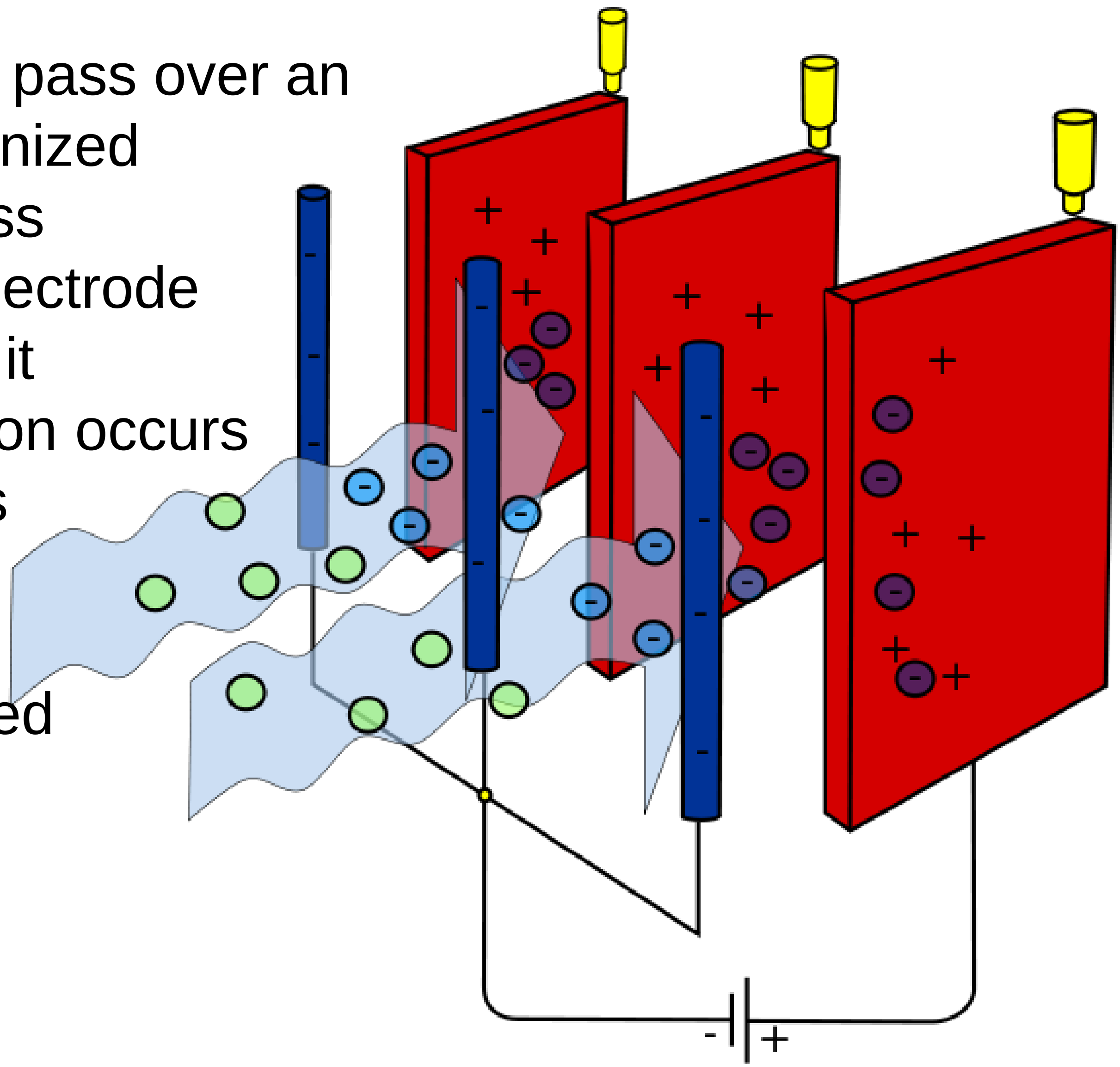
http://www.cset.iastate.edu

Collection of bio-oil: ESP



Electrostatic precipitation

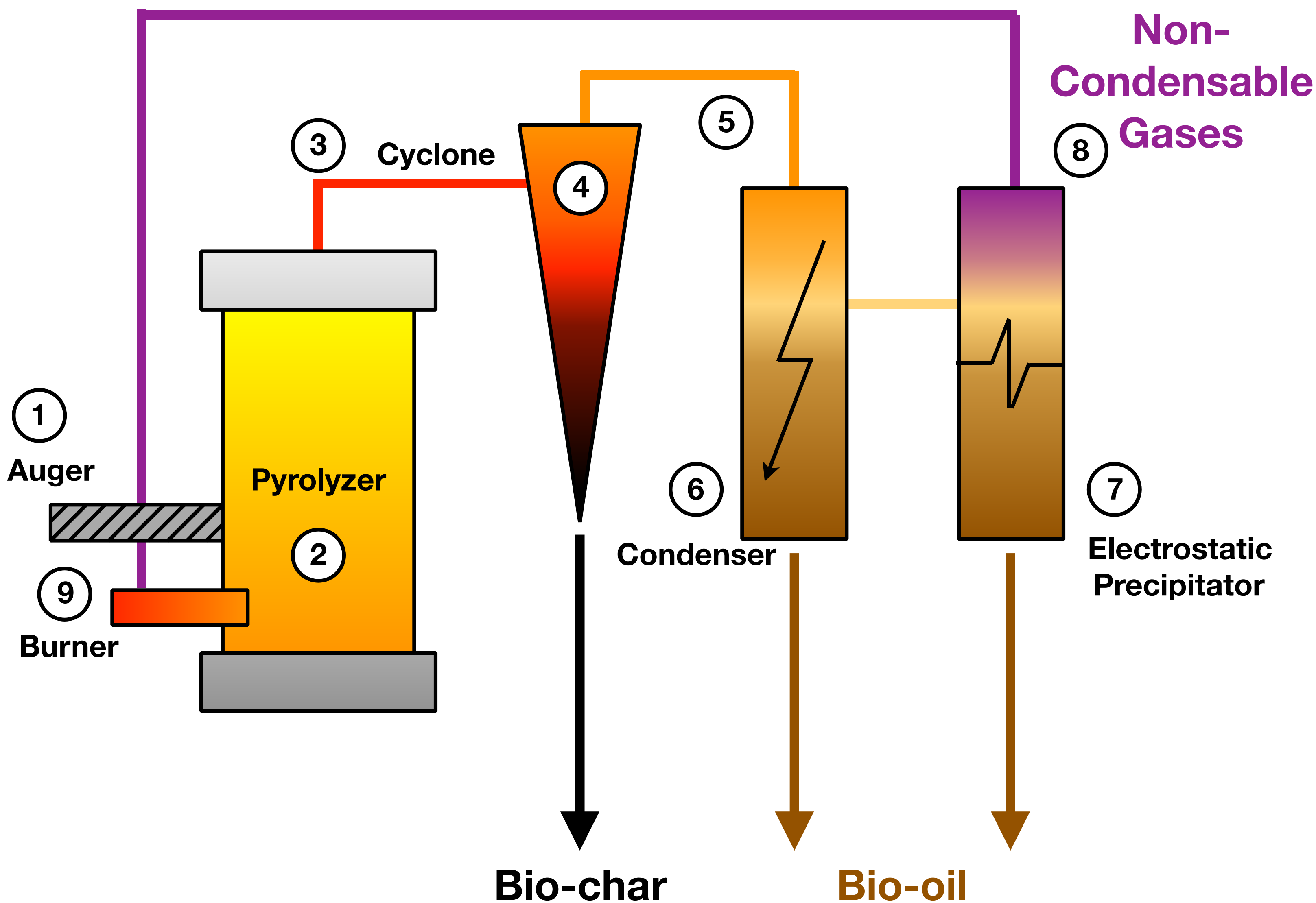
1. Gaseous molecules pass over an electrode and are ionized
2. Ionized particles pass between opposite electrode and are attracted to it
3. Charge recombination occurs and neutral particles “fall out” of the gas stream
4. Particles are collected as additional bio-oil



