NSF Workshop on Sustainable Manufacturing

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Challenges in Sustainability

Energy

CO_2

Water

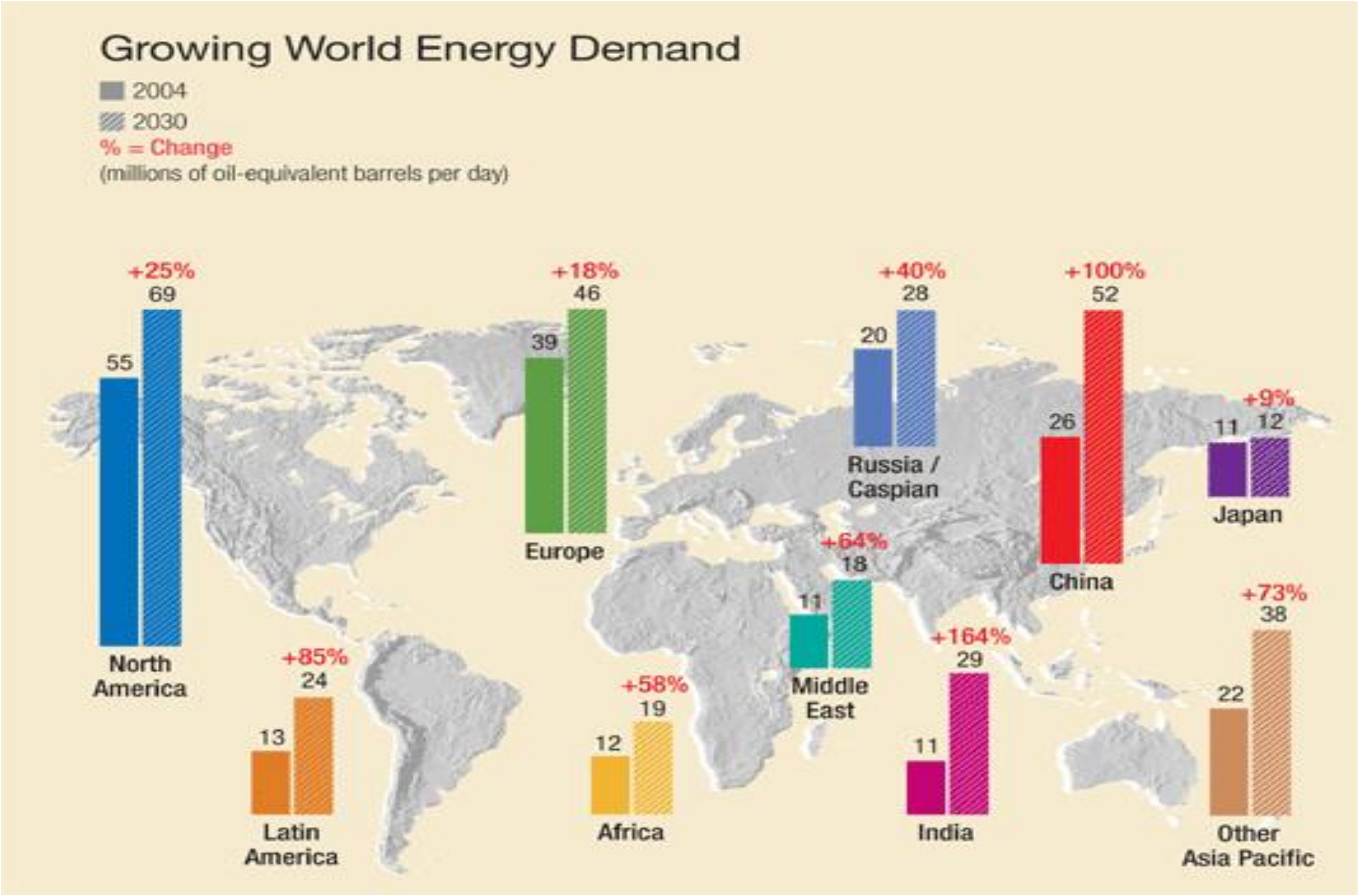
Process Intensification

Water reuse/recycle

Optimizing Renewables

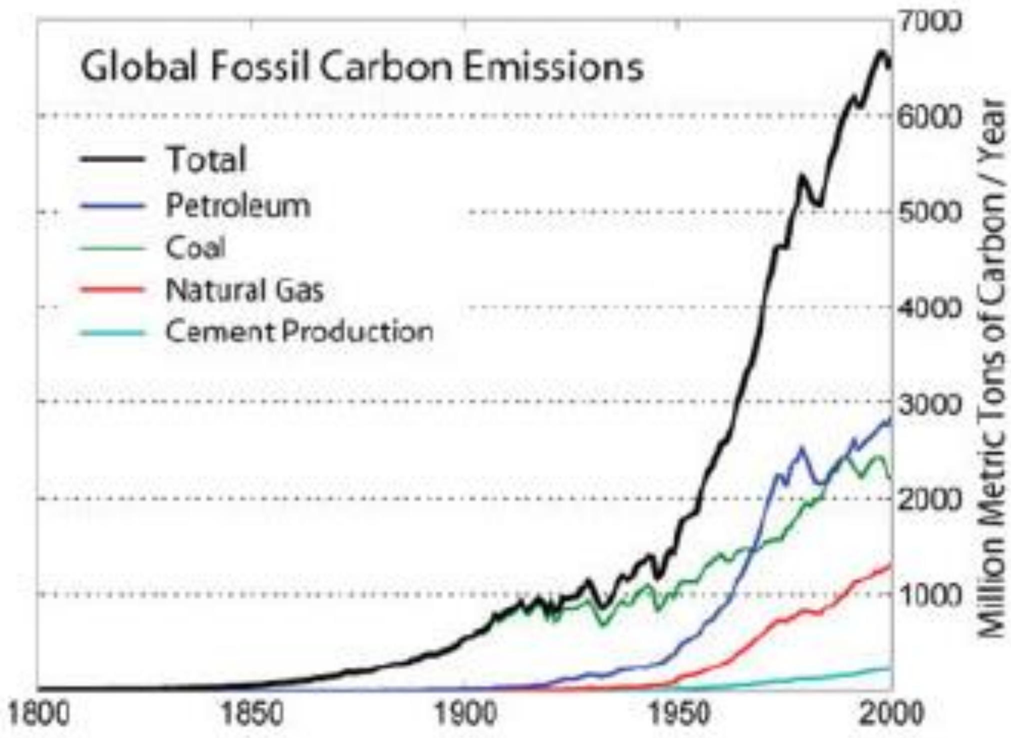
