Perspectives from USDA research…. Hot Feedstocks for SAF.

William Orts
USDA Western Regional Research Center

Our USDA Research Mission:

Add value to agricultural products to help the rural economy

Agricultural Research Service

USDA's chief scientific research agency

1,800 PhD-level scientists

120+ research locations

ARS is the in-house research arm of the USDA.

USDA Western Regional Research Center

The Center has ~350 people,

~45 in bioproducts & biofuels.

We partner with companies and industry groups to take bioproducts to market.

Partnerships:

Providing viable solutions to the industry is a primary mission driver

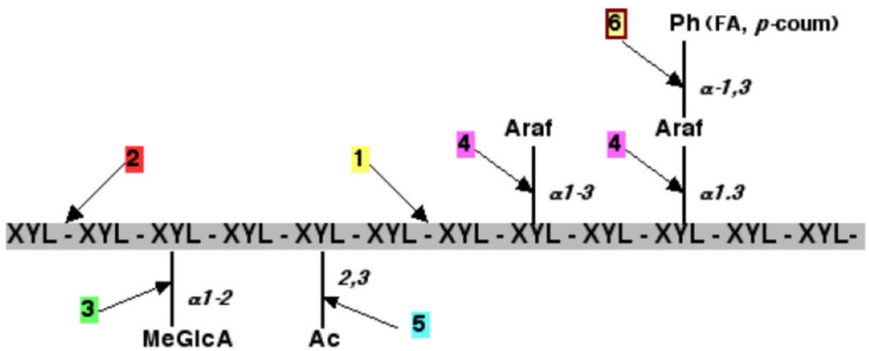
We partner with companies and industry groups to take bioproducts to market.

USDA Projects: Biorefinery Development

Mission: 2020-2025

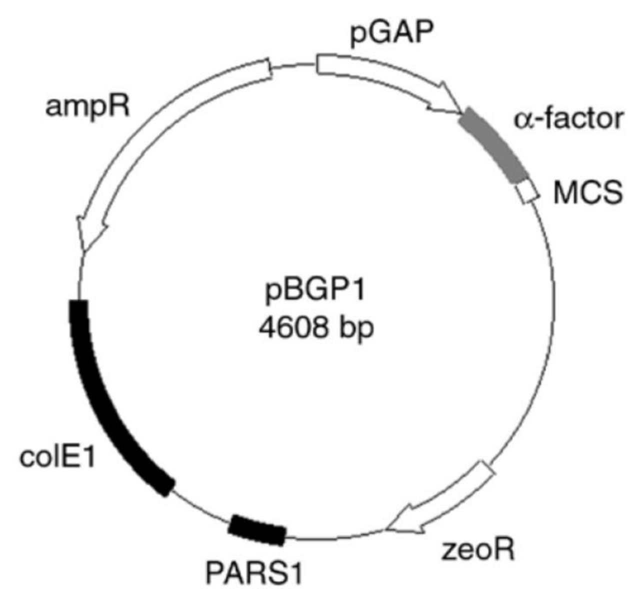
1. Bioproducts and Biopolymers from Ag Feedstocks
2. Zero Waste Agricultural Processing
3. Domestic Production of Natural Rubber and Resins

Biomass-degrading enzymes: cloning, characterizations, engineering

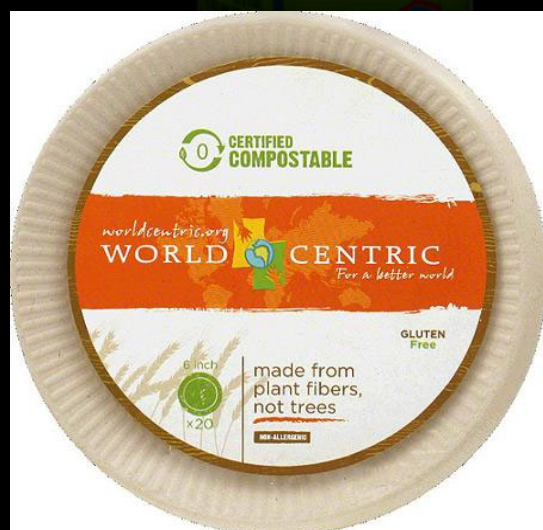


1 endo-β-1,4-xylanase (EC 3..2.1.8)
2 β-xylosidase (EC 3.2.1.37) or exo-β-xylanase
3 α-glucuronidase (EC 3.2.1.139)
4 α-L-arabinofuranosidase (EC 3.2.1.55)
5 acetylxylan esterase (EC 3.1.1.72)
6 feruloyl esterase (EC 3.1.1.73)

- ❖Constructed and screened metagenomic DNA libraries
- ❖Designed new high-throughput discovery assays
- ❖Developed new expression reagents
- ❖Isolated >40 novel genes
- ❖Executed >60 MTAs



USDA - Partnerships

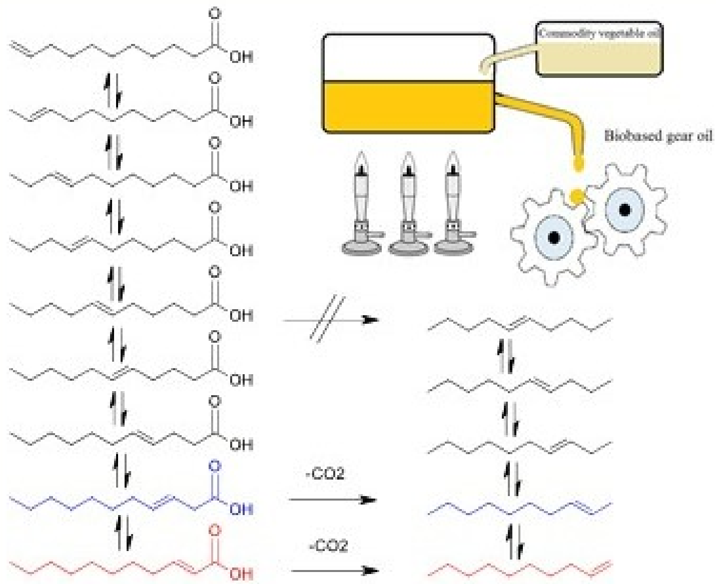


USDA research on biomass conversion to SAF

Conversion of Biobased Materials into Chemicals and Fuels and Electroactive Materials

Kenneth M. Doll, Ph.D.
USDA, ARS, NCAUR, Bio-Oils Research – Peoria, Illinois
kenneth.doll@usda.gov (309) 681-6103

- Lead Scientist and with a PhD in organic chemistry
- Experience in the chemical modification of vegetable oils and agricultural products into value-added industrial products
- Multiple vegetable oil-based chemical derivative families
- Decarboxylation technology for polymer and fuel use
- Publication of ~100 peer-reviewed publications and U.S. patents (ORCID: 0000-0002-5328-7848)



Proximate isomers exhibit facile decarboxylation

Decarboxylation of fatty acids

- Mechanistic study
  - Isomerization-based mechanism
- Multiple catalysts
  - Ruthenium
  - Osmium
  - Iridium
- Renewable jet fuel from vegetable oils
- Composition mimics conventional jet fuel

Research on biobased lubricants

- New evaluation of lubrication methods
- Additives based on boron or phosphorous in combination with vegetable oils

Introduction

Conversion Technologies:
End-products

Infrastructure:
Collection & storage

- In the past, funding did not necessarily focus on the need for infrastructure.
- Hot feedstocks ⇔
  - Crop residues
  - Energy crops – specifically grown for biofuels
  - Food/Ag-processing wastes.
  - Gathered biomass sources -- landfills, wastewater treatment facilities, MRFs, ……Wherever there's biomass

- There is no single answer – Solutions will be regional, smaller.

- Collaboration across industries, academia and government will be essential.

Energy Policy: The way things were supposed to be…..

Renewable Fuel Standard-2 (RFS2). It's the law!

36 billion gallons/year by 2022

Biofuels Technology	2020 Statutory*	2020 Final
Corn grain ethanol	15*	13.8
Biomass – Biodiesel	1.5	2.4
Advanced biofuels	12	5.1
Cellulosic biofuels	10.5	0.6
Total biofuels	30++	21.9

Need to catch up!

* Targets are adjusted yearly.

Crop residues to feed biorefineries

ISSUES:

- Straw varies with seasons
- Aging ⇔ harvest time is once per year
- Moisture and storage are challenging
- Transportation ⇔ Low density
- Supply is not near highest demand.

Purpose-Grown Energy Crops

Sorghum

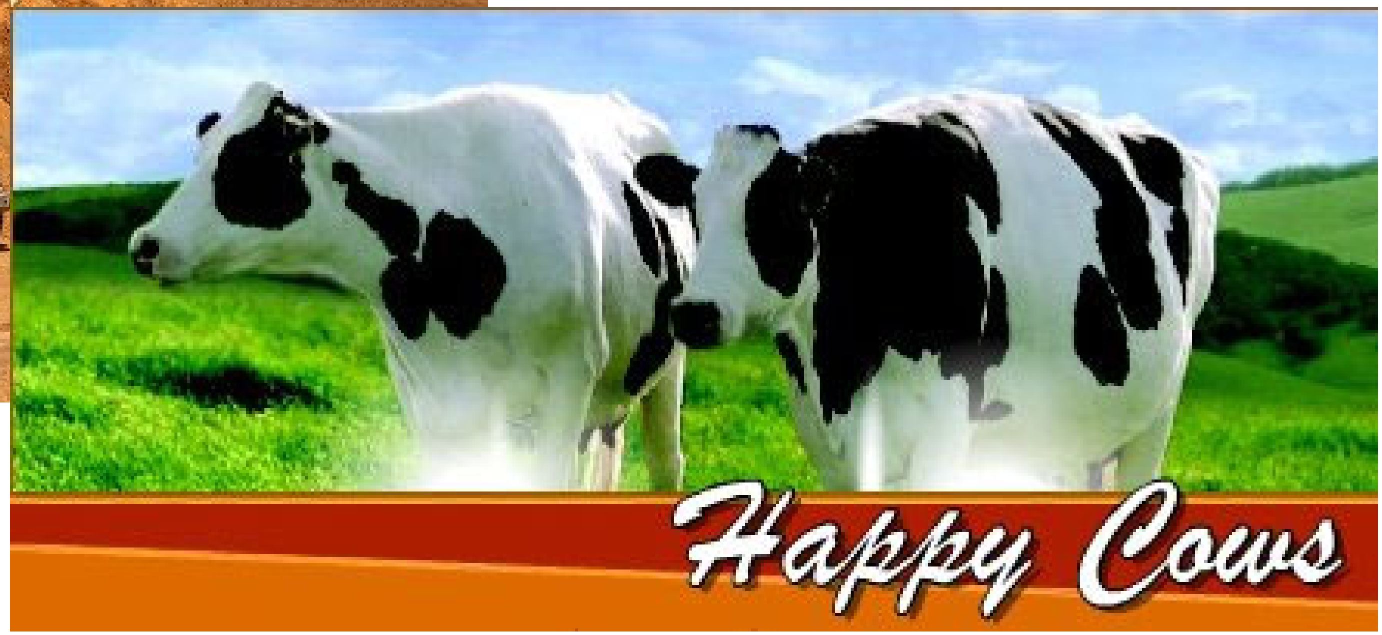
Miscanthus

- Bioconversion ?1?
- How to convert this complex lignocellulosic crop to useful pulp?
- Seasonality???
- Storage – Who stores it?
- Seeds – How do we create a sustainable crop “industry”?
- Who “fights” for this crop?