“Fly ash”

E. Mason, https://en.wikipedia.org/wiki/Electrostatic_precipitator

Non-condensable gases



Physical properties of bio-oil

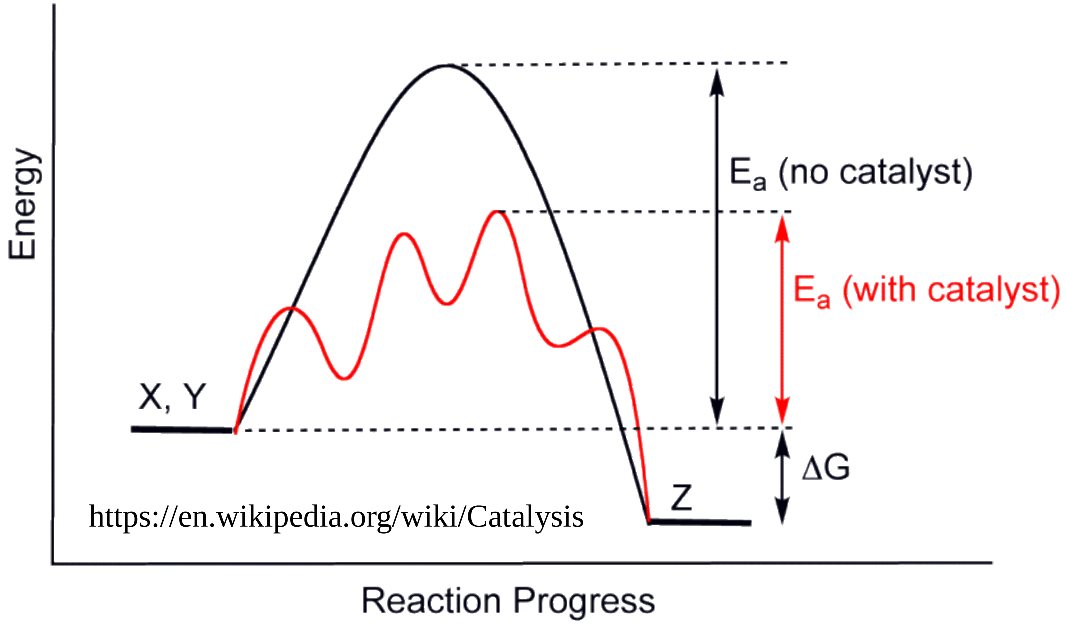
Typical Properties of Wood Pyrolysis Bio-oil and Heavy Fuel Oil[a]

physical property	Value: bio-oil	Value: heavy fuel oil
moisture content (wt %)		0.1
pH		
specific gravity		0.94
elemental composition (wt %)		
C		85
H		11
O		1.0
N		0.3
ash		0.1
HHV (MJ/kg)		40
viscosity, at 500 °C (cP)		180
solids (wt %)		1
distillation residue (wt %)		1

Mohan, D. *et al*. *Energy & Fuels*, **2006**, *20*, 848-889

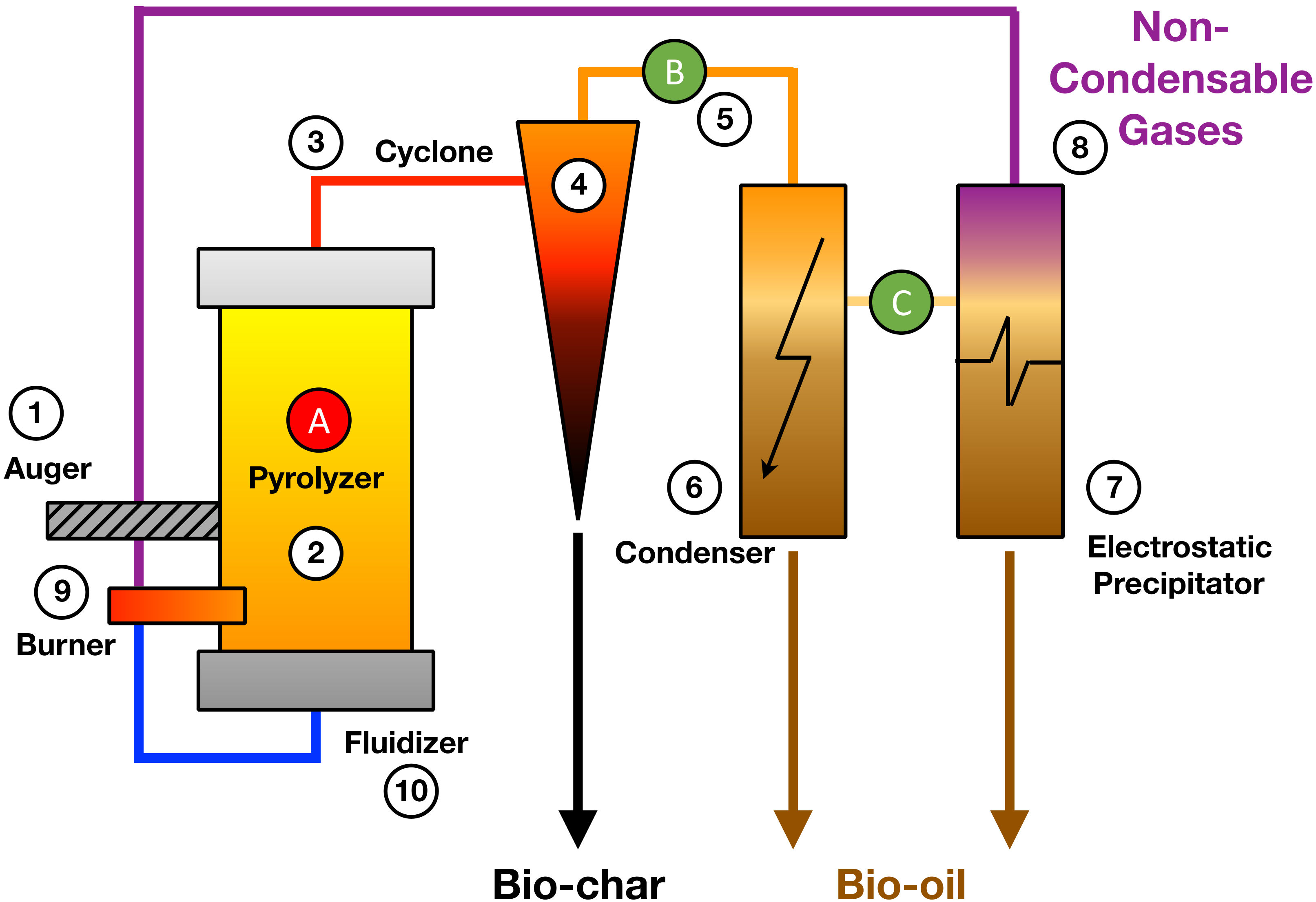
Catalysis

- Catalysts alter reaction rates
  - Homogeneous (same phase)
  - Heterogeneous (different phase)
- Over 90% of all industrially produced chemicals involve at least one catalytic step
- Demand of $16.3 billion (2013) = 0.1% GDP
- 6 of 10 Nobel Prizes from 2001-2010

