Prospects for the Development of Drop-in Liquid Biofuels (especially Gasoline) from Sustainable Feedstocks

Reinhard Seiser

Andrew Burke

Session 1: Biofuel and Biomethane Transportation Fuels - Setting the Stage

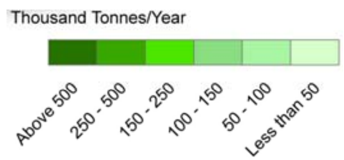
Workshop: Assessment of Critical Barriers and Opportunities to Accelerate Biofuels and Biomethane as Transportation Fuels in California

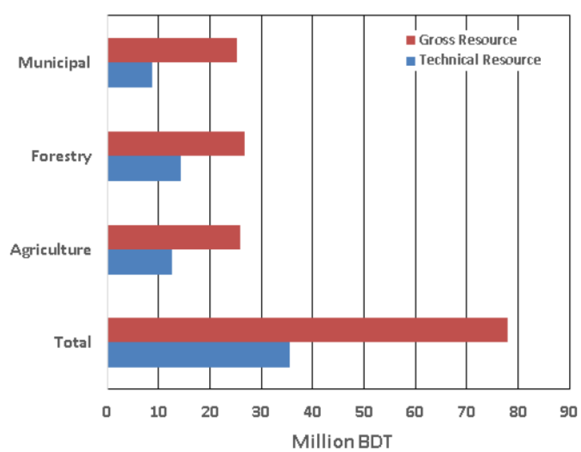
Biomass Resource

Source: http://www.nrel.gov/gis/mapsearch/

This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:
- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (switchgrass on Conservation Reserve Program lands).

See additional documentation for more information at http://www.nrel.gov/docs/fy06osti/39181.pdf





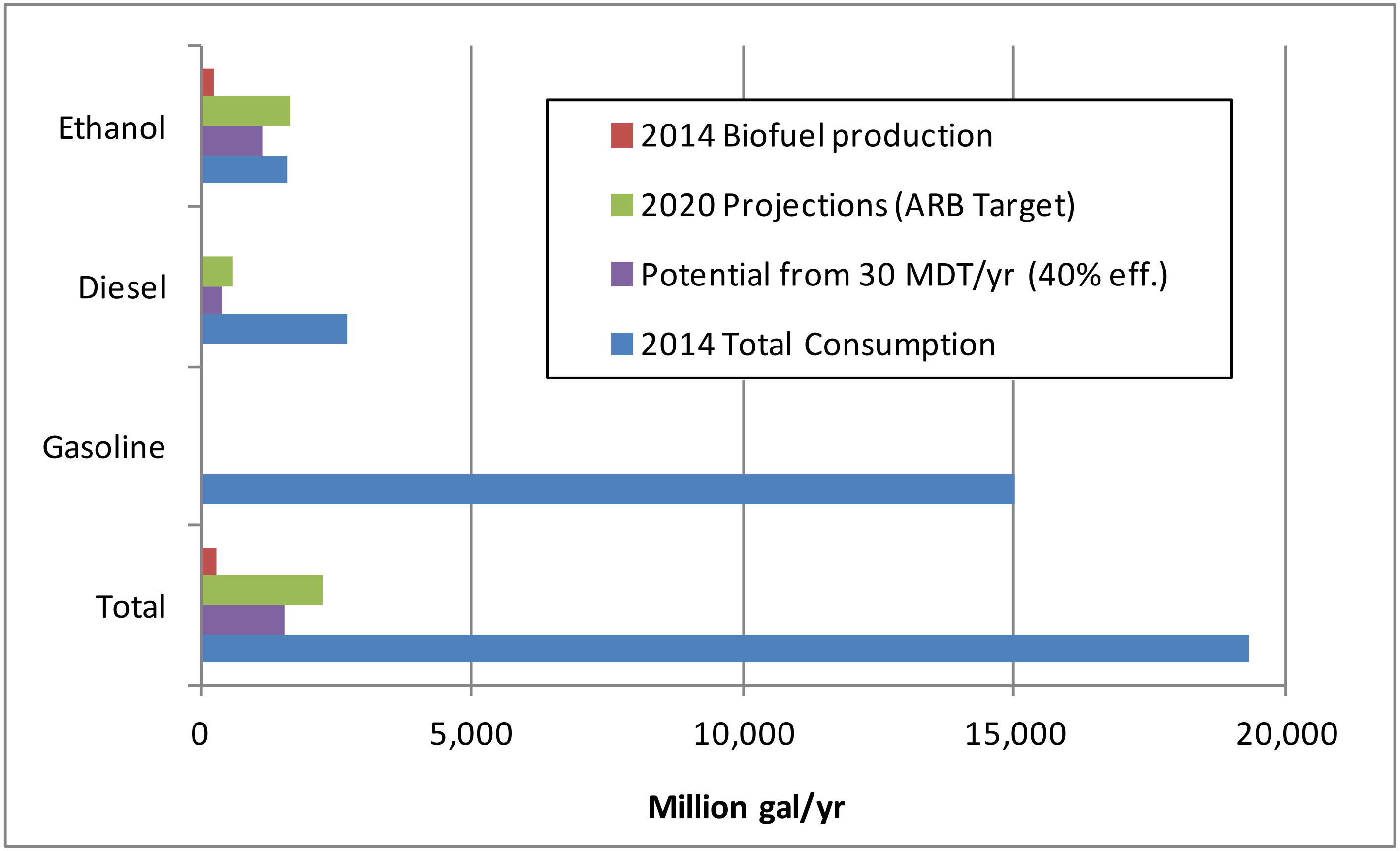
Williams, R. B., B. M. Jenkins and S. R. Kaffka (2015). An Assessment of Biomass Resources in California, 2013 Data - DRAFT. CEC PIER Contract 500-11-020, California Biomass Collaborative.