Switchgrass

Arundo Donax

Almond Trees Produce Three Co-products



California’s cows happily eat almond co-products

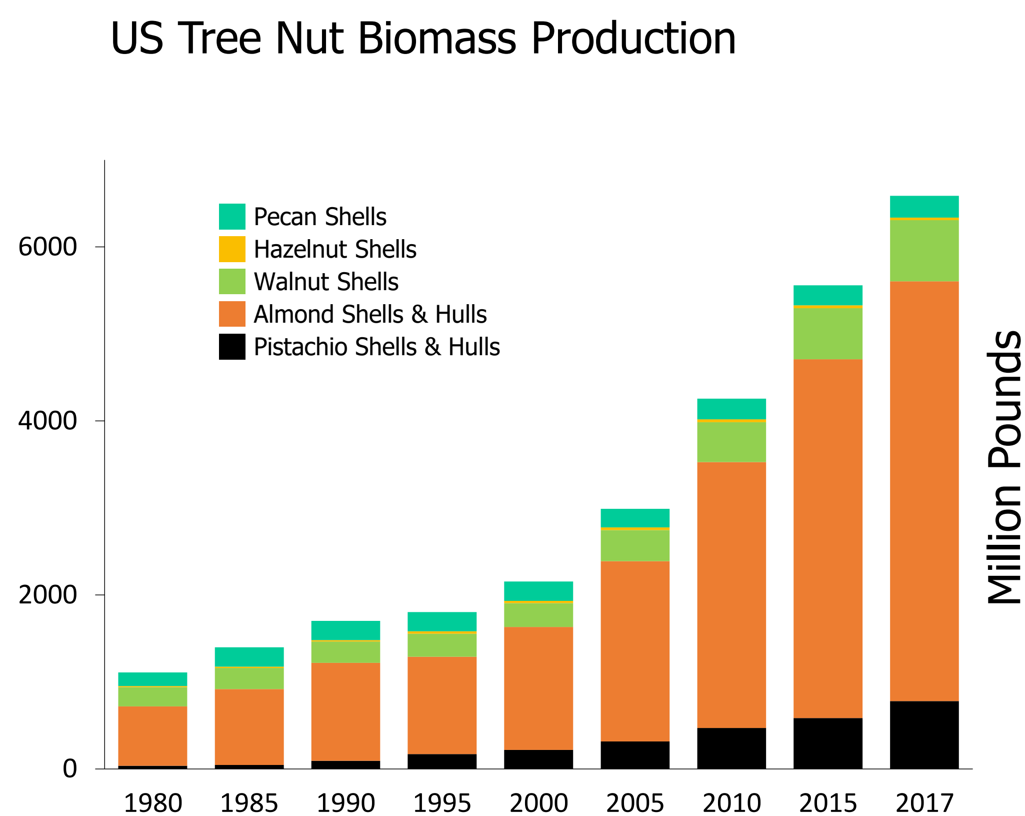
But lately, due to drought, changes in markets, land costs, etc.

There are fewer cows and lots more almonds….

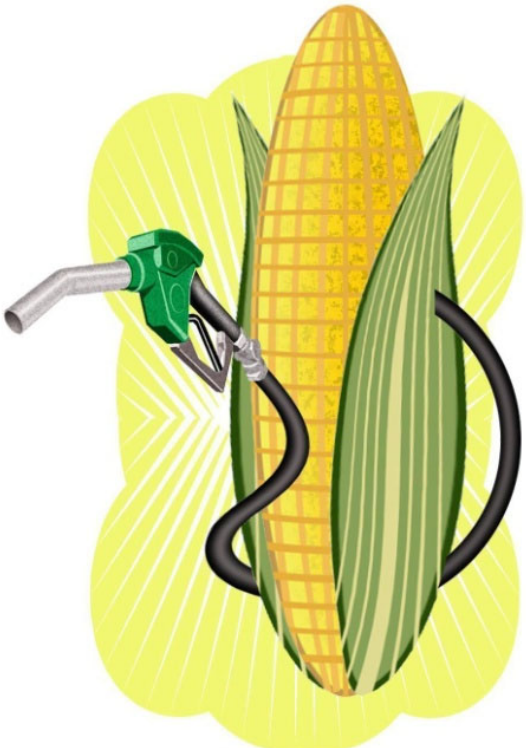
Agricultural Coproducts & Residues

California produces 82% of the world's almonds, resulting in nearly 1.5 billion pounds of shells annually.

New markets for almond shells and other agricultural byproducts are needed.



Should we make fuel ethanol from almond hulls?



Sugars in Almond Hulls

	% Sucrose	% Glucose	% Fructose	% Fermentable sugars	% Xylose	% Inositol	% Sorbitol	% Total sugars
Non-Pareil	3.84	17.61	15.04	36.49	1.03	2.36	4.37	44.24
Butte/ Padre	0.38	12.87	12.55	25.80	0.77	0.99	2.84	30.40
Cali-fornia	0.14	6.79	3.53	10.46	0.64	1.89	1.76	14.75

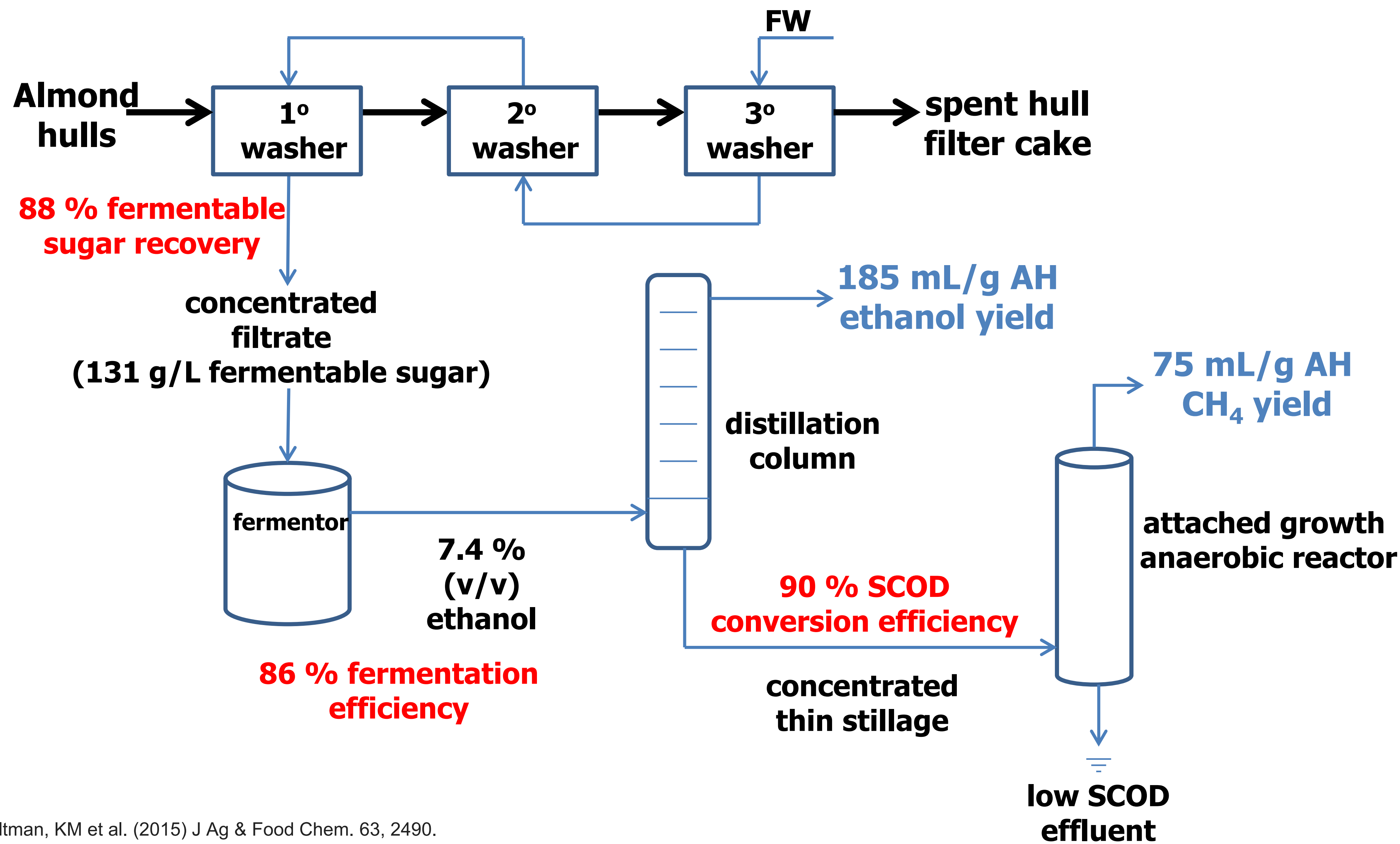
Almond hulls as a biofuels feedstock: variations in carbohydrates by variety and location in California
RD Offeman, KM Holtman, KM Covello, WJ Orts (2014). Ind Crops & Prod. 54, 109.