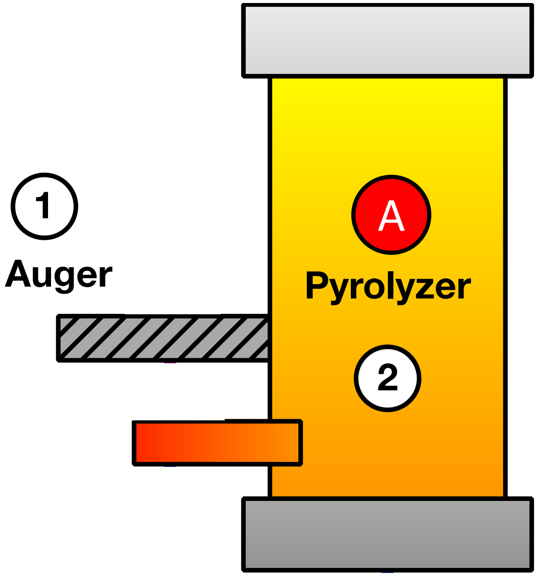


https://en.wikipedia.org/wiki/Catalysis

Catalytic fast pyrolysis (CFP)



In-situ CFP



PROS

- Catalyst is in direct contact with biomass
  - Mass & heat transfer
- Regeneration can occur on-stream

CONS

- Catalyst is in direct contact with biomass
  - Coking & fouling from inorganics
- Catalyst and support are physically stressed

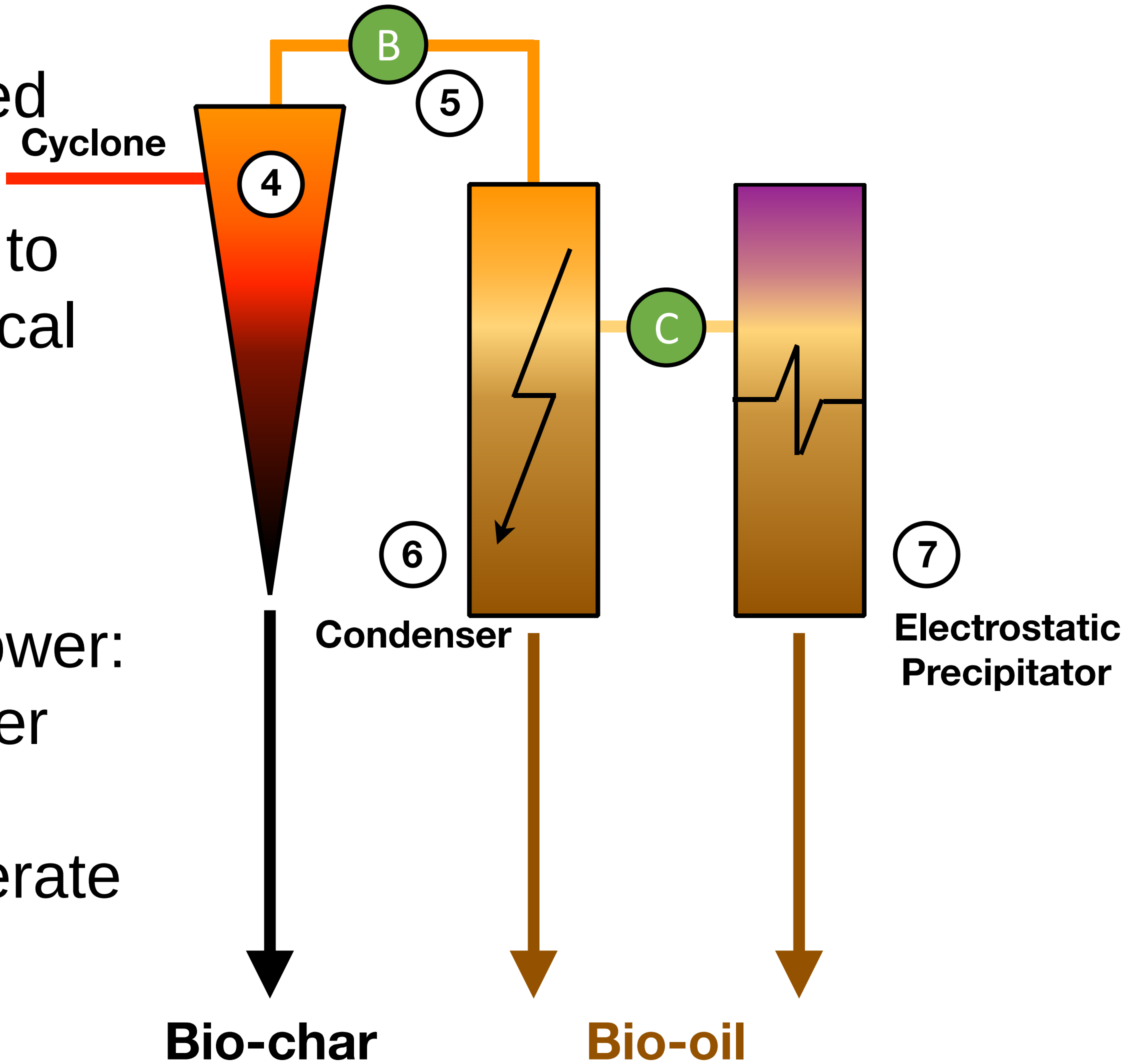
Ex-situ CFP

PROS

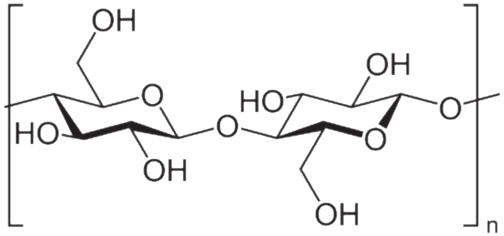
- Catalyst separated from biomass
- Less susceptible to fouling and physical destruction

CONS

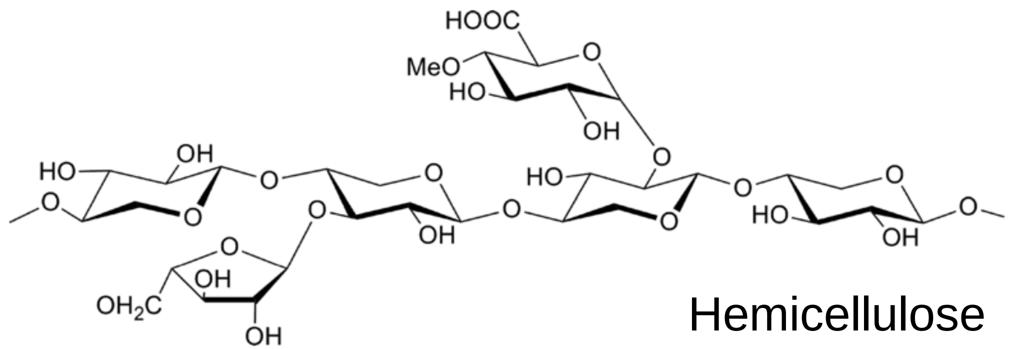
- Temperature is lower: could mean slower kinetics
- Difficult to regenerate on-stream