Supply Chain Integration

Energy



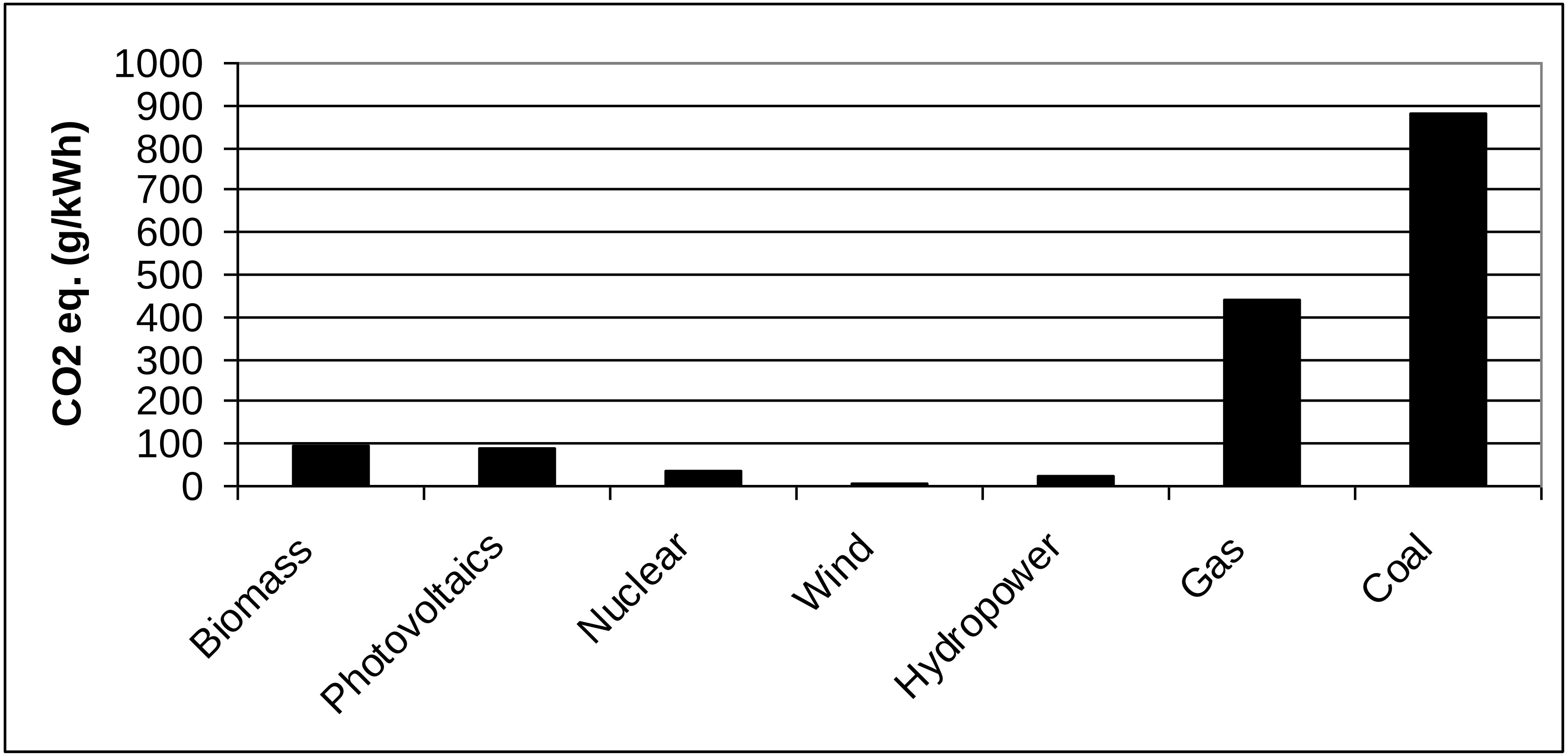
Overall 70% increase

Growing emissions of CO_2



Sheppard, Socolow (2007)

Renewables: Carbon footprint various Energy Options



Adisa Azapagic (2012)

Depletion of fossil fuels?