The difference between technical and gross resources arises from inaccessible or sensitive areas, losses from harvesting, and maintaining soil quality.

Laird et al., *Long-term impacts of residue harvesting on soil quality*:

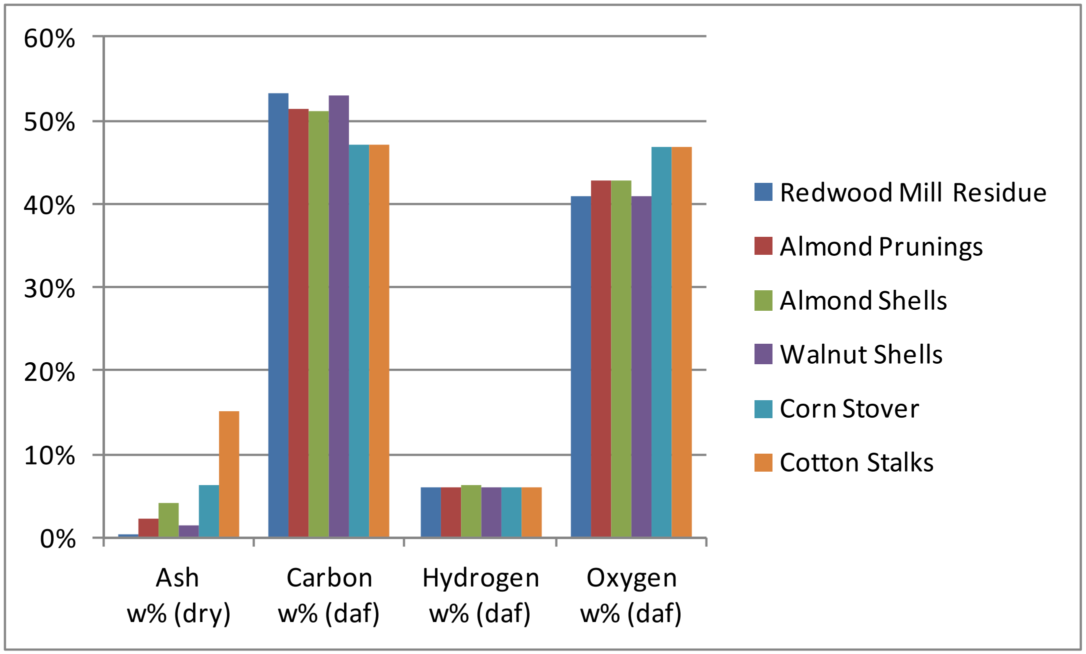
“Harvesting 90% of above ground residue [corn stover] for 19 years resulted in substantial degradation of soil quality. Organic C and total N were reduced.”