Almond Hulls vs. Sugar Beets

Almond Hulls
30-35% sugar

Sugar Beet Cossettes
15-20% sugar

Integrated Ethanol Plant



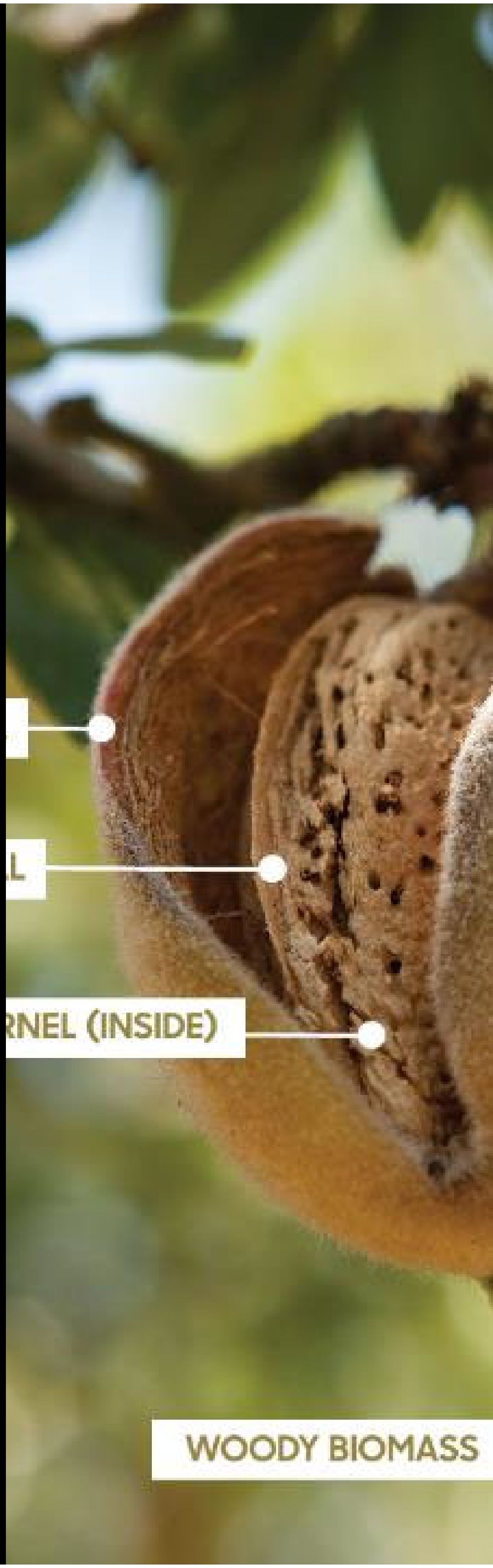
Holtman, KM et al. (2015) J Ag & Food Chem. 63, 2490.
Offeman, RD et al. (2015) Ind Crops & Prod. 65, 488.
Orts, WJ, Holtman, KM, Seiber (2008) J Ag & Food Chem. 11, 3892.

Ethanol Production from Hull Sugars?

Raw Feed	$/ton	% sugar	Sugar (lbs)	Ethanol (gal)	$/gal Ethanol
Corn kernels	132		1286	95	1.38
Sugar beets	39	18.5	370	27	1.42
Molasses (feed)	180	79.5	1590	118	1.52
Sugar cane	39	14	280	21	1.88
Almond hulls	**150**	**31**	**624**	**40**	**3.83**

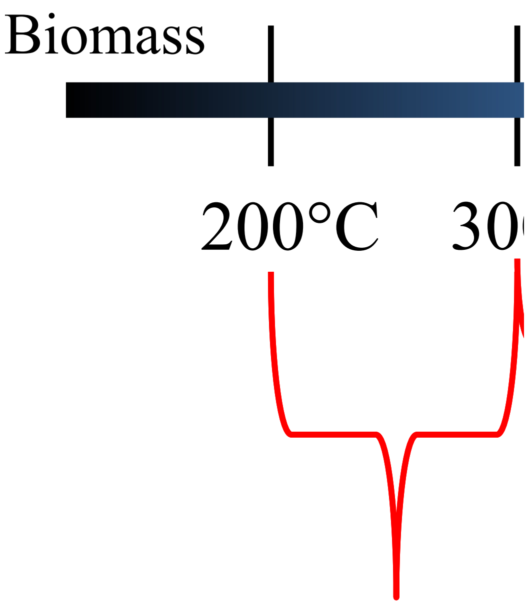
Should we make fuel ethanol from almond hulls?

What about the shells?



Torrefaction ⇔ Charcoal Production

Processing Temperature



Torrefaction

Densifies the biomass

Removes moisture and volatiles

Torrefied Almond Shells in Recycled Plastics

TRANPAK

USDA

Funded By CalRecycle

F-D-S Manufacturing Co.
Since 1950

RPAC LLC
ALMOND GROWER & PROCESSOR

Integrated Biorefinery Based on MSW and Ag-Derived Biomass

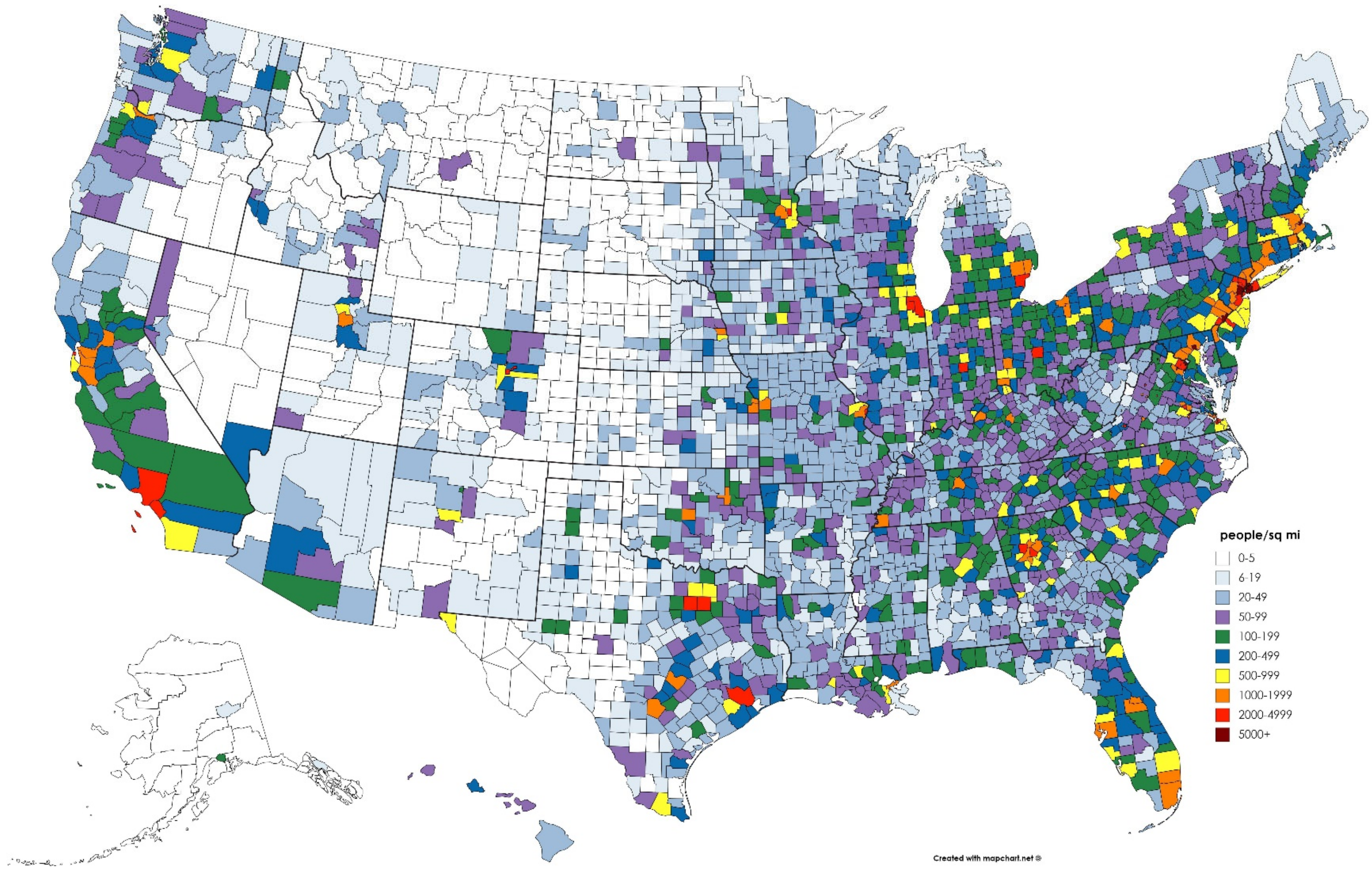
USDA

jbei
Joint BioEnergy Institute

SALINAS VALLEY
SOLID WASTE AUTHORITY
Promoting the Environmental Health of the Salinas Valley