Oil Reserves

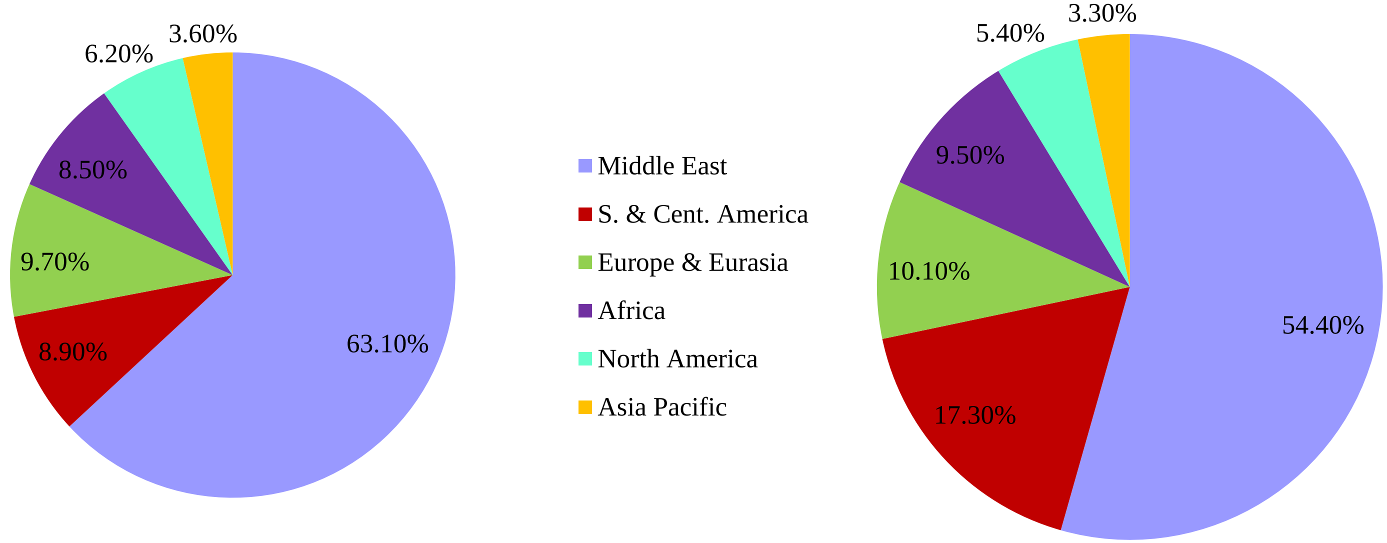
Year 2000

Total: 1105 thousand million barrels

Year 2010

Total: 1383 thousand million barrels

25% increase!

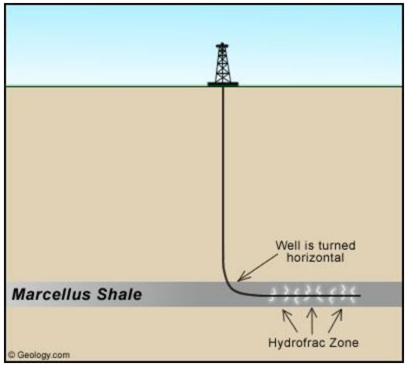


- ***Discovery of New Large Oil and Gas Reserves***
- ***New technologies for Offshore oil exploration and production***

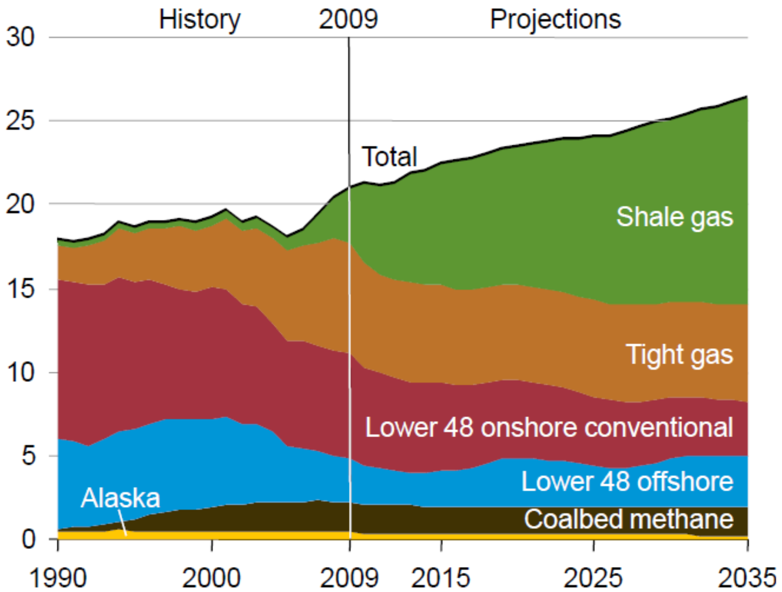
****Statistical Review of World Energy (June, 2011)***

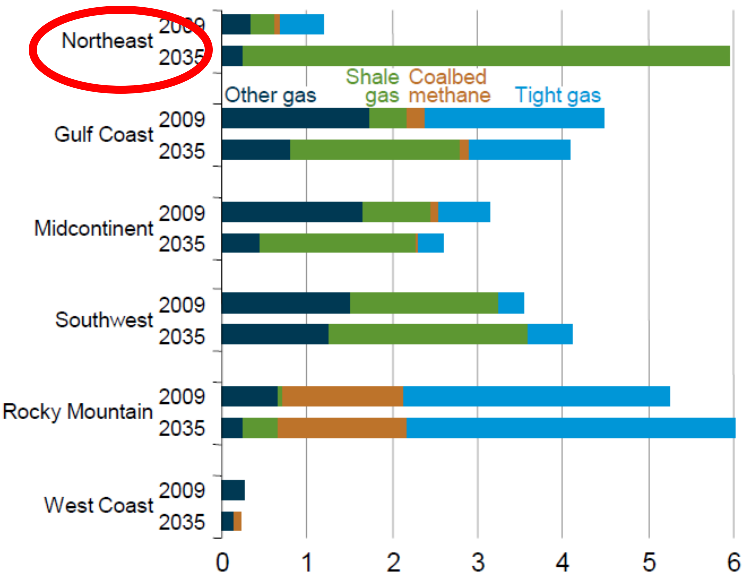
Depletion of fossil fuels?