Transportation Fuels in California



→ Strong need for renewable-gasoline production
→ Additional biomass resources and efficiency gains needed (energy crops, imports from other states, methanation of CO_2)

Biomass Composition

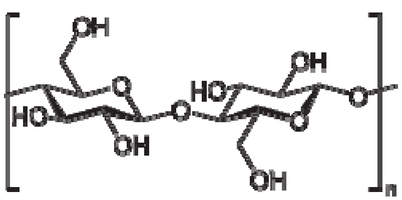


Converted to moles:
$(CH_{1.43}O_{0.65})_n$ (daf)
or ~ $(CH_2O)_n$ (waf)

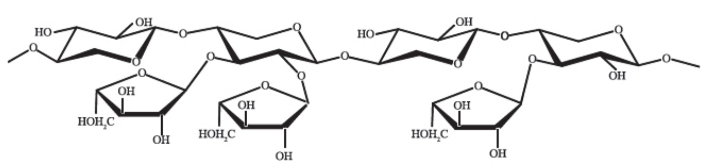
daf…dry and ash free
waf…wet and ash free

Ash: Si, K, Na, Ca, Mg, Al, Fe, and other metals.
Inorganics: N, S.

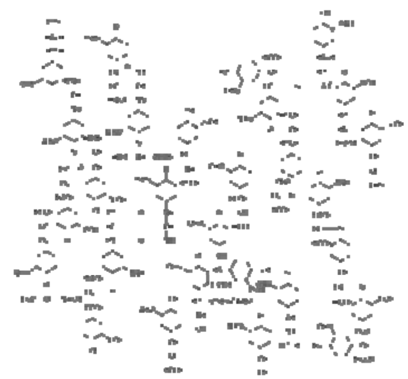
Cellulose $(C_6H_{10}O_5)_n$, 40-50%



Hemicellulose $(\sim C_5H_8O_4)_n$, 20-35%



Lignin $(\sim C_{31}H_{34}O_{11})_n$, 15-35%



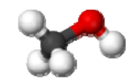
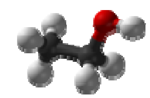
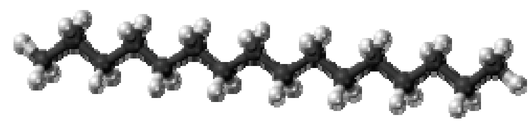
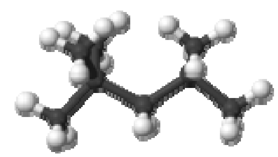
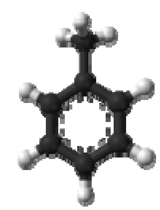
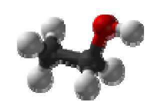
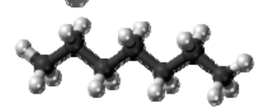
Biomass Conversion

Biomass, ~$(CH_2O)_n$

($+C+H_2O$) ← ↓

CO_2	← ↓ →	CH_4
$C+CO_2$	← ↓ →	CH_3OH
CO_2	← ↓ →	C_2H_5OH
CO_2+H_2O	← ↓ →	~CH_2
CO_2+H_2O	← ↓ →	~CH_2

Vehicle Fuels

- Natural Gas
  - Methane, CH_4 
  - Methanol, AKI: 99, CH_3OH 
  - Ethanol, AKI: 99, C_2H_5OH 
- Diesel components
  - Hexadecane, $C_{16}H_{34}$ 
- Gasoline components
  - Isooctane, AKI: 100, C_8H_{18} 
  - Toluene, AKI: 114, C_7H_8 → 
  - Ethanol, AKI: 99, C_2H_5OH 
  - (***No*** *n*-Heptane, AKI: 0, C_7H_{16}) 