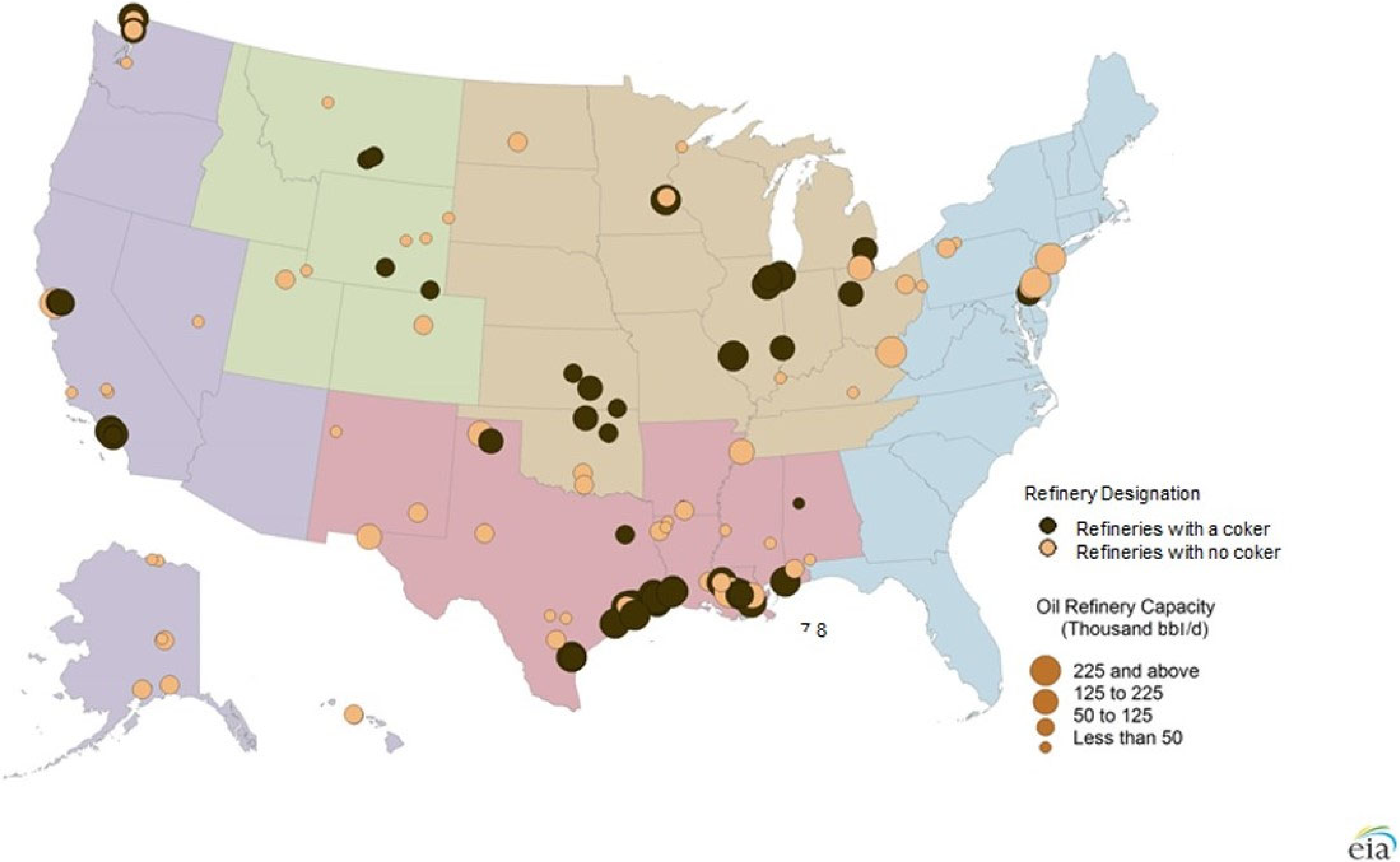
Reduce Recycle Reuse

U.S. Population Density



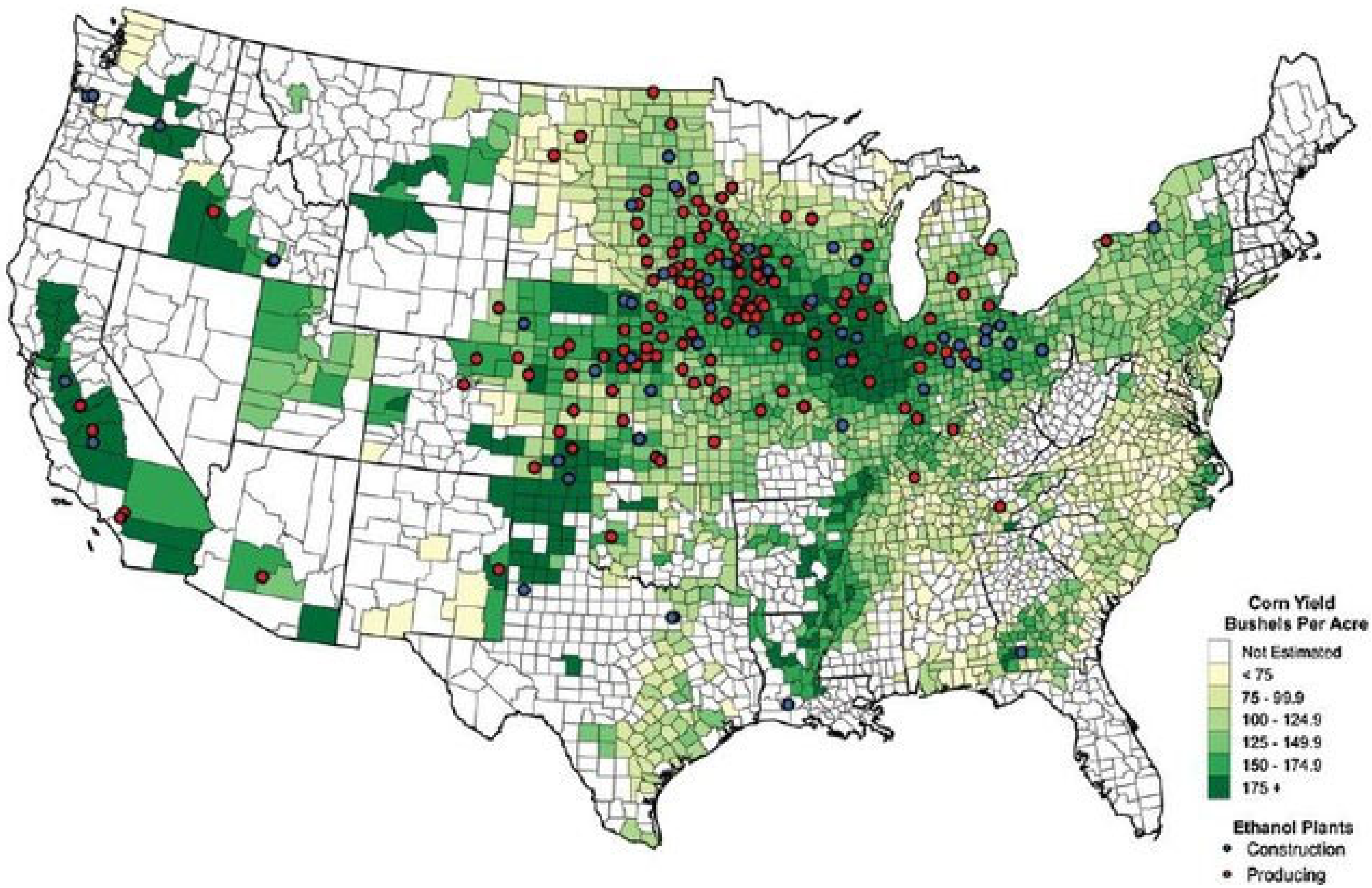
https://www.reddit.com/r/MapPorn/comments/8njjhx/the_population_density_of_the_us_by_county/

U.S. Oil Refineries



https://www.eia.gov/todayinenergy/detail.php?id=19591

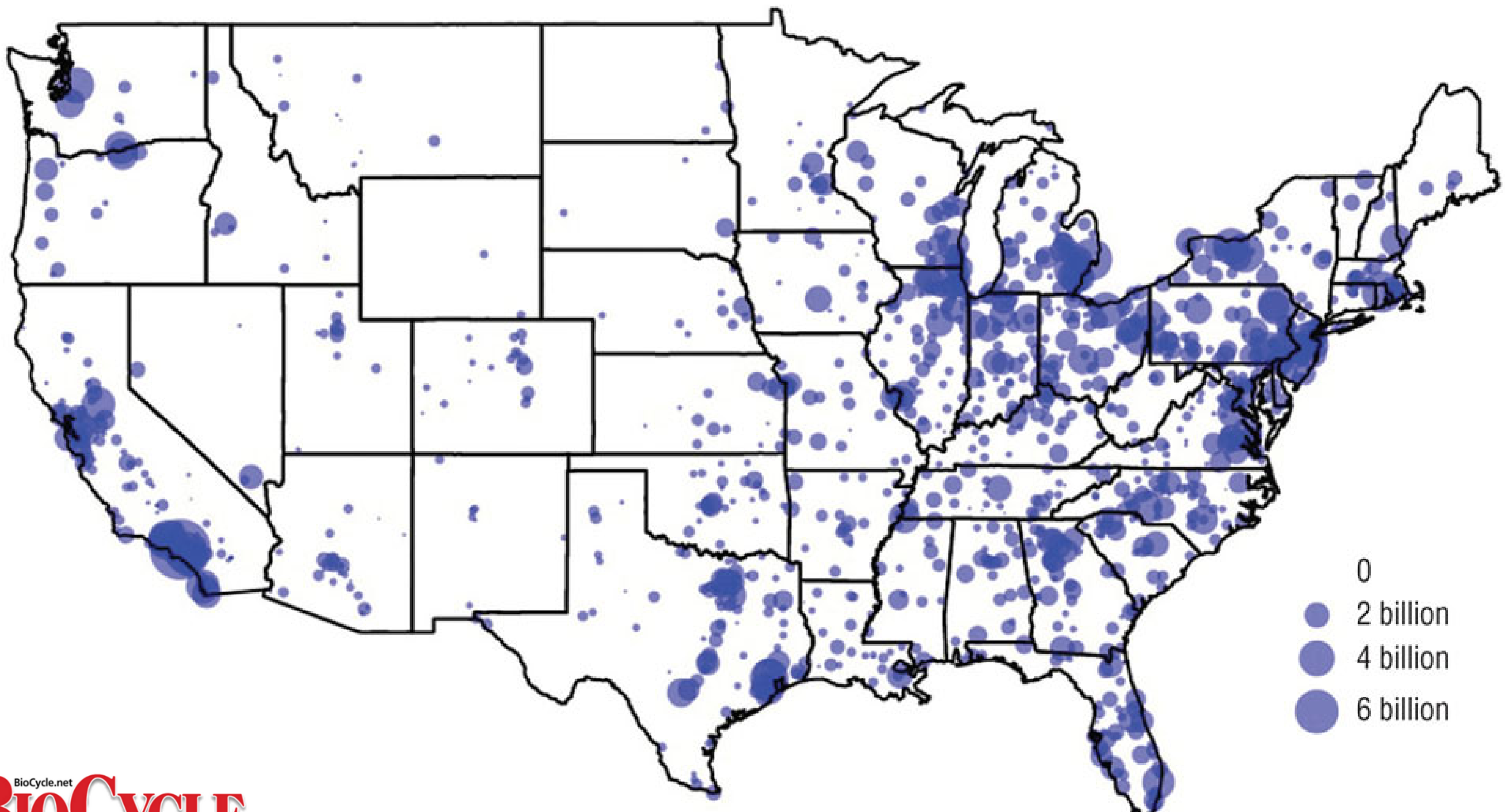
U.S. Ethanol Plants: Biorefineries



https://ethanolrfa.org/biorefinery-locations/

Landfills and their Methane Potential

Location of methane production at landfill point sources in continental U.S. (SCFY)[1]



A.E. Schauer-Gimenez, A.J. Cal, M-C. Morse, A.J. Pieja, K.M. Holtman and W.J. Orts   BioCycle November 2014, Vol. 55, No. 10, p. 43

Autoclaving solid waste

- Pressurized hot water treatment.
- Reduces volume.
- Isolates recyclables.