Growth in Shale Gas



Horizontal drilling
Hydraulic fracking



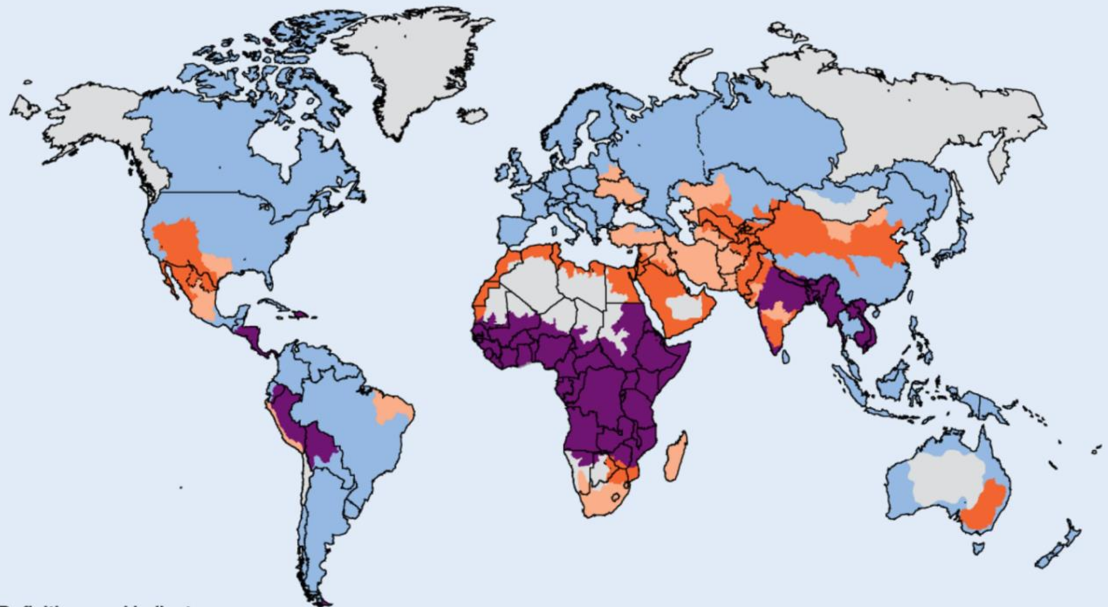


In 2035 close to 50% from Shale Gas

Northeast: from 0.3 trillion scft 2009
to 5.8 trillion scft 2035

Water scarcity

Little or no water scarcity | Approaching physical water scarcity | Not estimated
Physical water scarcity | Economic water scarcity



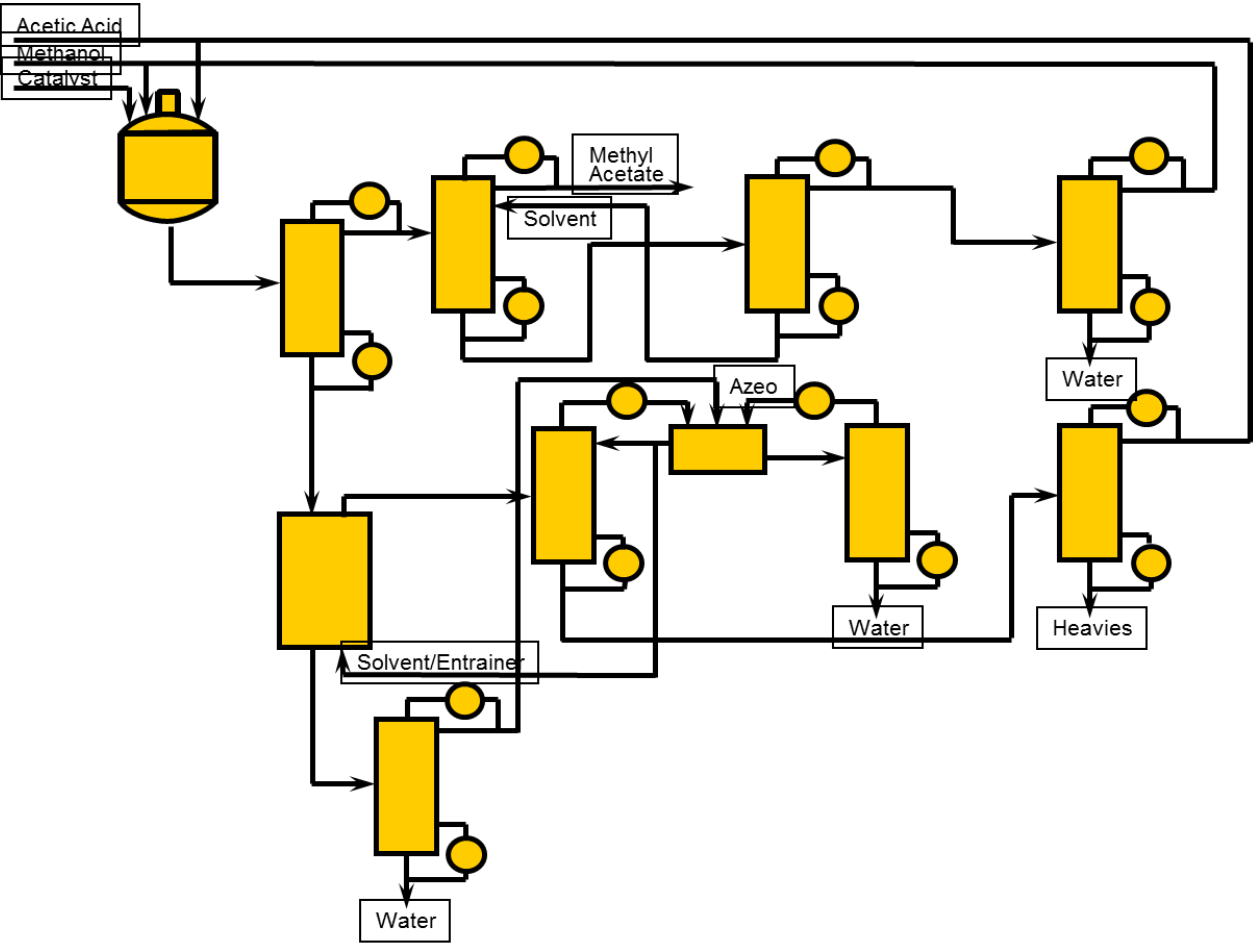
Definitions and indicators

- *Little or no water scarcity*. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- *Physical water scarcity (water resources development is approaching or has exceeded sustainable limits)*. More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- *Approaching physical water scarcity.* More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- *Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands)*. Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

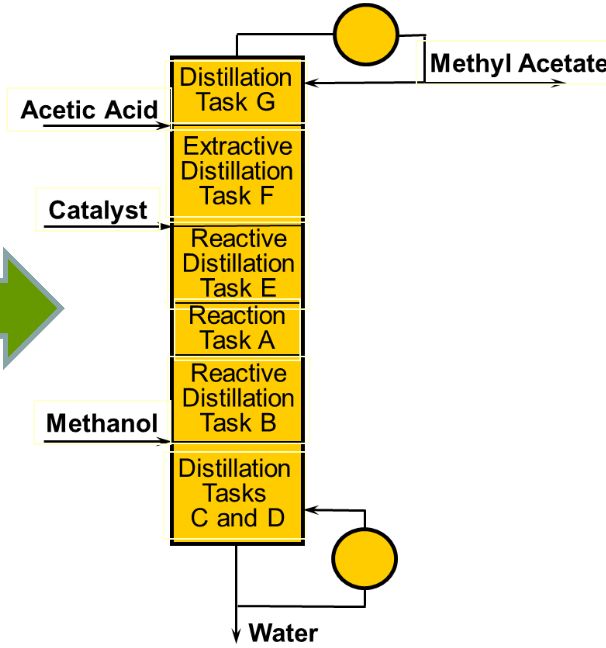
Source: International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 2.