AKI…Anti-knock index, (RON+MON)/2

Many Players in the Area of Biomass Conversion

Thermochemical Activities Outside of BETO

Working together to address challenges

Aalborg University
Abengoa Bioenergy New Technologies
Albemarle
Amaron Energy, LLC
Arcadis US
ARS-USDA
Aston University
Auburn University
Battelle
BioFuel Energy Corp
Biomass and Bioenergy
Black & Veatch
Blankney Estate
BP
Brookhaven National Laboratory
BTG Biomass Technology Group BV
Burns & McDowell
CanmetENERGY-Natural Resources Canada
Carbona, Inc.
Carmeuse Lime & Stone
Castorfields, S.A. P.I. de C.V.
CCAT, Inc.
Centre for Research & Technology Hellas (CERTH)
CERTH/CPERI
Chalmers University of Technology
Chevron
CIRAD
Colorado School of Mines
Conversion And Resource Evaluation Ltd.
Cool Planet
Cranfield
CRI Criterion
DCEO
Delft University of Technology
Desert Research Institute
Directorate General for Energy of the European Commission

Dow Chemical Company
Dupont
E.ON Gasification Development
ECN
Energy Center of the Netherlands (ECN)
Enerkem
ENI
Eon Gasification Development AB
ETC
Evonik
Extrel
ExxonMobil
Federal University of Itajubá
FP Innovations
Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
Frontier Laboratories
Gas Technology Institute
GDF SUEZ
GeertTech LLC
General Electric
Georgia Institute of Technology
Georgia Tech
Haldor Topsoe, Inc
Hart Energy
Honeywell
Idaho National Lab
IFPEN
Industrial Technology Research Institute
Ineos Bio
INSER SPA
Institute of Nuclear Energy Research
Iowa State University
Johnson Matthey
KBR
KiOR
Korea Forest Research Institute