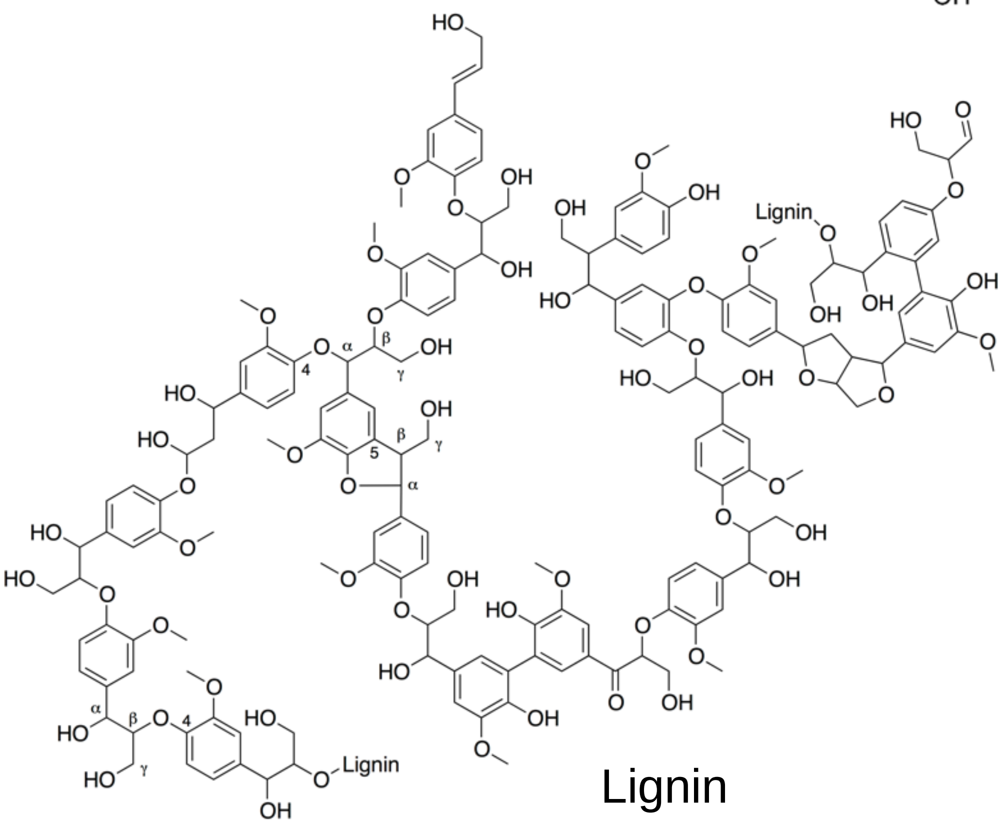
Catalytic deoxygenation



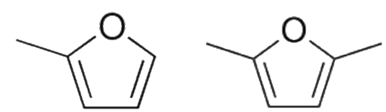
Cellulose



Hemicellulose

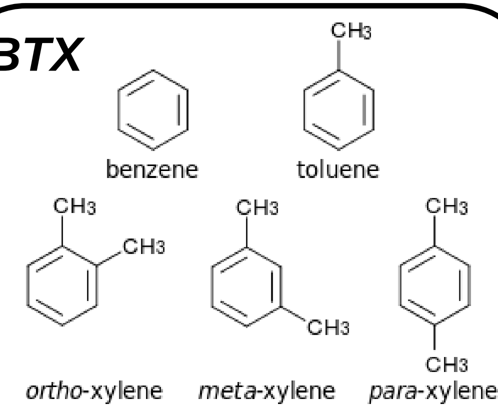


Lignin

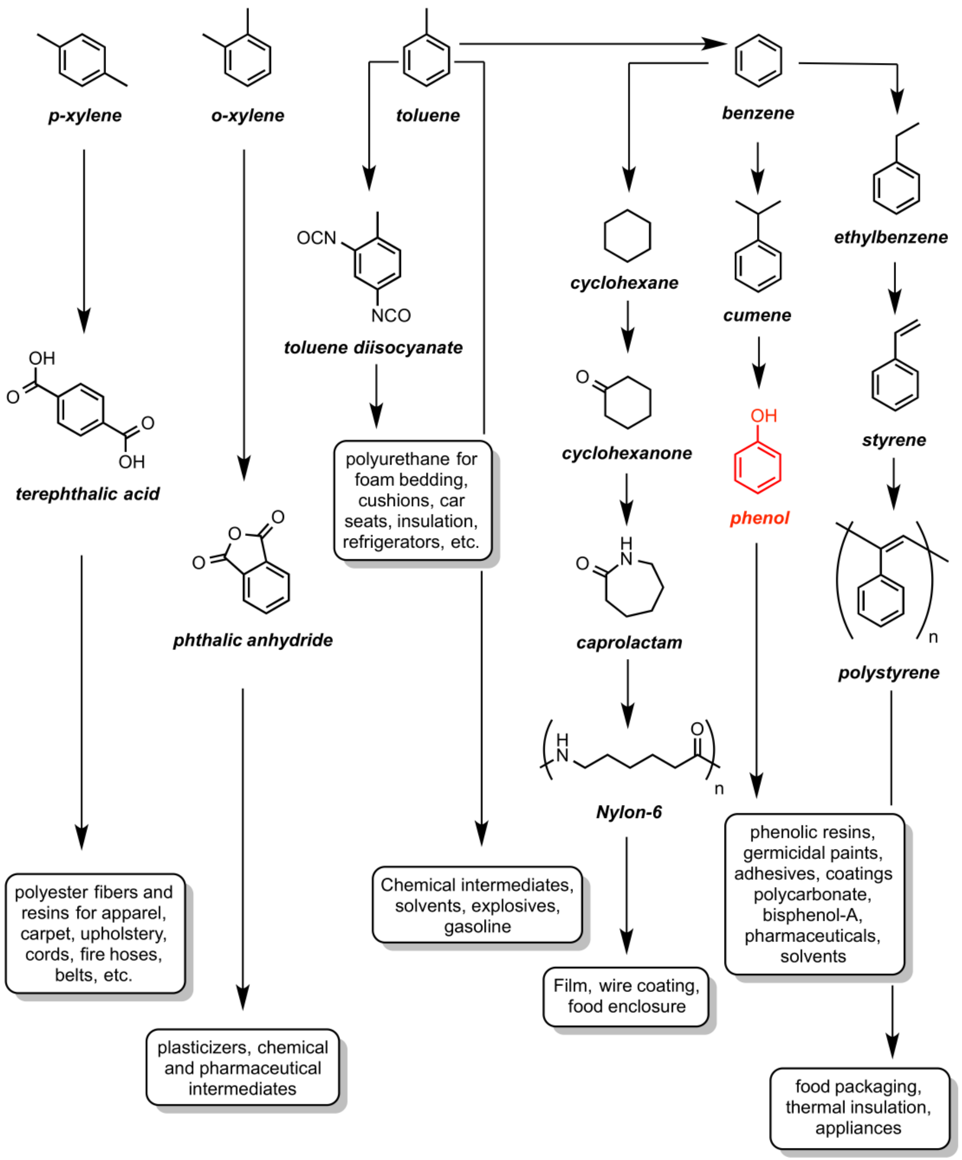


Furans

BTX



The BTX chain



Conclusions

PYROLYSIS

- Thermochemical decomposition **in absence of oxygen** 400-600 °C
  - **Is not combustion**
- Products are a liquid (bio-oil) and a solid (bio-char)
  - Can be used as direct replacement for petroleum and all fuels and chemicals derived from it
- Complex interplay of engineering and catalyst science
- Deoxygenation of bio-oil can afford useful and lucrative products

Acknowledgments

IBSS
Southeastern Partnership for
Integrated Biomass Supply Systems

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

CRC
Center for Renewable Carbon
The University of Tennessee Institute of Agriculture

UT AgResearch

October 21, 2015
National Bioenergy Day
Celebrating Nature's Energy Source

Indirect Effects of Bioenergy: International Standards & Science

National Bioenergy Day Webinar: Developing the U.S. bioeconomy within a global context

October 21, 2015
University of Tennessee, CRC

Maggie R. Davis

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

OAK RIDGE National Laboratory

Indirect Effects of Bioenergy: International Standards & Science

In collaboration with Keith Kline and ORNL staff, Fred Ghatala and Diego Goldin (conveners of WG4 for Project Committee 248). Presentation based in part on ISO WG4 findings included in ISO 13065.

Special thanks to Kristen Johnson and Alicia Lindauer, Alison Goss Eng, among others at the Department of Energy (DOE), BioEnergy Technologies Office (BETO)

Views expressed are the author's.