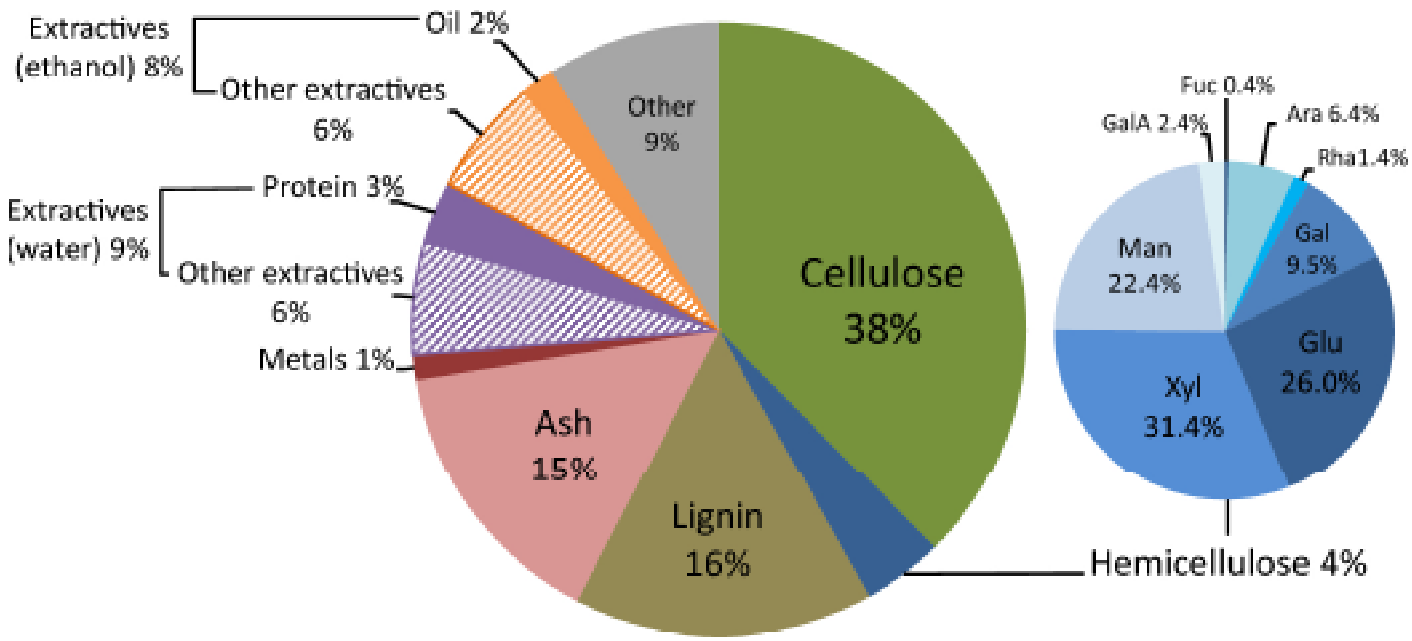


Figure 4. Percentage composition of MSW fiber produced on the Wilson Bio-Chemical Pilot Autoclave. (Dornau et al., 2019).

Salinas Crazy Horse Landfill

SALINAS VALLEY
SOLID WASTE AUTHORITY
Promoting the Environmental Health of the Salinas Valley
Reduce Recycle Reuse

Two-ton batch autoclave, Salinas, CA

Conveyor loading MSW to autoclave

MSW in the autoclave prior to treatment

MSW after steam treatment

Post-autoclave MSW sorting

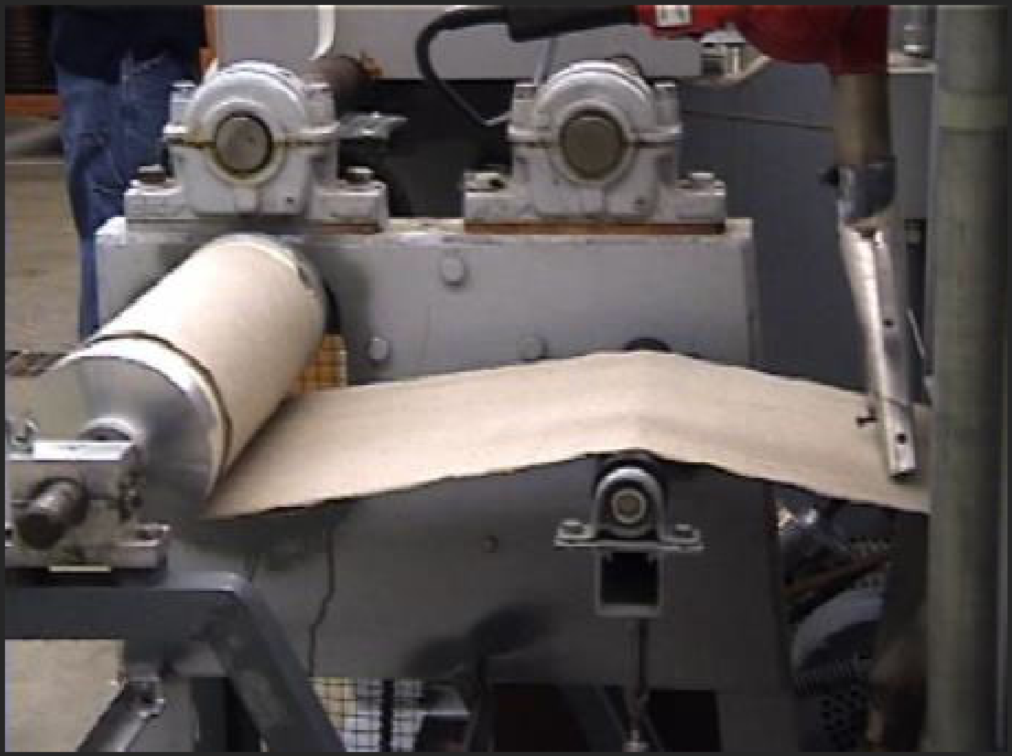
3/8” ½” 1” >1”

Trommel Screen Side View

Trommel Screen Front

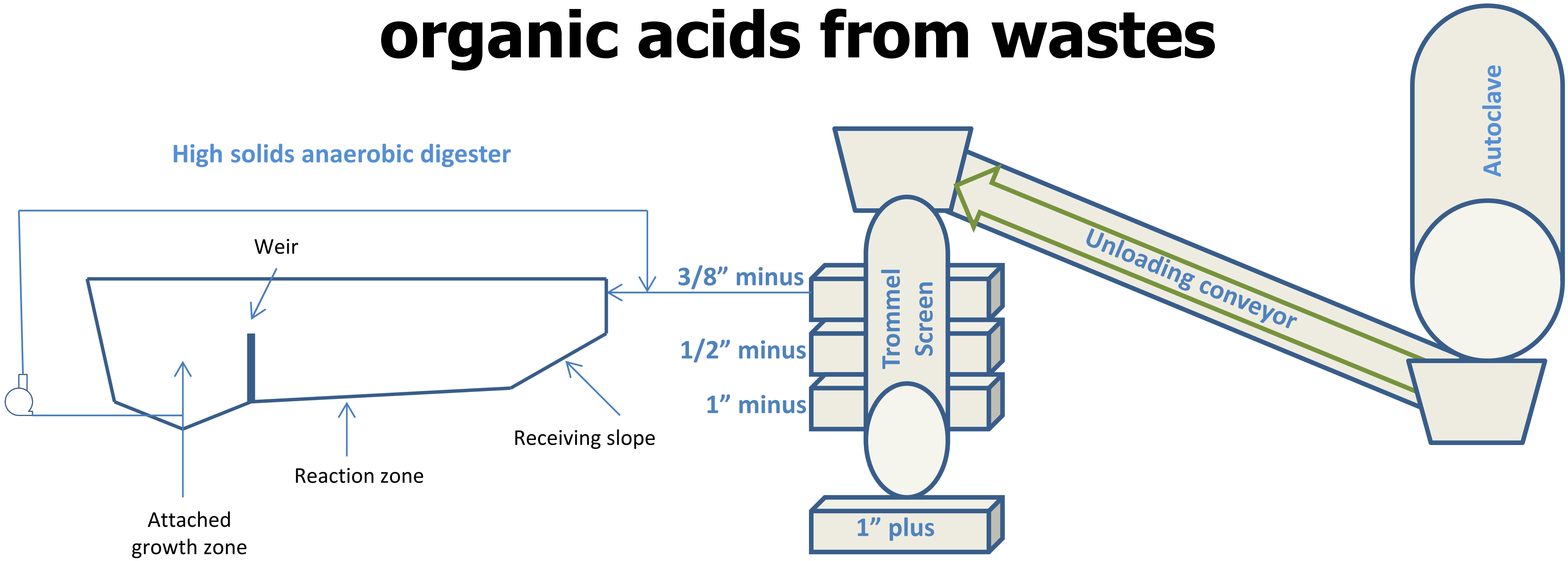
Fiber from MSW after centrifugal cleaners

Cellulose from autoclaved MSW



Processed paper from recovered fiber

Anaerobic digestion: Methane and organic acids from wastes



SALINAS VALLEY
SOLID WASTE AUTHORITY
Promoting the Environmental Health of the Salinas Valley
Reduce Recycle Reuse

USDA

Kevin Holtman - USDA

One life-cycle analysis published in Science (May 8, 2008), concluded that bioelectricity produces an average 81% more transportation kilometers and 108% more emissions offsets per unit area cropland than cellulosic ethanol through either production of electric cars or through use of liquefied biomethane.