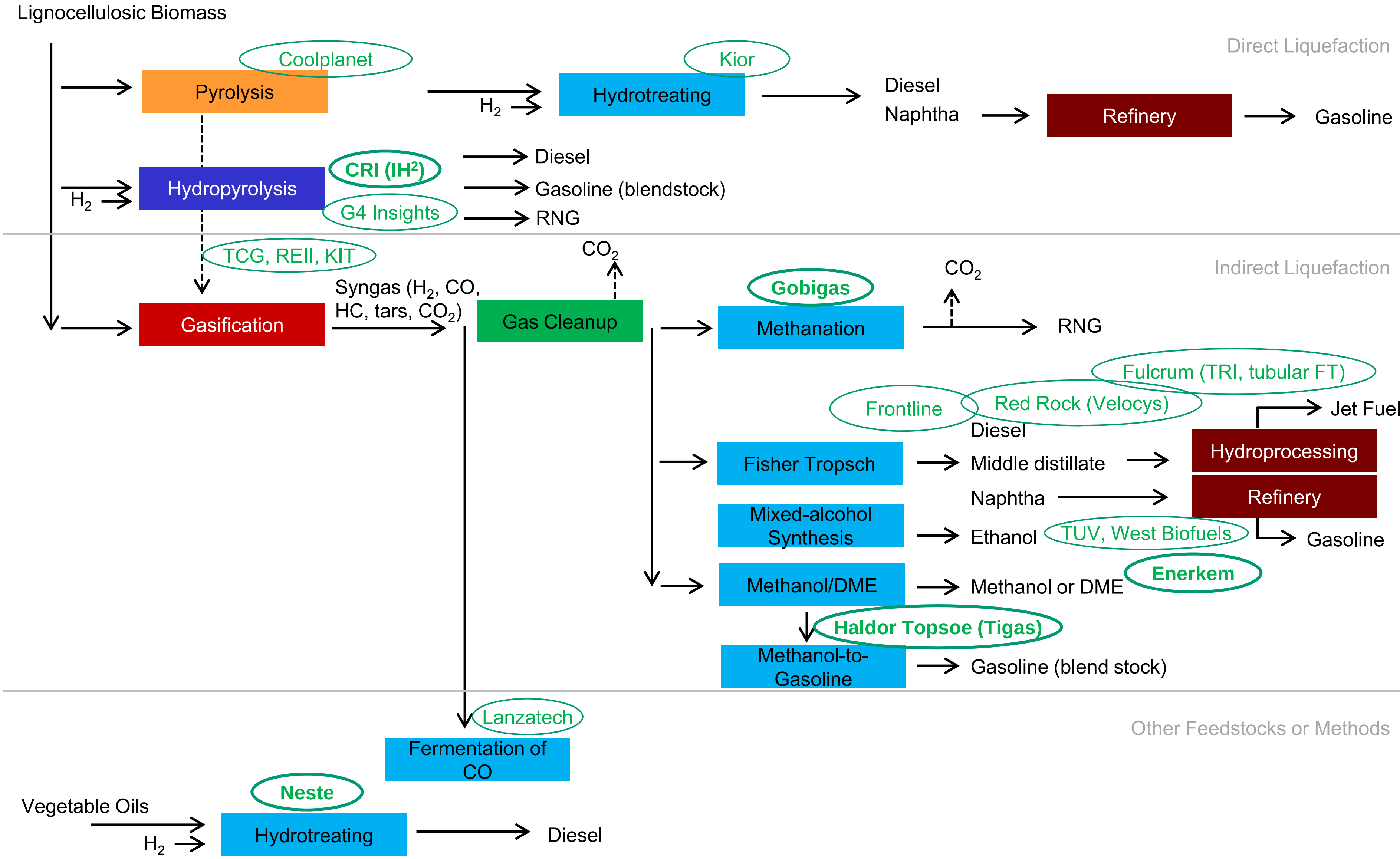
Korea Institute of Machinery & Materials
KTH Royal Institute of Technology
LanzaTech, Inc.
Linde AG
Luleå University of Technology
Massachusetts Institute of Technology
Memorial University-Chemistry
Metabolix
Metso
Michigan State University
Michigan Technological University
MINES
Mississippi State University
National Renewable Energy Laboratory
Natural Resources Canada
NexTech Materials
Niksa Energy Associates LLC
North Carolina State University
Northrop Grumman
Northwestern University
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Pall Corporation
Petrobras
Phillips 66
Philo Consulting
PlasMet LLP
Praxair
Princeton University
Quantum Analytics
RE-CORD and University of Florence
Rentech
RTI International
Sacramento Municipal Utility District
Saint-Gobain NorPro
Scion Research

Shell Global Solutions Int.
Shell Oil Company
Southern Research Institute
Steeper Energy
TaylorEnergy / Kobelco-Eco
Technische Universität Berlin
ThermoChem Recovery International, Inc.
Thünen Institute of Wood Research
TU-Berlin
UFPE
Umeå University
University of California, Berkeley
University of California San Diego
University of Colorado at Boulder
University of Groningen
University of Hamburg
University of Idaho
University of Maine
University of Massachusetts
University of Minnesota Duluth
University of Ottawa / CanmetENERGY Natural Resources Canada
University of Pretoria
UPM Biofuels
Utah State University
Villanova University
VTT Technical Research Centre of Finland
Waldheim Consulting
Washington State University
West Biofuels
Western University Canada
World Fuel Services
Yonsei University
Zeton Inc.
Zhengzhou University