Two-thirds of the world population will face water stress by year 2025

Methyl Acetate Flowsheet



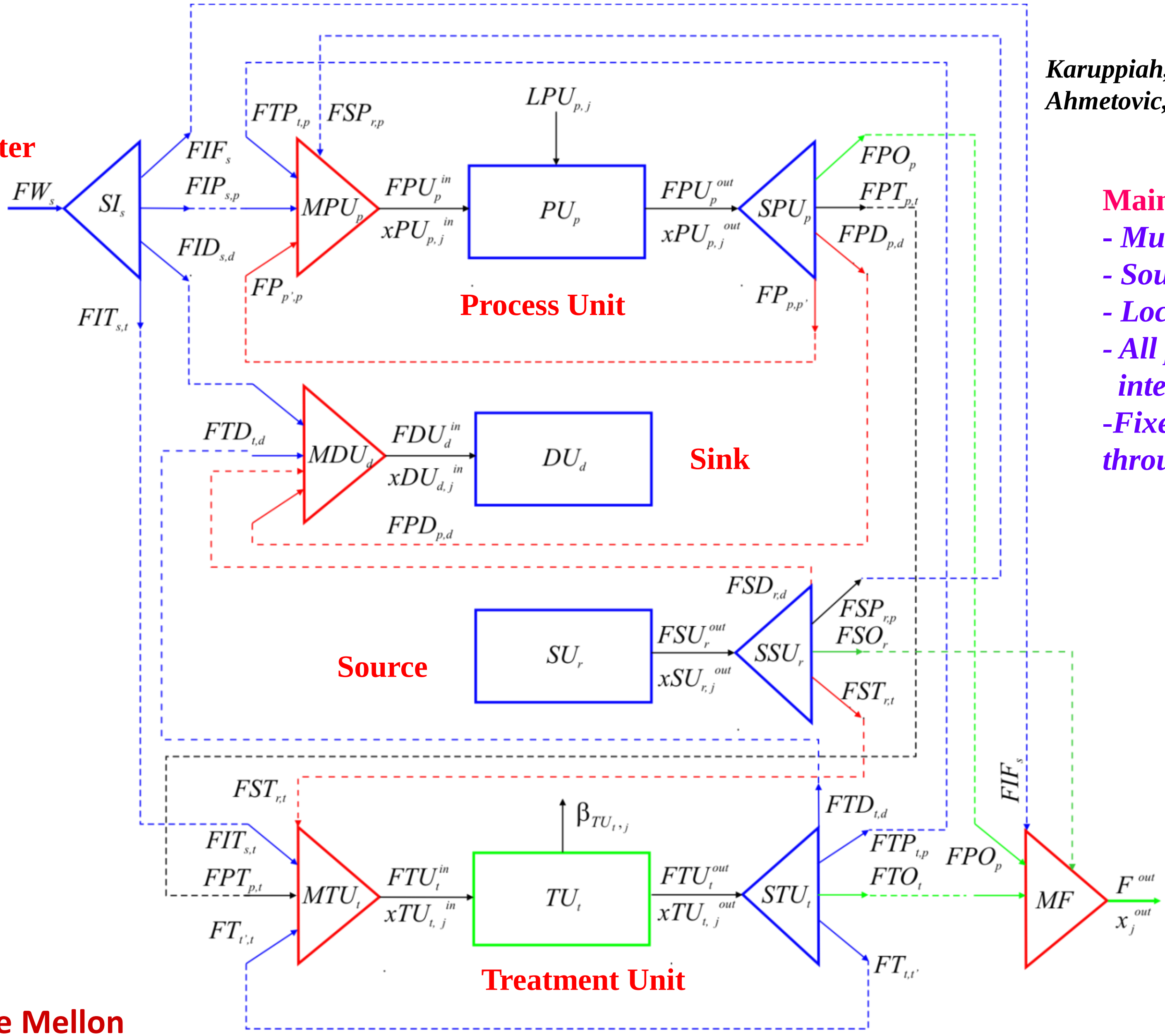
Single Reactive Dist Col!



EASTMAN *Siirola (1988)*

Superstructure for water networks for water reuse, recycle, treatment, and with sinks/sources water

Karuppiah, Grossmann (2008)
Ahmetovic, Grossmann (2010)