Oak Ridge National Laboratory

Outline

- **Background**
  - ***Indirect effects introduction***
  - ***Relevance***
  - ***Emergence of sustainability schemes***
- ***Approach to looking at indirect effects***
  - ***ISO 13065***
  - ***WG4***
- ***Conclusions***

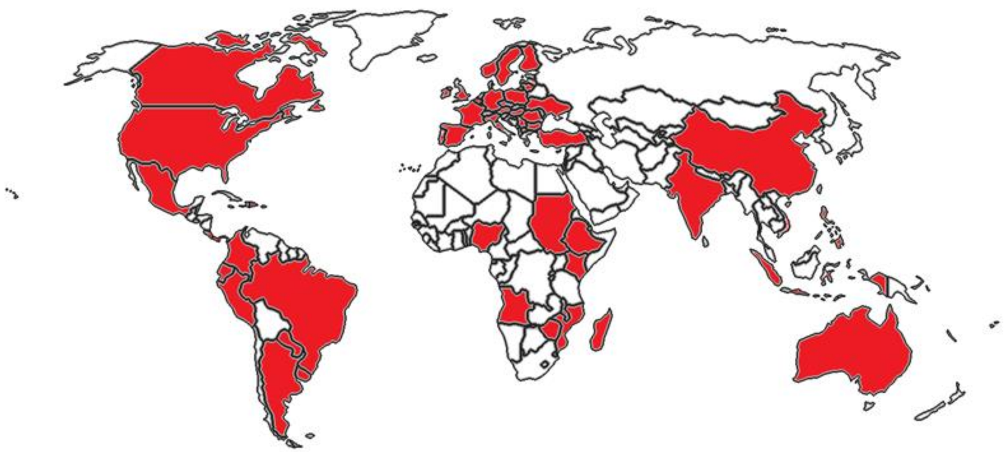
Background

Indirect effects

- **Do not meet criteria:**
  - **measurable**
  - **under the direct control of the economic operator**
  - **caused by the process being analysed**
    - **"Indirect land use change cannot be observed or measured" (Finkbeiner 2013).**
    - **"…macro-level impacts are likely to be beyond the control of the individual farmer or biofuels producer" (RSB 2013).**

Nations with Ethanol Blend Mandates in Part or All of Country

(May not be comprehensive due to lack of data for some countries.)



Source: FAS GAIN Reports and Stratas Advisors

Image source: USDA FAS "U.S. Ethanol Exports Rebound in 2014", May 1 2015

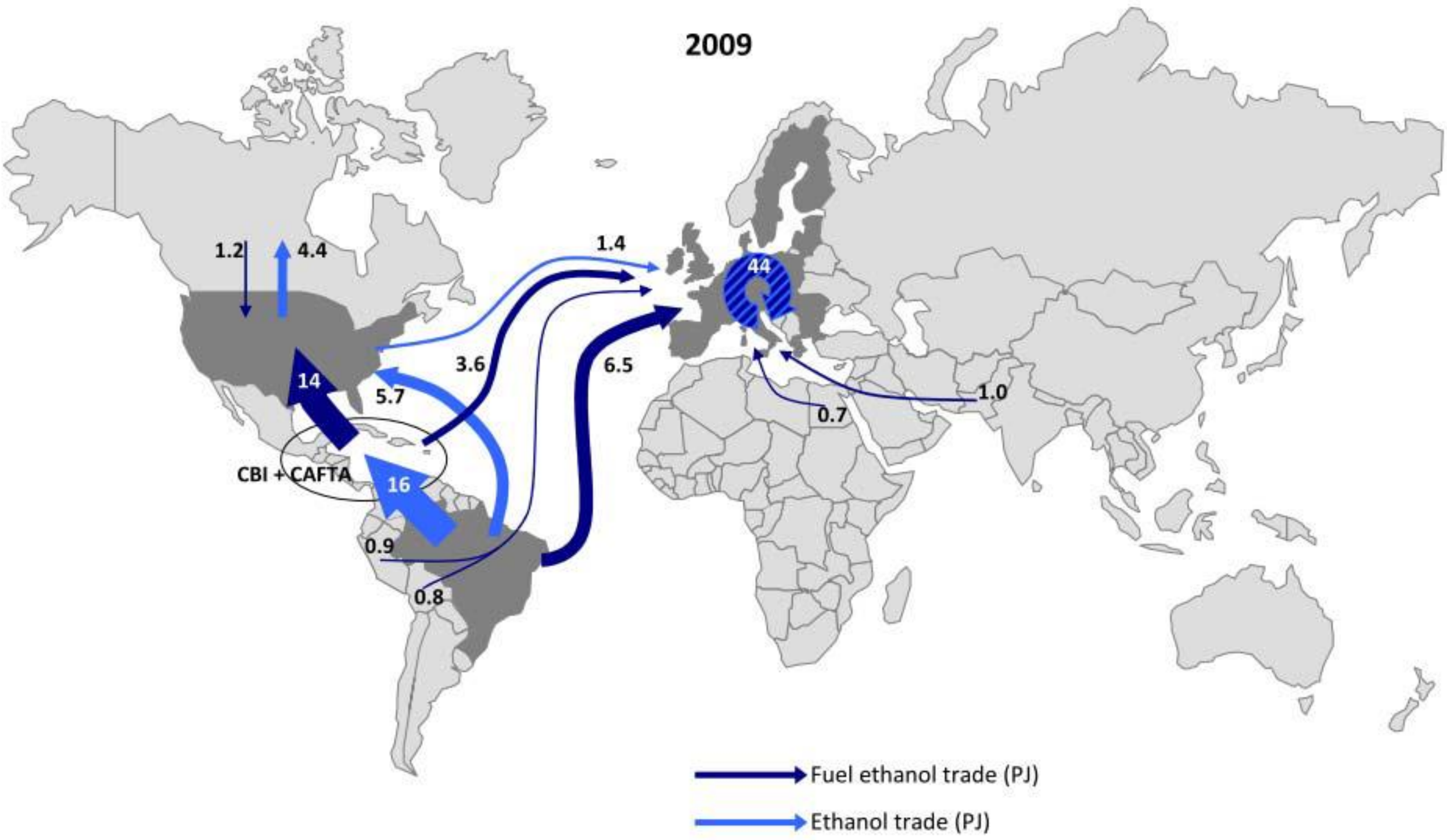
Relevance

- EU's Renewable Energy Directive
- US's Energy Independence and Security Act,
  - Renewable Fuel Standard Program (RFS2)

1. lower emissions in the transport sector,
2. diversify the fuel supply,
3. increase fuel security,
4. provide new markets for agricultural products,
5. foster value adding innovation,
6. reduce greenhouse gas emissions,
7. other environmental or social merit