Compressed Biomethane vs Ethanol

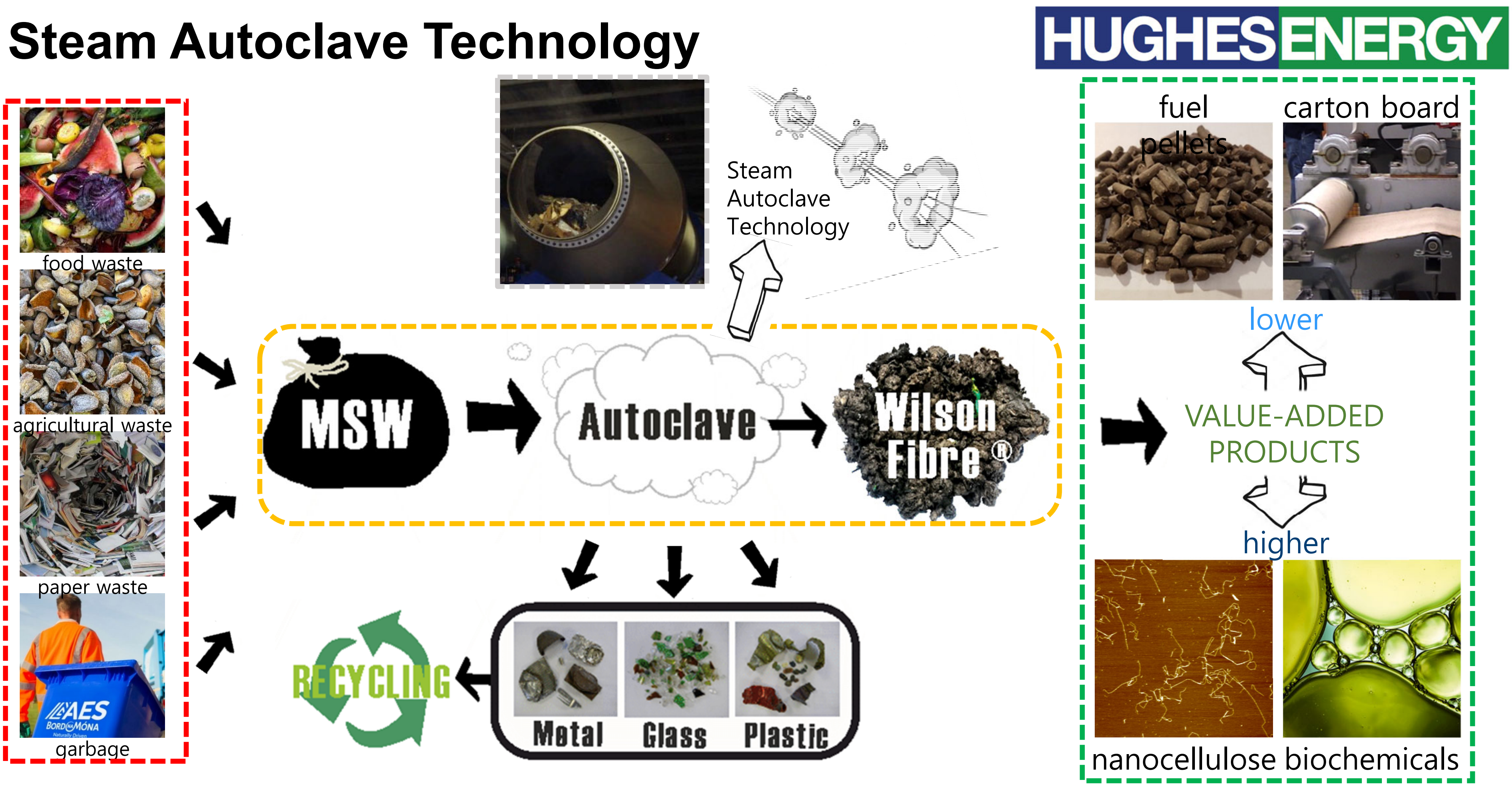
Ethanol

- **Achieve 70 gallons per mt of autoclave pulp product (dry basis).**

Biomethane

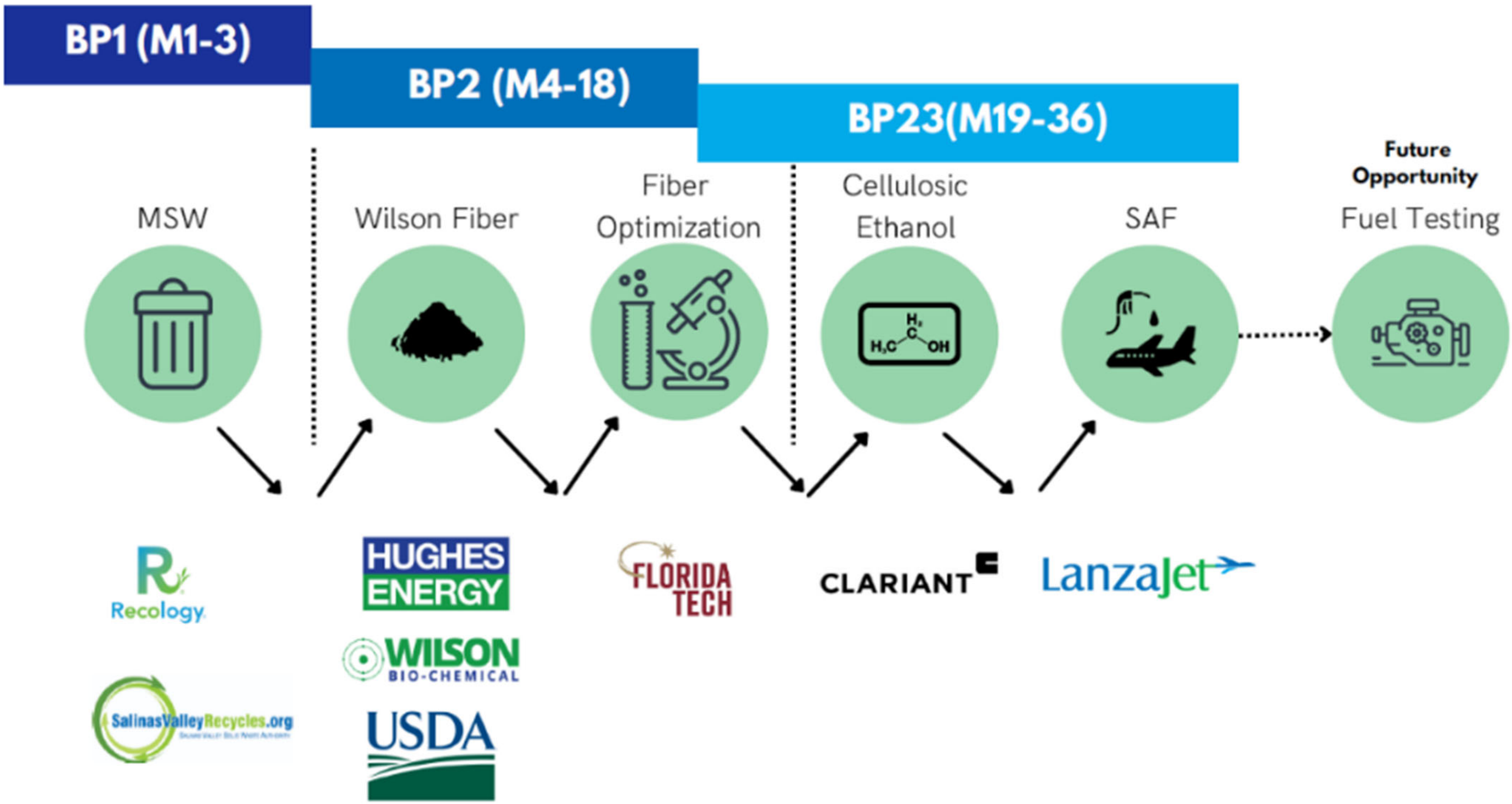
- **Achieve 428 mL CH_4/g VS with MSW pulp.**
- **99 diesel equivalent gallons per mt of autoclave pulp product (dry basis).**
- **155 ethanol equivalent gallons per mt of autoclave pulp product (dry basis).**

Steam Autoclave Technology



Bioethanol Proof of Principle

- *First drop of Bioethanol from Municipal Solid Waste - August 2022*


BP1 (M1-3)
BP2 (M4-18)
BP23(M19-36)
Future Opportunity
MSW
Wilson Fiber
Fiber Optimization
Cellulosic Ethanol
SAF
Fuel Testing
H3C
OH

Methane: Potent greenhouse gas!!

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

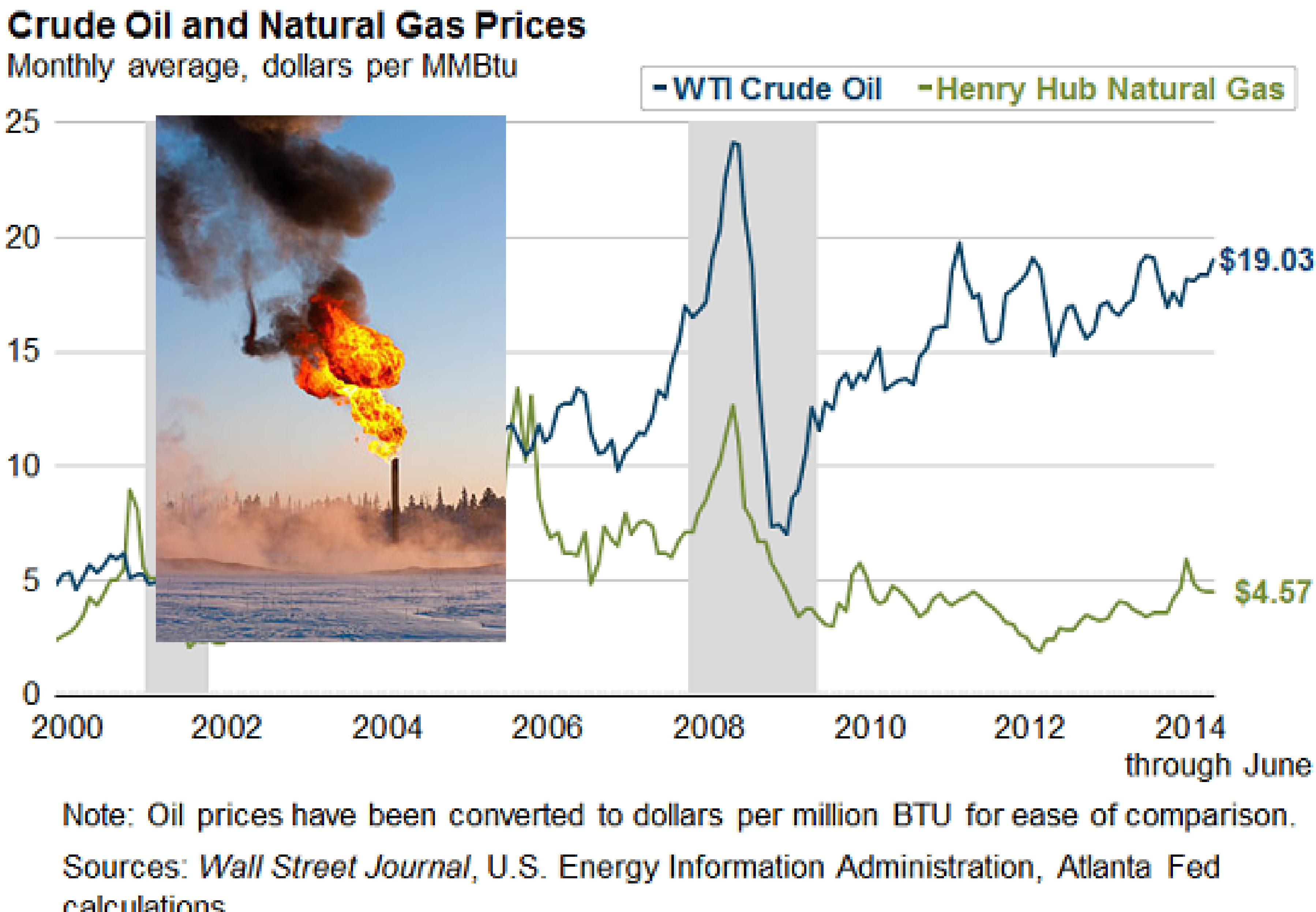
https://www.edf.org/climate/methanemaps/leaks-problem

Carbon Intensity: Carbon markets are coming….