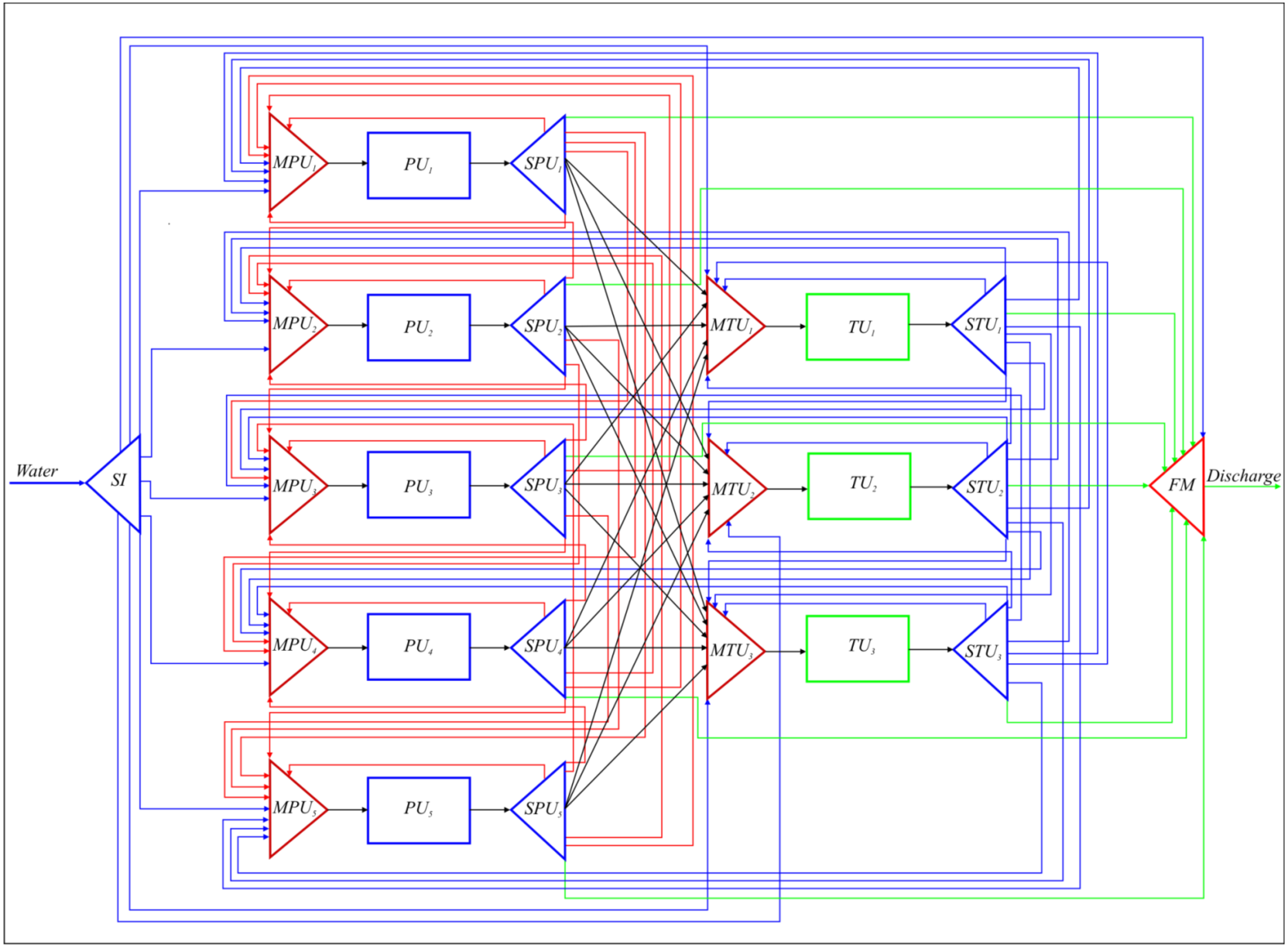


Main features:

- *Multiple feeds*
- *Source/Sink units*
- *Local recycles*
- *All possible interconnections*
- *Fixed and variable flows through process units*

Superstructure of the integrated water network

1 feed, 5 process units, 3 treatment units, 3 contaminants



MINLP: 72 0-1 vars, 233 cont var, 251 constr
BARON optcr=0.01 197.5 CPUsec

Optimal design of the simplified water network with 13 removable connections

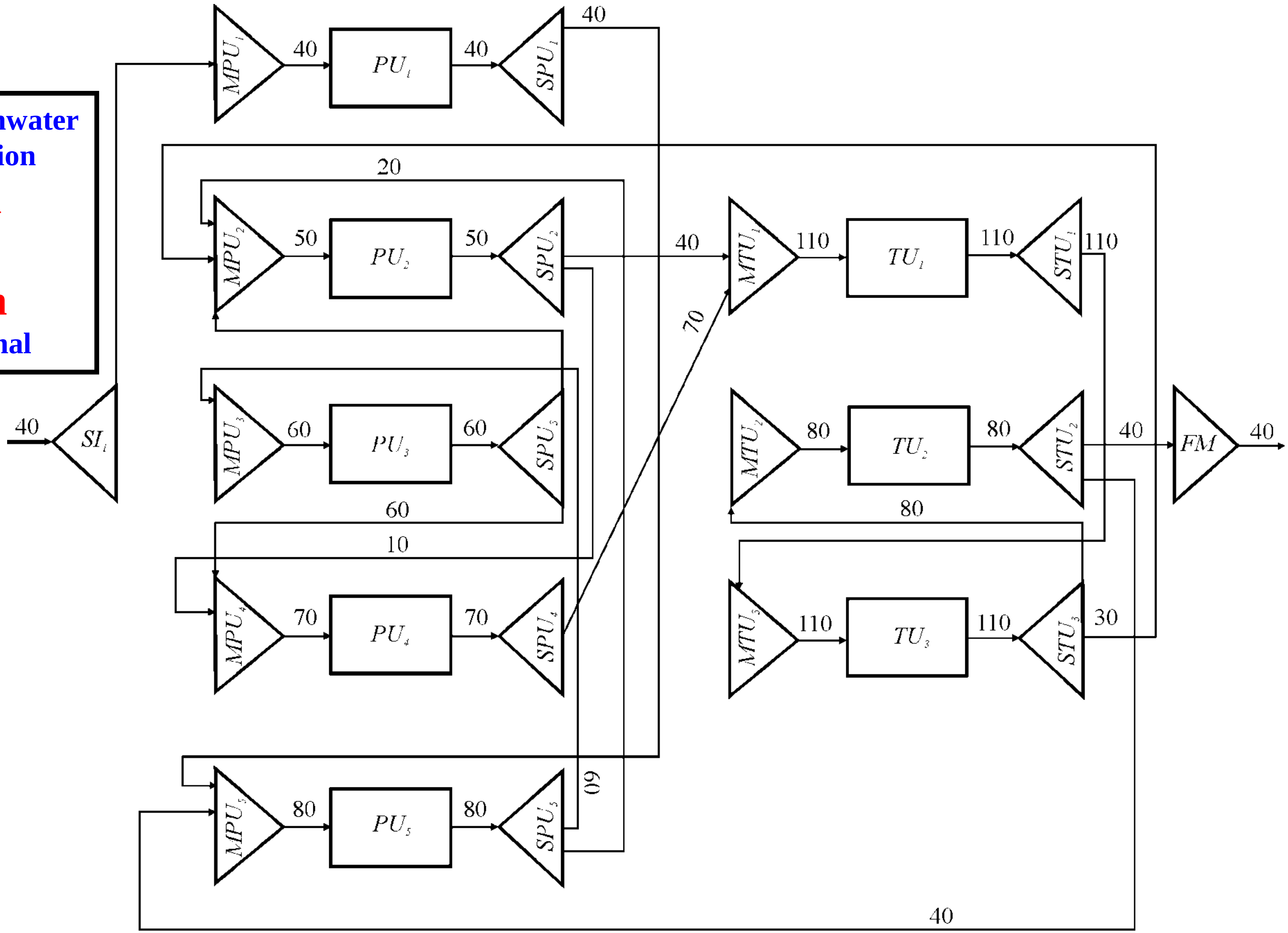
Optimal Freshwater Consumption

40 t/h

vs

300 t/h

conventional



Scope of Advanced Process Systems Engineering Tools

Energy consumption corn-based ethanol

Author (year)	Energy consumption (Btu/gal)
Pimentel (2001)	75,118
Keeney and DeLuca (1992)	48,470
Wang et al. (1999)	40,850
Shapouri et al. (2002)	51,779
Wang et al (2007)	<u>38,323</u>