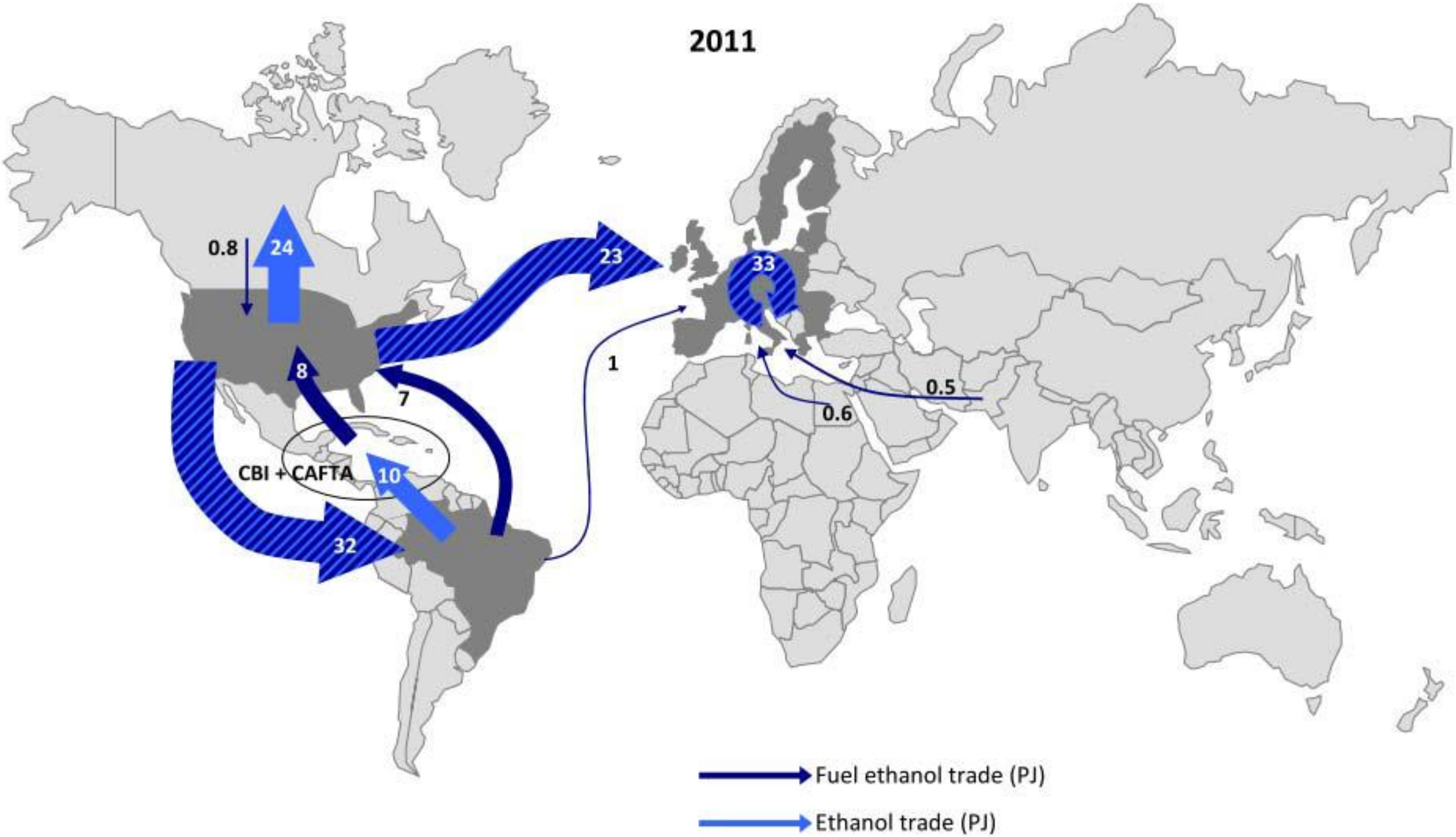
- sustainability and life-cycle-assessment + policymaking

Relevance – ethanol trade



Source: Lamers et al., RSER, 15 (2011) 2655– 2676

Relevance – ethanol trade



Source: Lamers et al., RSER, 15 (2011) 2655– 2676

Relevance – ethanol trade

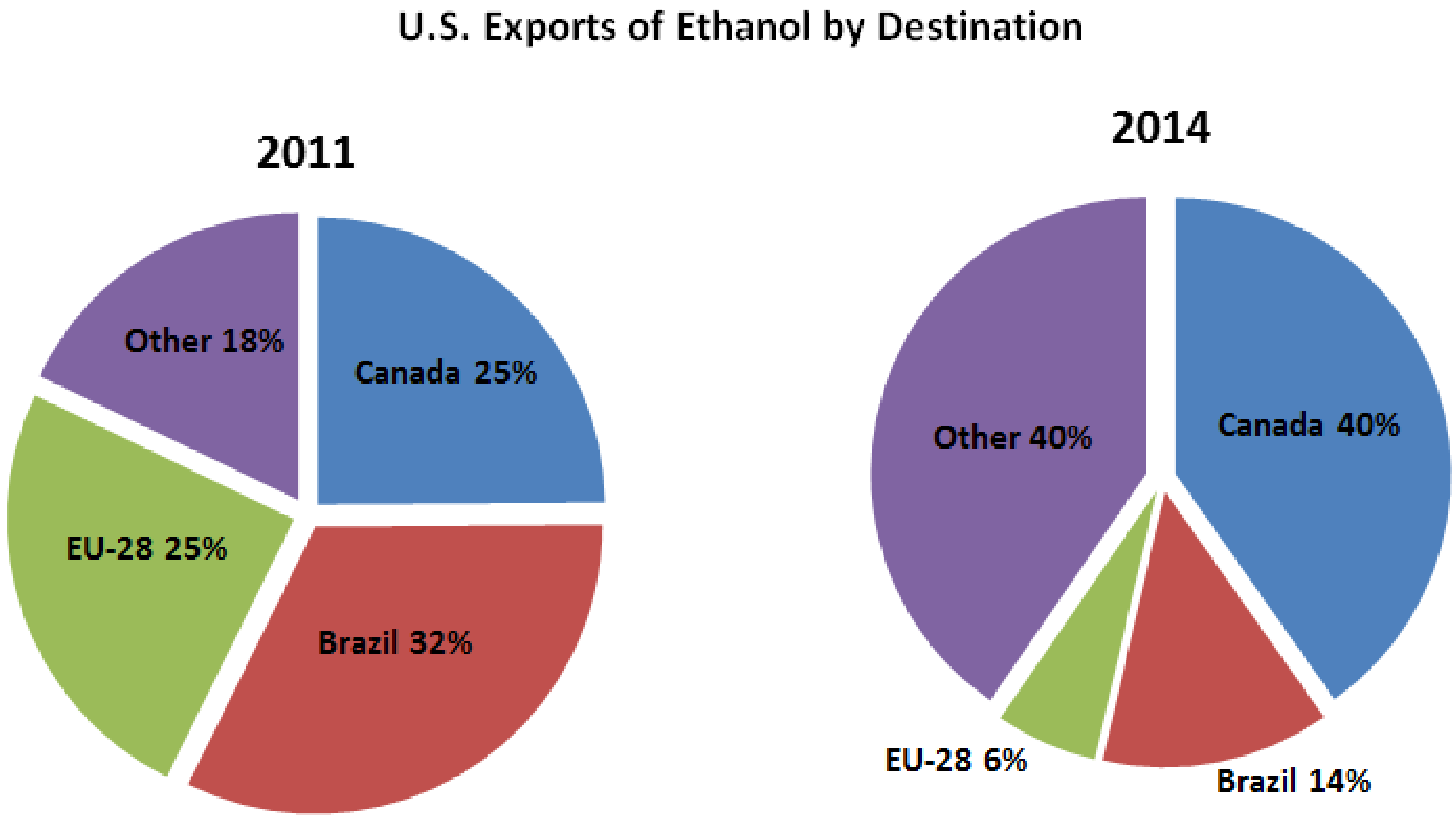


Image source: USDA FAS “U.S. Ethanol Exports Rebound in 2014”, May 1 2015

Relevance – ethanol trade

U.S. Ethanol Exports, Volume

Market	2010-2011 Average (million liters)	2014 (million liters)	Change	U.S. Market Share
Canada	789	1,272	+61%	98%
Brazil	773	425	-45%	89%
EU-28	780	190	-76%	4%
United Arab Emirates	177	259	+46%	75%
Philippines	36	256	+602%	55%
India	74	157	+133%	61%
South Korea	21	136	+542%	23%
Mexico	93	115	+24%	80%
Other	262	354	+34%	--
Total	**3,007**	**3,163**	**+5%**	**Approx. 50%**