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

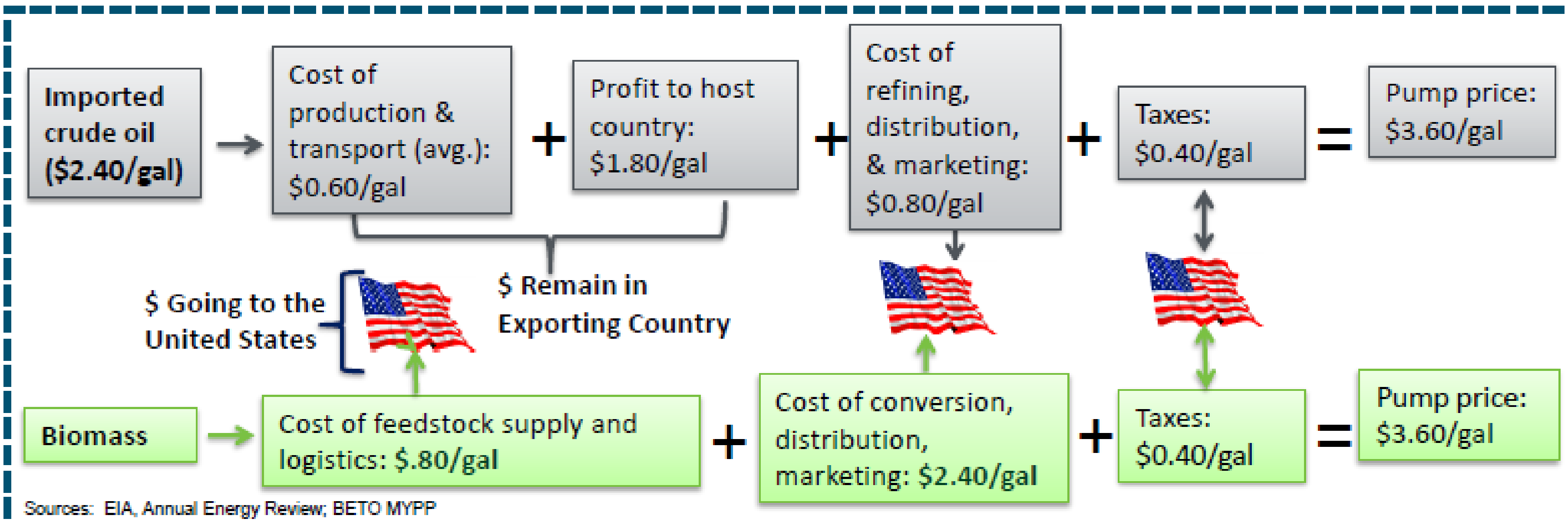
Source: US DOE

Conversion Technologies



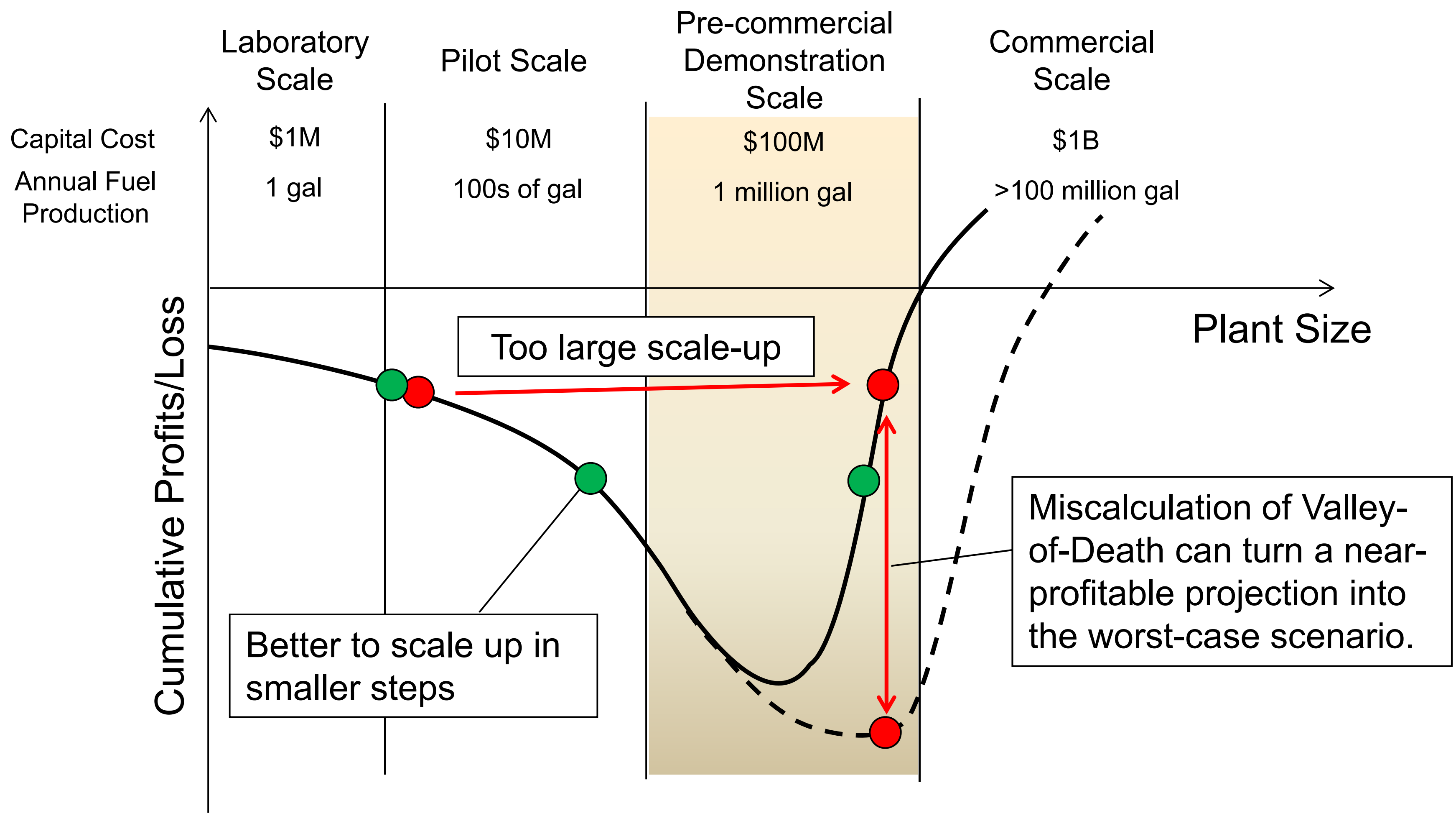
Price Components of Gasoline

- To be price competitive, cost of conversion needs to be near difference between imported crude oil plus refining and biomass costs.
- Other large benefits such as jobs, energy security, forest management, fire hazard mitigation, pollution, and greenhouse gas reduction would accrue.



Source: US DOE

Financial Barrier: Scale-up Risk



Range Fuels: 5 tons/day → 125 tons/day (Phase1) … failed
Kior: 50 times from demonstration to commercial … on hold