From Karrupiah et al (2007)
<u>24,918 Btu/gal</u> vs 38,323 Btu/gal
Why? ***Multieffect distillation and heat integration***

Water consumption corn-based ethanol

Author (year)	Water consumption (gal/gal ethanol)
Gallager (2005) First plants	11
Philips (1998)	5.8
MATP (2008) Old plants in 2006	4.6
MATP (2008) New plants	<u>3.4</u>

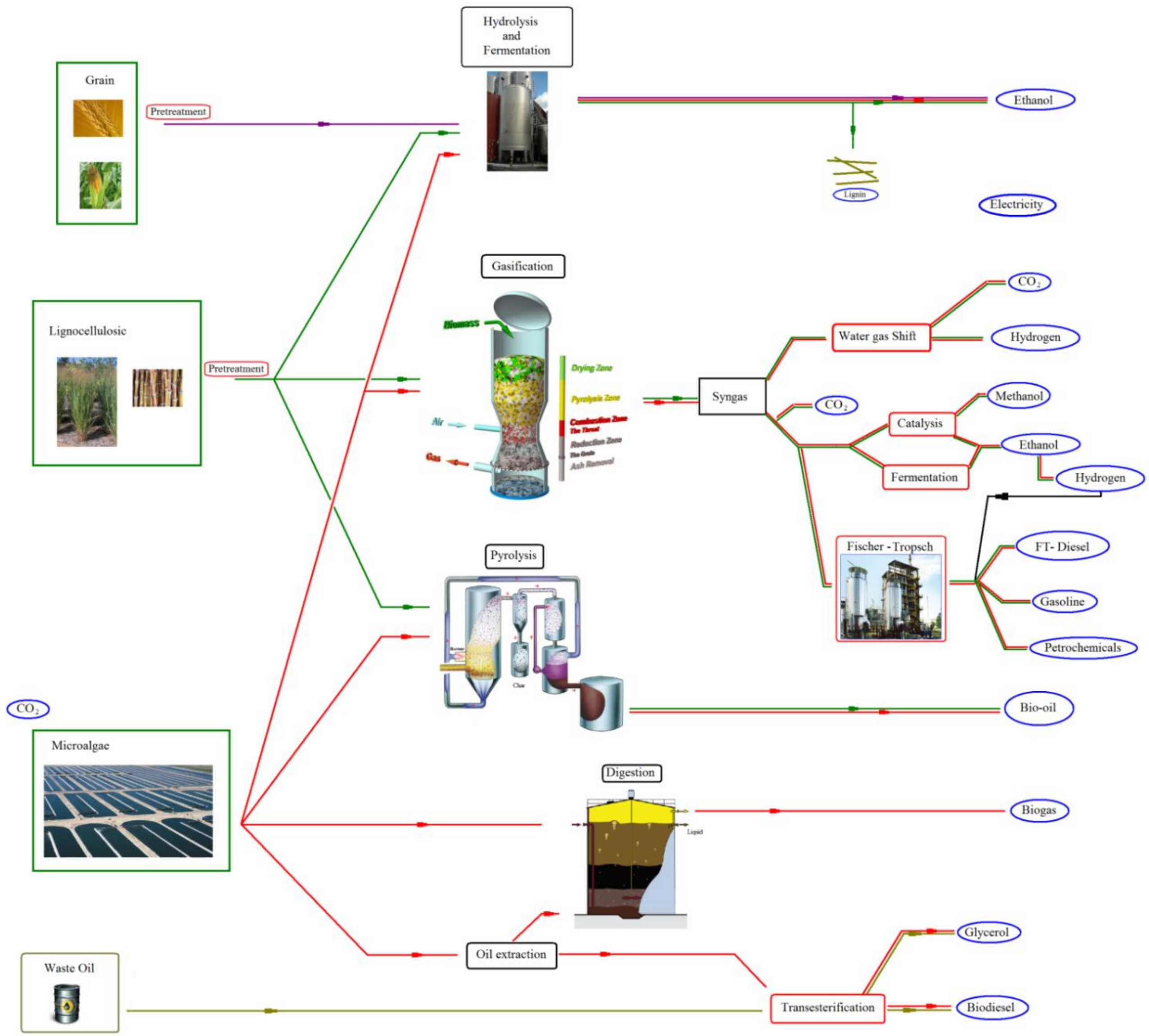
From Martin and Grossmann (2010)
<u>1.5 gal water/gal ethanol</u> vs 3.4
Why? ***Integrated process network with reuse and recycle***