Table source: USDA FAS “U.S. Ethanol Exports Rebound in 2014”, May 1 2015

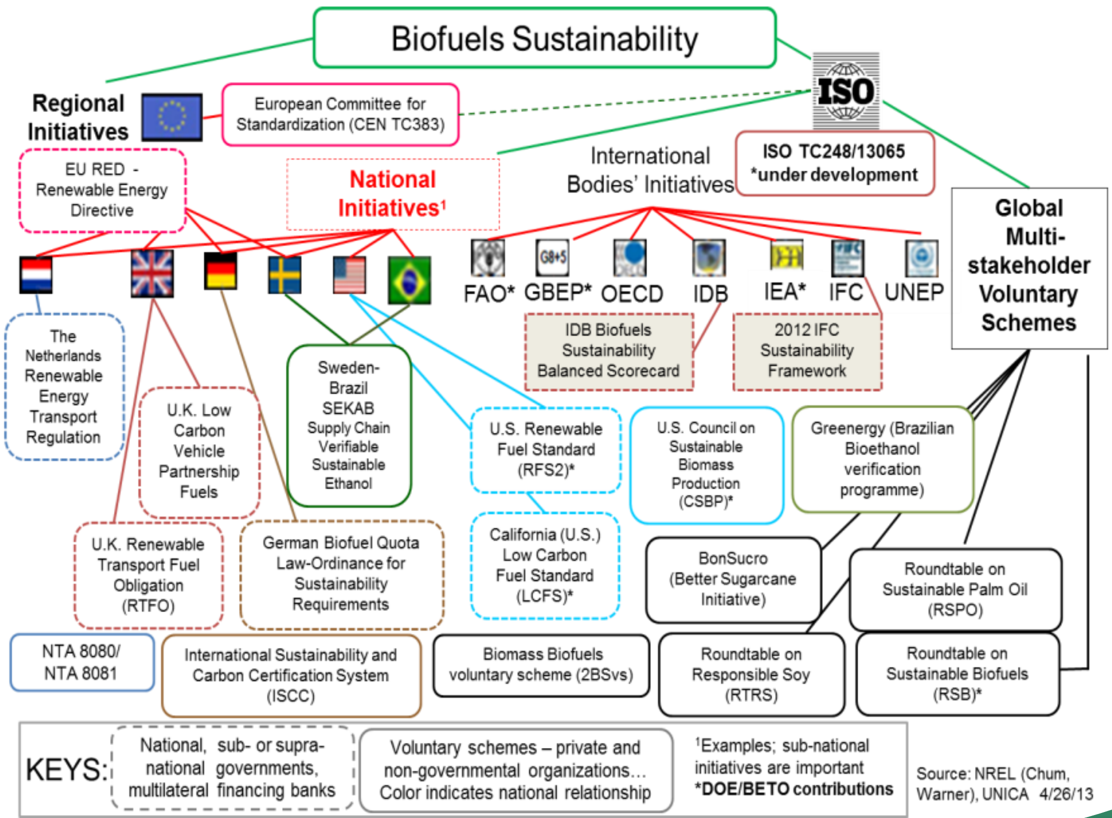
Relevance - Models of indirect effects

- **Searchinger was among the first to get wide publicity (e.g., Searchinger et al. 2009, Science)**
  - **high estimates of GHG emissions coming from ILUC**

- **The indirect effects argument gained traction (e.g., "Maized and confused," The Economist)**
  - **policy makers began to respond (CA & Federal)**
  - **researchers and scientists argued for additional scrutiny**
  - **rebuttals by scientists engaged in LCAs advised caution (e.g., Wang and Haq 2008).**

Emergence of sustainability schemes

- Full life cycle assessment of emissions: the entire life of the fuel,
  - "cradle" (cultivation) → "grave" (use/disposal)
- 2007 to present: Multiple groups created sustainability certification programs



Approach to looking at indirect effects

International Organization for Standardization (ISO) 13065

- **Global reach and impact**
  - **163 member countries**
  - **19,500 published International Standards**
- **Rio 1992: Series of Environmental Standards (ISO 14000)**
  - **250,000 users**
  - **Applied in 155 countries**
- **Social Responsibility (ISO 26000:2010)**
- **ISO 14064:2006 and ISO 14065:2007 standards to provide**
  - **An internationally agreed framework for measuring GHGs**
  - **so that " a tonne of carbon is always a tonne of carbon"**
- **Rio+20 ISO commitment to foster Sustainable Development**

International Organization for Standardization (ISO) 13065

"Sustainability Criteria for Bioenergy"

Photo credit: DIN staff, Friday, Jan 23rd, Final Plenary for ISO PC 248

International Organization for Standardization (ISO) 13065 "Sustainability Criteria for Bioenergy"

- **Project committee 248 Mandate:**
  - **"Standardization in the field of sustainability criteria for production, supply chain and application of bioenergy. This includes terminology and aspects related to the sustainability (e.g. environmental, social and economic) of bioenergy"**
- **Working Group 4, creation (volunteer member base) and mandate ("report on state of the science of indirect effects")**
  - **General agreement in scientific community that uncertainty in ILUC calculations is far beyond acceptable for quantitative sciences (Finkbeiner 2013)**
  - **disagreement in the WG, polarized opinions on range (high or low end)**

Conclusions

Results of WG4

- “(T)he state of science, in terms of evidence based research, is inconclusive or contradictory regarding indirect effects of bioenergy. …
- An economic operator should not be held responsible for indirect effects and variables that are outside the operator’s control.”
- “Recent modeling (of indirect effects) has highlighted potential impacts as well as the high variability in results though much of the modeling thus far has relied on assumptions that may not be supported by empirical evidence.

Results of WG4

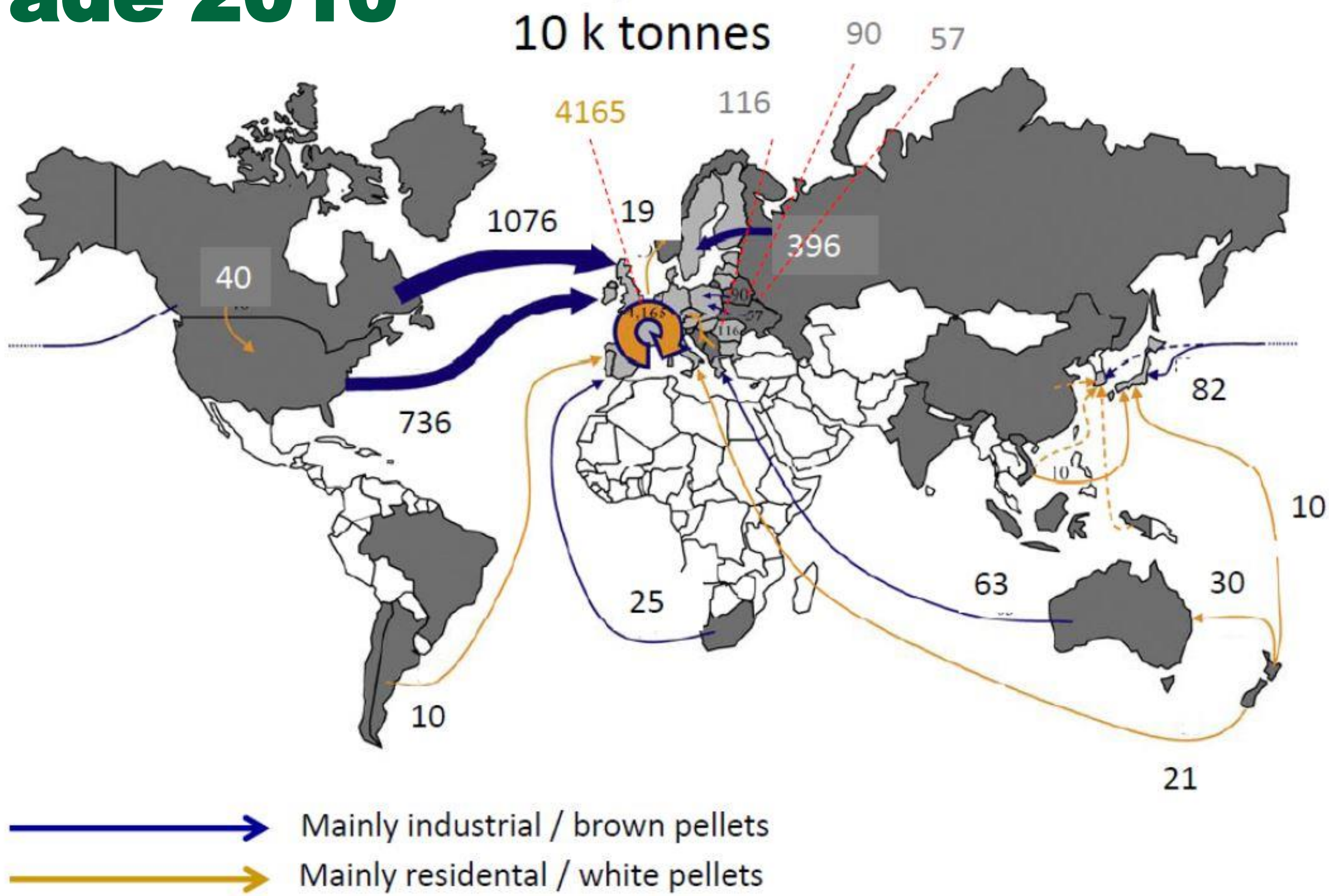
- **“To date, there has been limited causal analysis to support assumptions underlying indirect effects modeling.”**
- **“There needs to be equitable treatment of direct and indirect effects for any energy options being analyzed including baseline fuel(s) that would be replaced by proposed bioenergy sources.”**
- **ISO13065 is limited to direct effects**