Technical Barrier: Catalyst Deactivation

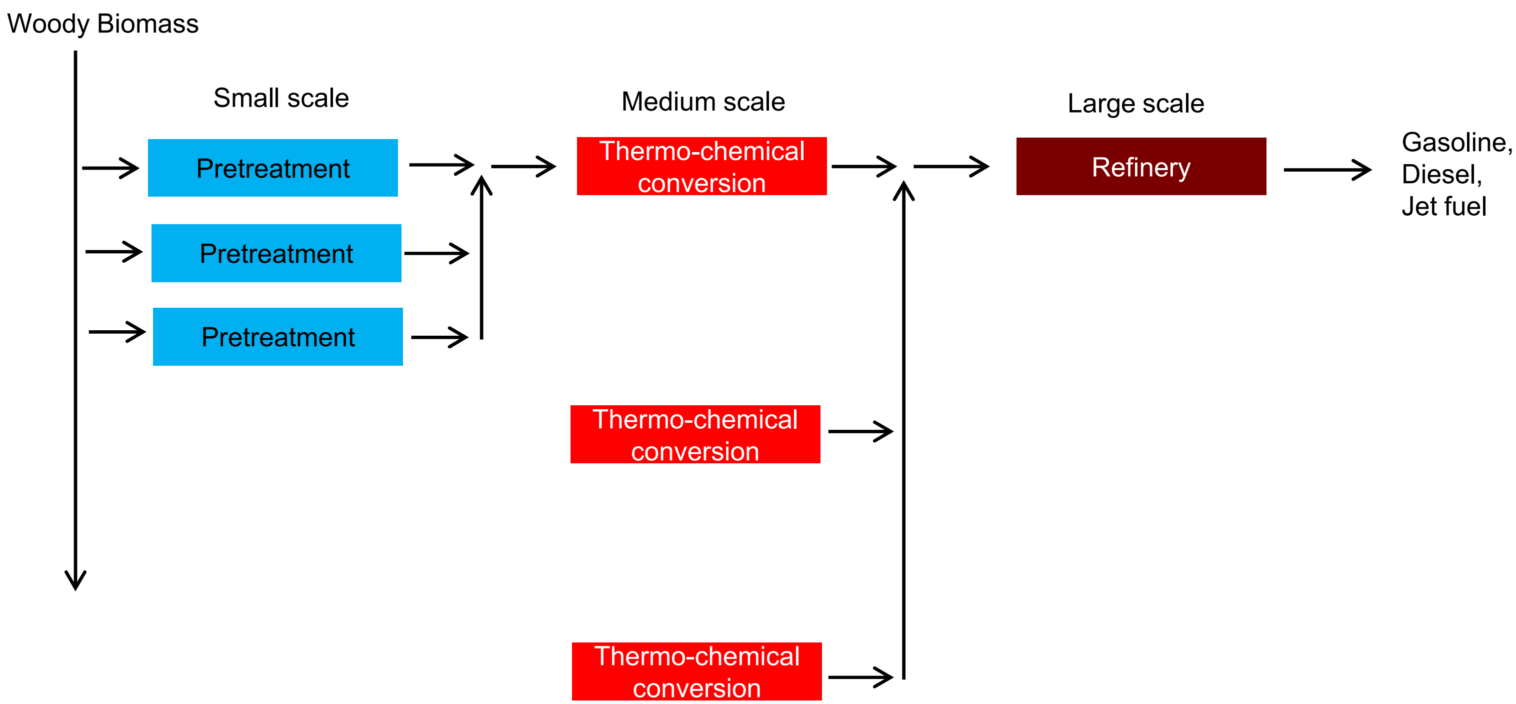
Contaminant	Methanol Synthesis	FT Synthesis	Mixed Alcohol Synthesis	Fixed-/ Fluidized-bed Methanation
Particulate	< 0.02 mg/Nm3	n.d.		
(soot, dust char, ash)				
Tars (condensible)	< 0.1 mg/Nm3	< 10ppb		
Inhibitory compounds		< 1 ppm		< 1/1000ppm
(class 2-heteroatoms, BTX)				
Sulfur	< 1 mg/Nm3	< 10ppb	< 300ppm	< 10/10ppb
(H2S, COS)				
Nitrogen	< 0.1 mg/Nm3	< 20ppb		
(NH3, HCN)				
Alkali		< 10 ppb		
Halides (primarily HCl)	< 0.1 mg/Nm3	< 10 ppb		

ppm…parts per million, ppb…parts per billion

Many thermo-chemical processes employ catalysts and are subject to catalyst deactivation. High demands on gas cleanup.
Kior: Reports indicated 75% reduction of planned output.

Feedstock Barrier: Scale and Logistics

- Biomass is distributed and biomass facilities are small.
- Refineries are concentrated and large. Fuel specifications for gasoline are tight.
- Possibly combine process streams after they are being concentrated in energy:



Pretreatment could be drying, torrefaction, or pyrolysis

Thermo-chemical conversion could be pyrolysis, or gasification+synthesis

Refining could be hydrocracking, hydrotreating, isomerization, distillation, sulfur removal

Conclusions

- Without drop-in biofuels from lignocellulosic biomass, it will be difficult to meet renewable fuel targets for 2030.
- Facilities/processes to produce hydrocarbon drop-in fuels are in an early stage of development.
- A number of pathways are being developed with plans for demonstration projects.
- Financial, technical, and logistical barriers exist for near-term commercialization of drop-in fuel production.