Biorefinery

Bioethanol, FT-diesel and hydrogen from switchgrass

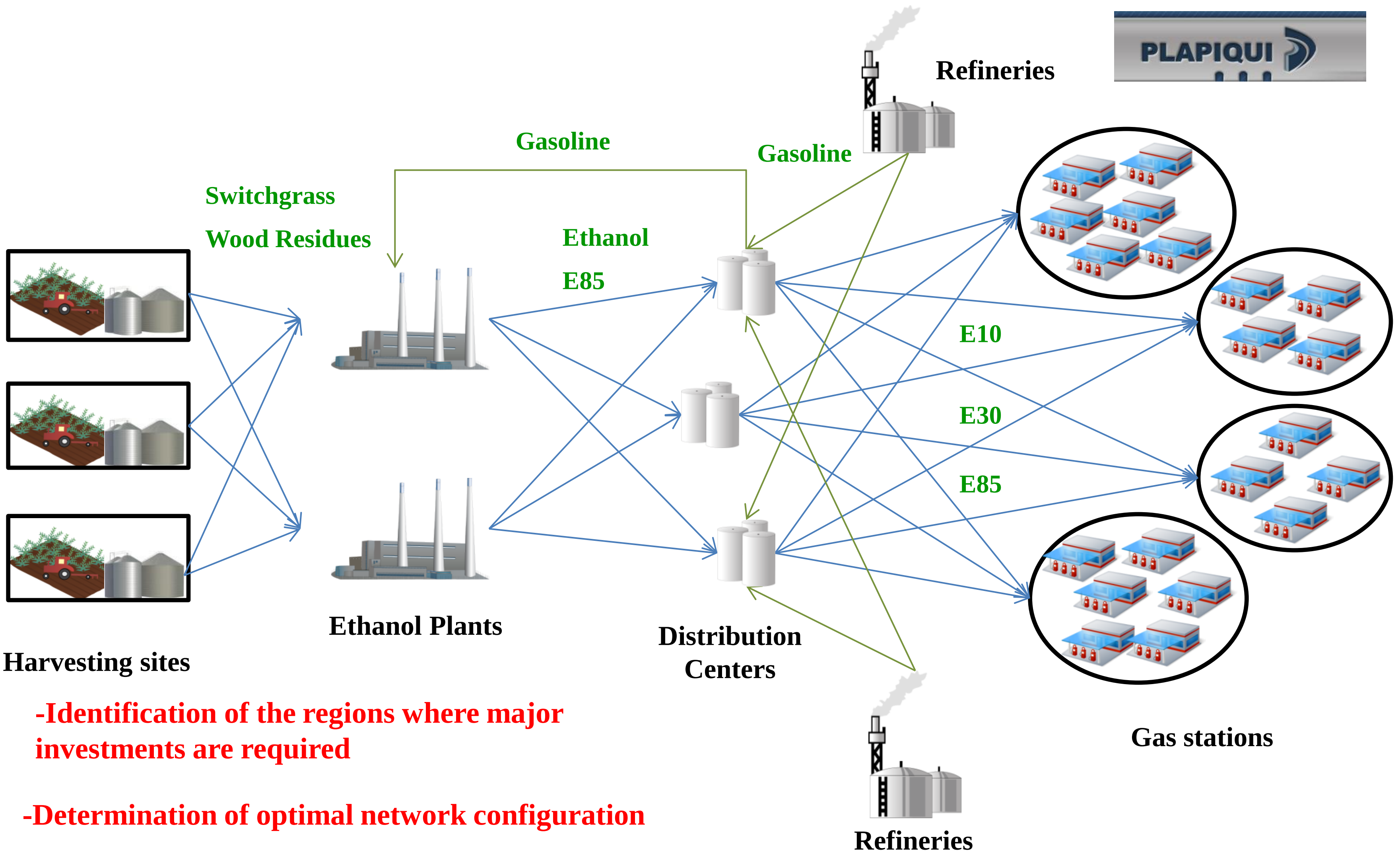
Biodiesel from cooking oil or algae oil

Martin, Grossmann (2012)



Strategic Planning for the Design of Integrated Ethanol and Gasoline Supply Chain

Andresen, Diaz, Grossmann (2012)



-Identification of the regions where major investments are required

-Determination of optimal network configuration

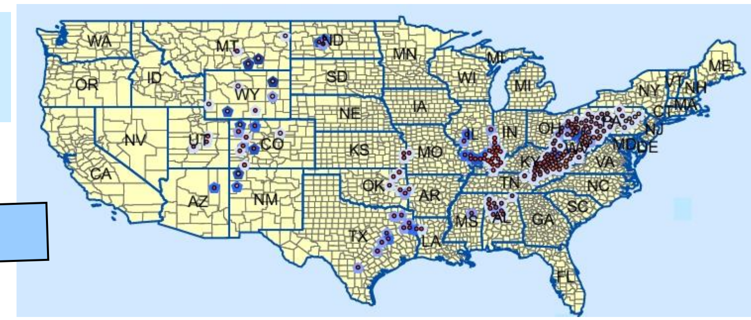
Energy Supply Chain Model

Floudas et al., (2011)

Hybrid Coal, Biomass, and Natural Gas to Liquids Systems

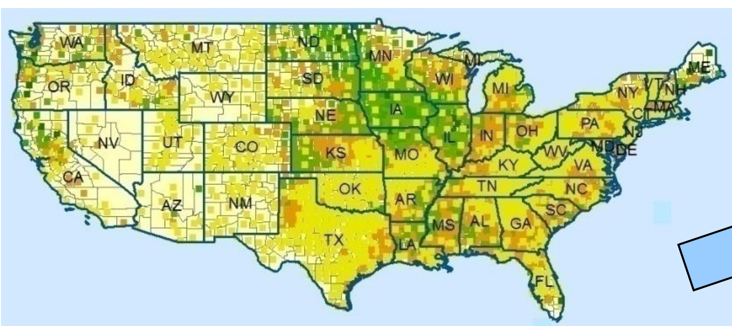
Grid points of candidate facility locations

Coal availabilities from database



Transportation fuel demand

Biomass availabilities from database

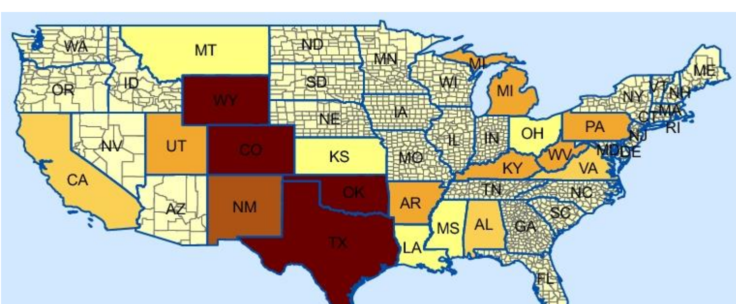


Water supply

Carbon dioxide sequestration capacities

Energy Supply Chain Optimization Model

Natural gas availabilities from database



CBGTL plant parameters

Transportation infrastructure