ISO 13065 Final Wording:

Direct and indirect effects

- "In developing this International Standard, issues concerning direct and indirect effects were carefully considered. The aim of this International Standard is to provide clear guidance to produce consistent and replicable results. The term "indirect effects" can be understood in different ways due to various opinions and definitions.
- **This International Standard considers the measurable environmental, social and economic effects that are under the direct control of the economic operator and caused by the process being assessed."**
- **Science Based Approach Preference**

Relevance – Global wood pellet trade 2010



Source: Lamers et al., RSER, 16 (2012) 3176-3199

Path forward:

Science based approach
Causal Analysis: attribution and drivers of change

“equitable treatment of direct and indirect effects for any energy options being analyzed including baseline fuel(s) that would be replaced by proposed bioenergy sources.”

- Scales are different

Thank you!

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

See the website for

- **Reports**
- **Forums**
- **Other presentations**
- **Recent publications**

Collaborators include
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Z Haq, K Johnson, A Lindauer, A Goss-Eng.

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The views in this presentation are those of the authors who are responsible for any errors or omissions.

References

Oak Ridge National Laboratory

- ISO 13065 available at: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=52528
- Lamers et al., 2011. ”International bioenergy trade--A review of past developments in the liquid biofuel market”, RSER, 15 2655– 2676
- USDA FAS “U.S. Ethanol Exports Rebound in 2014”, May 1 2015 http://www.fas.usda.gov/data/us-ethanol-exports-rebound-2014
- Lamers, P., M. Junginger, C. Hamelinck, A. Faaij, 2012. Developments in international solid biofuel trade—An analysis of volumes, policies, and market factors Renewable and Sustainable Energy Reviews 06/2012; 16(5):3176-3199. DOI:10.1016/j.rser.2012.02.027
- Finkbeiner, M., (2013). Indirect Land Use Change (iLUC) within Life Cycle Assessment (LCA) – Scientific Robustness and Consistency with International Standards. March 29, 2013 Publication of the Association of the German Biofuel Industry, Berlin, Germany. Available at: http://www.fediol.eu/data/RZ_VDB_0030_Vorstudie_ENG_Komplett.pdf
- Searchinger, T. D., Hamburg, S. P., et al. (2009). Fixing a Critical Climate Accounting Error. Science 326(5952): 527-528.
- "Maized and confused,” The Economist 2009-08-10. Retrieved 2009-08-10
- Michael Wang and Zia Haq (2008-03-14). "Letter to Science about Searchinger et al. article" (PDF). Argonne National Laboratory. Retrieved 2009-06-07. The published version on Science Letters is included in Searchinger E-Letter responses 2008-08-12
- Timilsina, G.R., & Mevel, S. (2011). Biofuels and Climate Change Mitigation: A CGE Analysis Incorporating Land-Use Change. Policy Research Working Paper, World Bank. Available at: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2011/06/02/000158349_20110602160352/Rendered/PDF/WPS5672.pdf
- Oladosu, G., Kline, K., Uria-Martinez, R., & Eaton, L. (2011). Corn Ethanol Sources Decomposition Analysis empirical data and ILUC: Sources of corn for ethanol production in the United States: a decomposition analysis of the empirical data. Biofuels, Bioproducts and Biorefining, 305. Available at: http://onlinelibrary.wiley.com/doi/10.1002/bbb.305/abstract.
- Oladosu, G., Kline, K., Leiby, P., Uria-Martinez, R., Davis, M., Downing, M. & Eaton, L. (2012). Global economic effects of US biofuel policy and the potential contribution from advanced biofuels. Future Science – Biofuels 3(6):703-723.
- Kloverpris, J.H., Mueller, S. (2012). Baseline time accounting: Considering global land use dynamics when estimating the climate impact of indirect land use change caused by biofuels. DOI 10.1007/s11367-012-0488-6
- Kim, S., Dale, B.E., Ong, R.G. (2012). An alternative approach to indirect land use change: Allocating greenhouse gas effects among different uses of land. Biomass and Bioenergy 46:447-452. Available online: http://dx.doi.org/10.1016/j.biombioe.2012.07.015
- 115. Njakou Djomo, S. & Ceulemans, R. (2012). A comparative analysis of the carbon intensity of biofuels caused by land use changes. Journal of Global Change Biology Bioenergy 4: 392–407. doi: 10.1111/j.1757-1707.2012.01176.x
- RSB, 2015. RSB Low iLUC Risk Biomass Criteria and Compliance Indicators. Available at: http://www.rsb.org/pdfs/standards/RSB-STD-04-001-ver0.3RSBLowiLUCCriteriaIndicators.pdf

Supplemental slides
WG4 Literature Review

Models of indirect effects Varying estimates

- **More studies were released countering the high-ILUC and associated emissions estimates. E.g.,**
  - **Timilsina and Mevel (2011): annual rate of deforestation does not increase proportionally along with annual rate of biofuel expansion**
- **Other studies counseled for different approaches to how ILUC was calculated. E.g.,**
  - **Oladosu et al. (2011):**
    - **science-based method (empirical data, replicable methods),**
    - **systematic analysis of historic U.S. data**
    - **found no scientific support for assumptions used in modeling indirect effects of U.S. biofuels.**
      - **See also Oladosu et al. (2012)**

Models of indirect effects papers examining differing methods

- **Baseline land use assumptions:**
  - Using a static land use baseline is incorrect:
    - Static: ILUC leads to a one-time expansion of an otherwise fixed agricultural area.
  - Kloverpris and Mueller (2012):
    - actual impact of ILUC (using dynamic land use baseline) may:
      - bring land into production sooner than otherwise (accelerated expansion)
      - and/or delay agricultural land from going out of production (delayed reversion)
    - no gross expansion of cropland area in the developed world from 1998 to 2007
- **Attribution to drivers:**
  - Kim et al. (2012): multiple drivers of LUC exist, allocation of GHG releases should be distributed
  - GHG estimates in the GTAP model, allocation techniques: lower ILUC GHG estimates by up to 73%

Models of indirect effects Continued uncertainty

Njakou Djomo, S. & Ceulemans, R. (2012):

- **Standardization of methods:**
  - more consistency, comparability among models;
  - still lacking better estimates
- **estimates of ILUC depend on input parameters:**
  - highly uncertain
  - based on other models and assumptions
- **sources of uncertainty:**
  - crop yields,
  - coproducts,
  - carbon stocks of different,
  - yield elasticity on price.