Fuel	Pathway	Carbon Intensity Values (gCO_2/MJ)		
		Direct Emissions	Indirect/ Land Use Emissions	Total
Gasoline	CARBOB –Avg. California refinery	95.9	---	95.9
Corn Ethanol	Midwest Dry Mill; Wet DGS; 80% NG; 20% Biomass	56.8	30	86.8
Corn Ethanol	California Dry Mill; Dry DGS; 80% NG; 20% Biomass	54.2	30	84.2
CNG	California NG via pipeline;	67.7	---	67.7
CNG	Landfill gas (bio-gas) cleaned to pipeline quality.	11.3	---	11.3
CNG	Dairy Digester Gas, cleaned to pipeline quality.	13.5	---	13.5

(http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf)

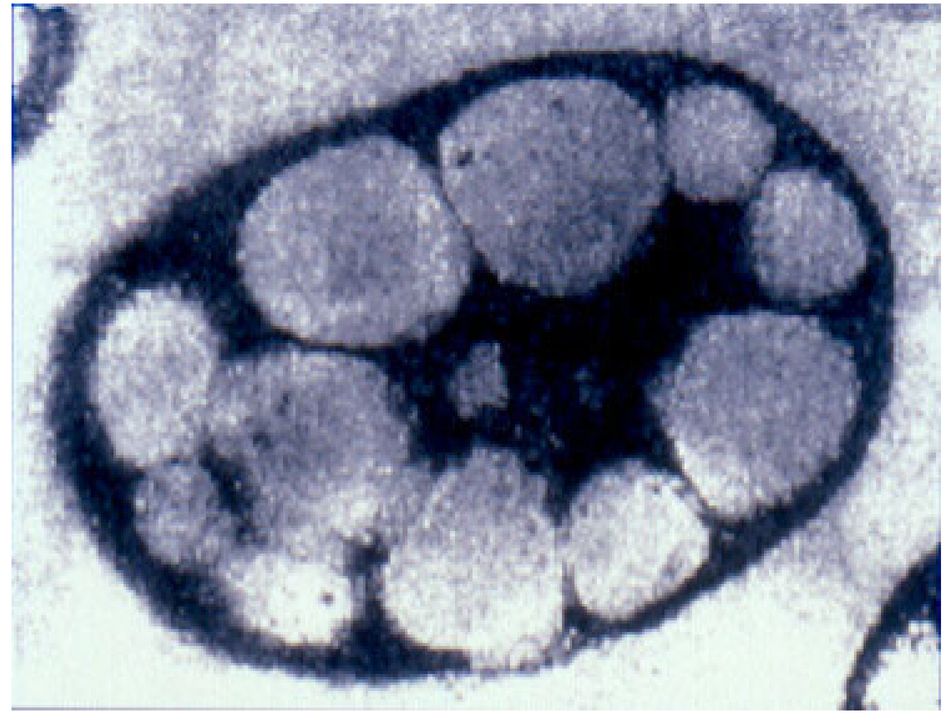
Natural Gas vs Oil Prices

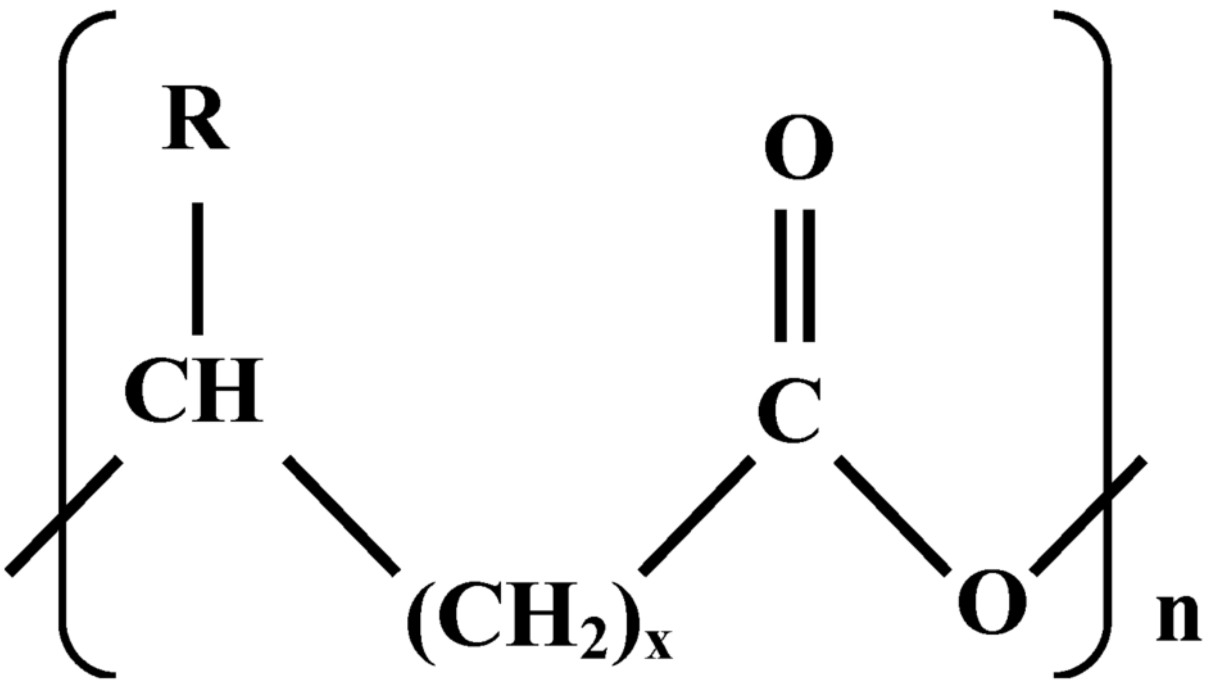


http://farmdocdaily.illinois.edu/2011/11/trends_in_crude_oil_and_natura.html

PHA Biorefineries:
PolyHydroxyAlkanoates

properties similar to polypropylene

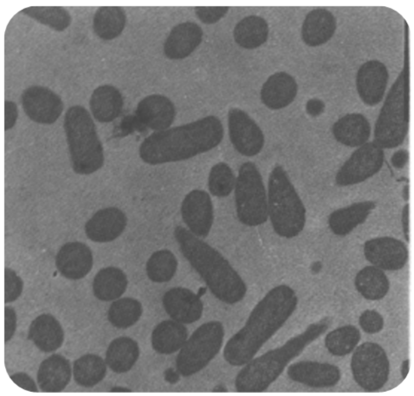




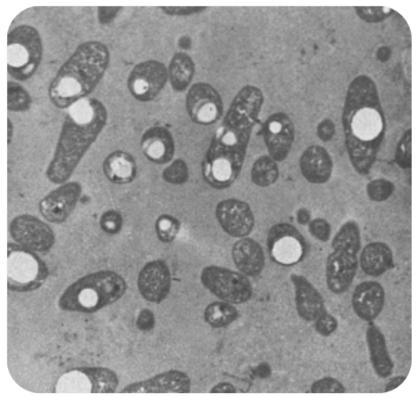
Methanotrophs producing P(HB-co-HV)

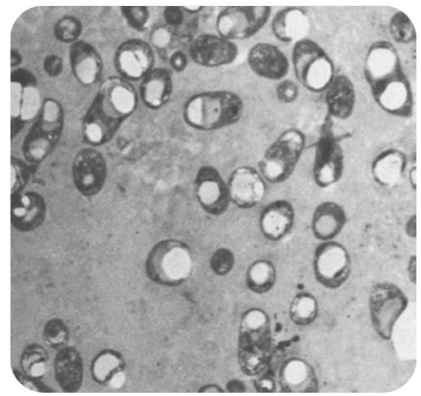
- PHA is produced when excess carbon is present and/or when a key nutrient is limiting

Balanced growth conditions



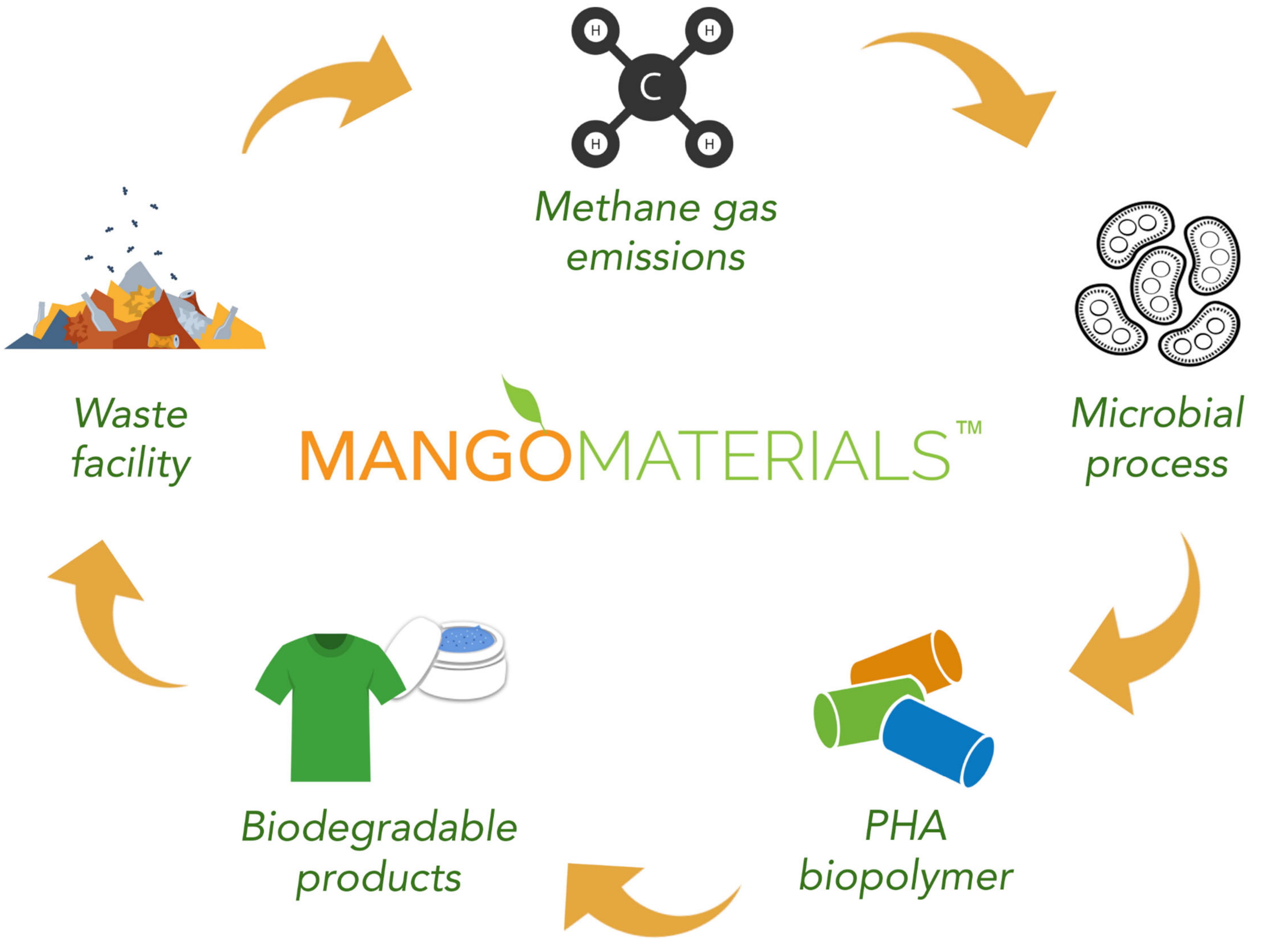
Carbon excess and/or nutrient deficiency; PHA granules begin to form

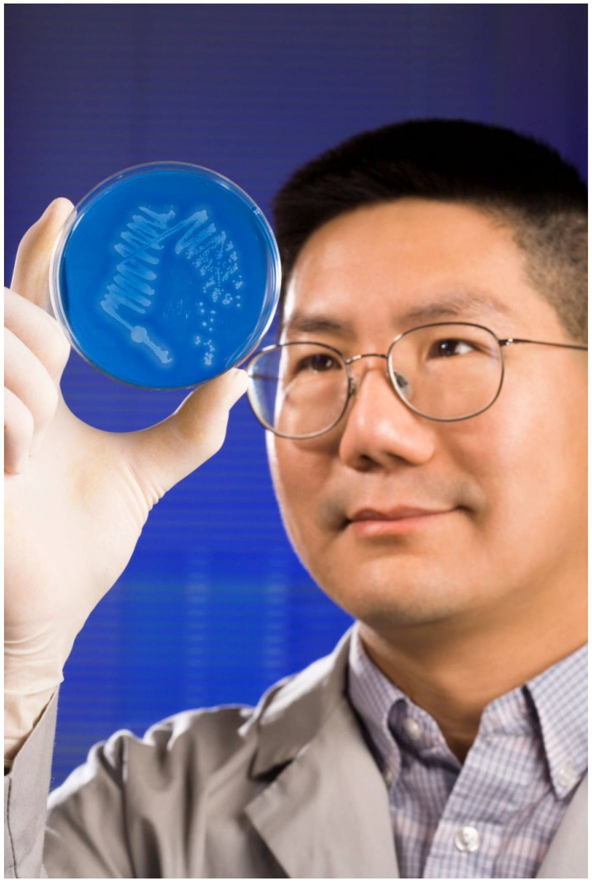




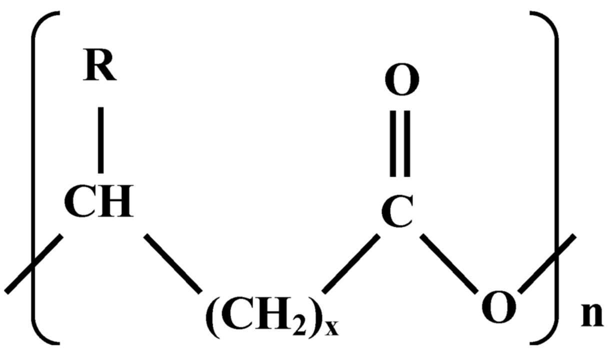
Daniel et al (1992)

- Type II methanotrophic bacteria produce PHA.
- Strain, *Methylocystis* sp. WRRC1 was capable of producing a wide range of polyhydroxybutyrate-co-hydroxyvalerate copolymers (PHB-co-HV) when co-fed methane and valerate or n-pentanol.


Methane gas emissions
Microbial process
PHA biopolymer
Biodegradable products
Waste facility
MANGOMATERIALS™

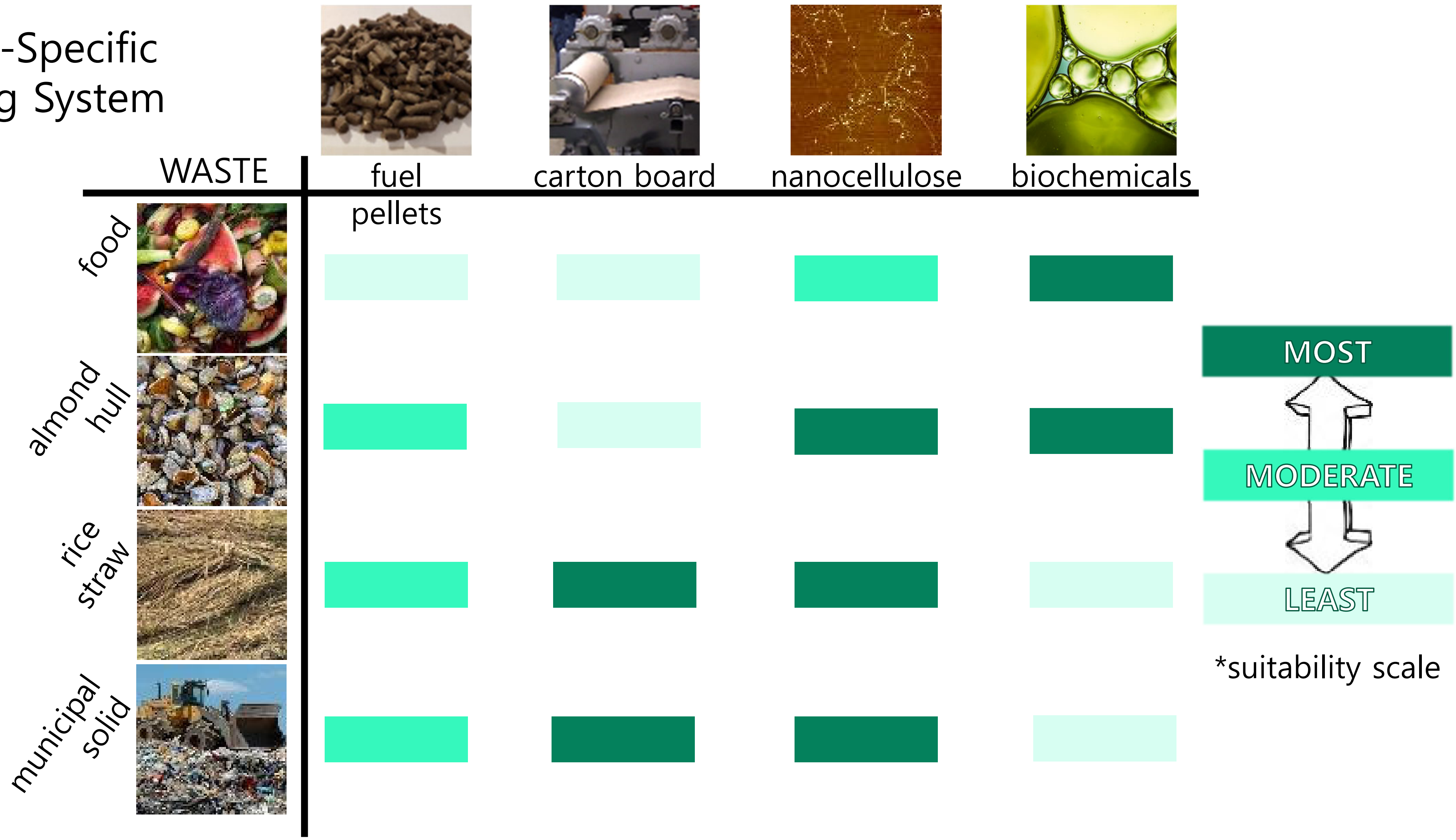


MANGO MATERIALS



PHA fibers from Ag-Wastes

Waste-Specific Scoring System



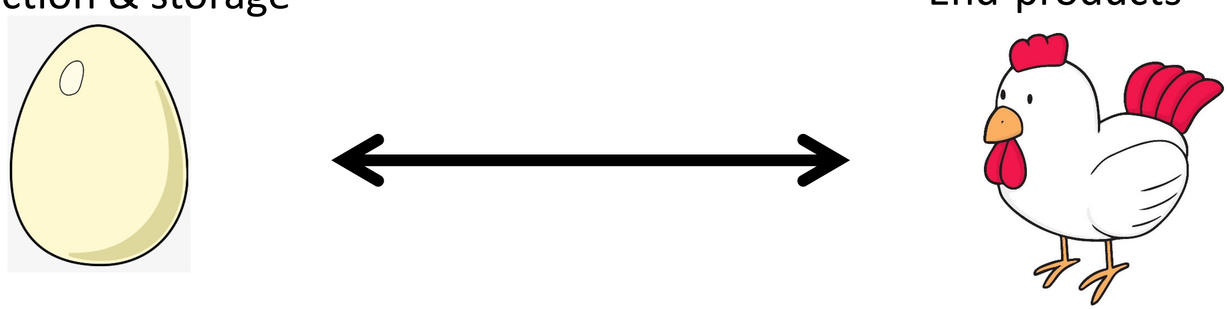
Conclusions/ Comments

- Building biorefineries does not require us to build from scratch
  - Biorefineries are originally grain mills, but also could be⇔
    - Landfills, wastewater treatment facilities, MRFs
    - Large food processing plants
    - Anywhere there’s biomass
- Low hanging fruit ⇔ biomass that has already been collected.
- Better ⇔ biomass that has no “higher use”
- Better yet ⇔ biomass that “they pay you to take”
- Methane! Don’t release methane as a greenhouse gas

- Multi-institutional collaboration across industries, agencies and regulators will be essential.

Infrastructure/
Collection & storage

Conversion Technology/
End-products



Industrial Collaborators

SALINAS VALLEY
SOLID WASTE AUTHORITY
Promoting the Environmental Health of the Salinas Valley

Reduce Recycle Reuse

FULL CYCLE
Bioplastics for the Circular Economy

www.worldcentric.org
WORLD CENTRIC
For a better world

method

HUGHES ENERGY

Recology
WASTE ZERO

california almonds

CALIFORNIA Walnuts
www.walnuts.org

CORUMAT
BETTER MATERIALS

BRIDGESTONE

CalRecycle

F-D-S Manufacturing Co.
Since 1950

Sylvatex

MANGO MATERIALS

Researchers: Biorefinery Team

Gregory Glenn
Colleen McMahan
Charles Lee
William Hart-Cooper
De Wood
Bor-Sen Chiou
Dominic Wong
Lennard Torres
Tina Williams
Zach McCaffrey
Trung Cao
Andrew Cal
Dirk Sikema
Kevin Holtman
Diana Franqui
David Bozzi
Richard Offeman
William Orts

Bill.Orts@USDA.GOV

William Orts ⇔ 510-559-5730
bill.orts@ars.usda.gov