Uncovering System Behaviors in Biofuels Production and Use

A Multi-Actor System Approach

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RCN Conference on Pan American Biofuels & Bioenergy Sustainability, Recife, Brazil, 2014

Actors' decisions and (in)actions matter

Understanding of:

- **Motives, interests and decision options**
- **Rational decision criteria**
- **Irrational behaviors**
- **Dynamics and Feedback loop**

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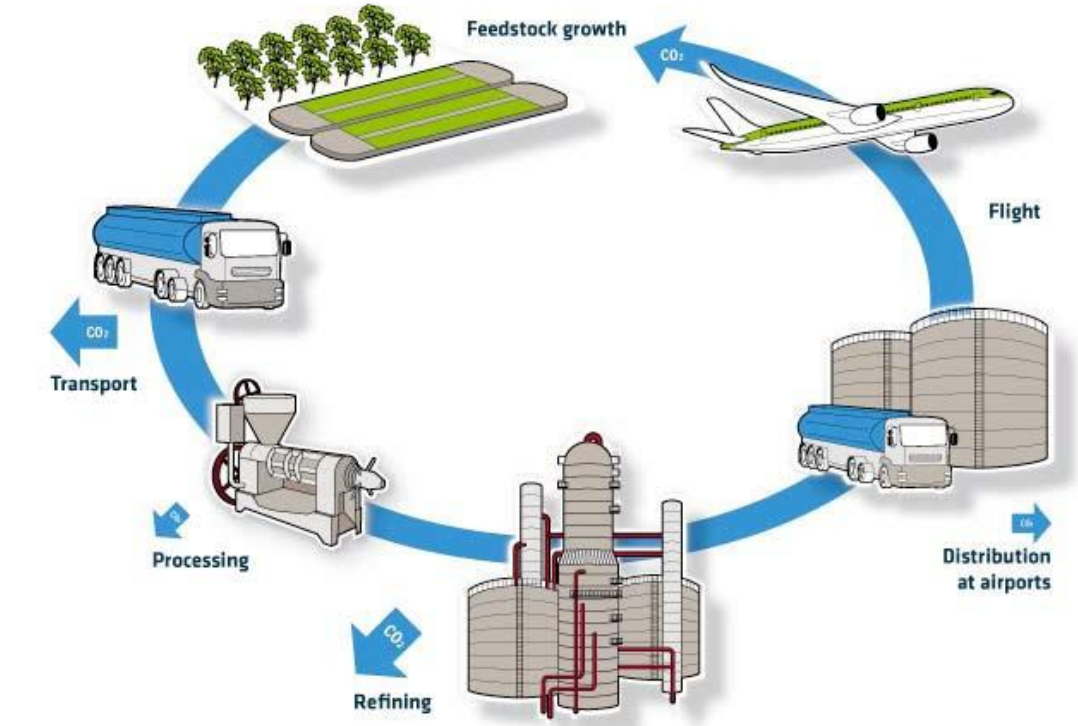
uop
A Honeywell Company

Troubles at “Multi-Actor Land”



http://eflightlevel.blogspot.com/2012/03/airbus-boeing-embraer-collaborate-on.html

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3. Asymmetry of cost-benefit distribution = Equity Issue

1. Individual actor vs. Supply Chain Network performance

2. “Achievable” Biofuels Life Cycle Impact Assessment

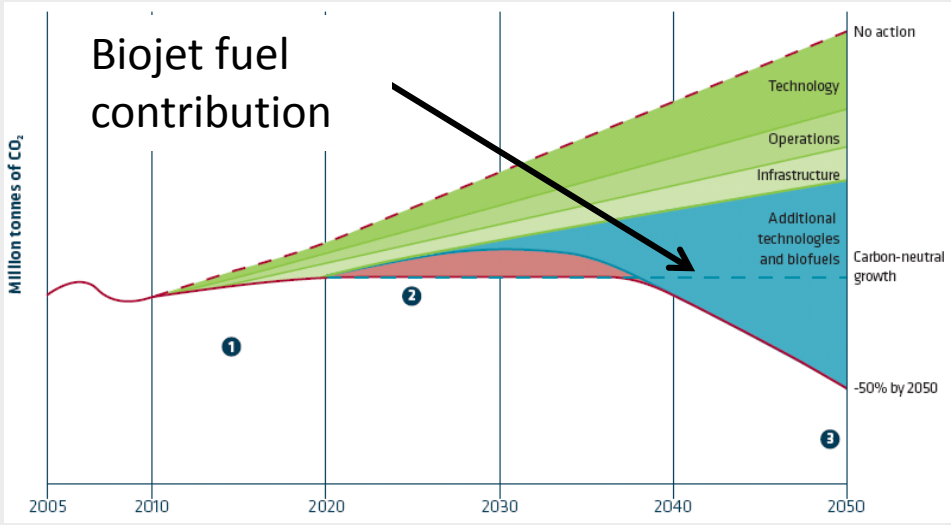
Observation 1: Ethanol Industry Boom and Bust

- **The US Energy Independent and Security Act of 2007 :**
  - 1.6 billion gallons in 2000 to 13.2 billion gallons in 2010
- **Biorefineries will likely face large financial uncertainties**
  - **Dried up capital** due to the credit crunch and the recent expiration of a federal subsidy for ethanol blenders
  - Recent **drought** has caused a spike in corn price leading to temporary shut down or scale back production of many ethanol refineries
  - Increased **price of corn** has squeezed refineries' profit margin below the sustainable level

Biofuels supply chain network is a complex system

Observation 2: Aviation Biofuels Potentials

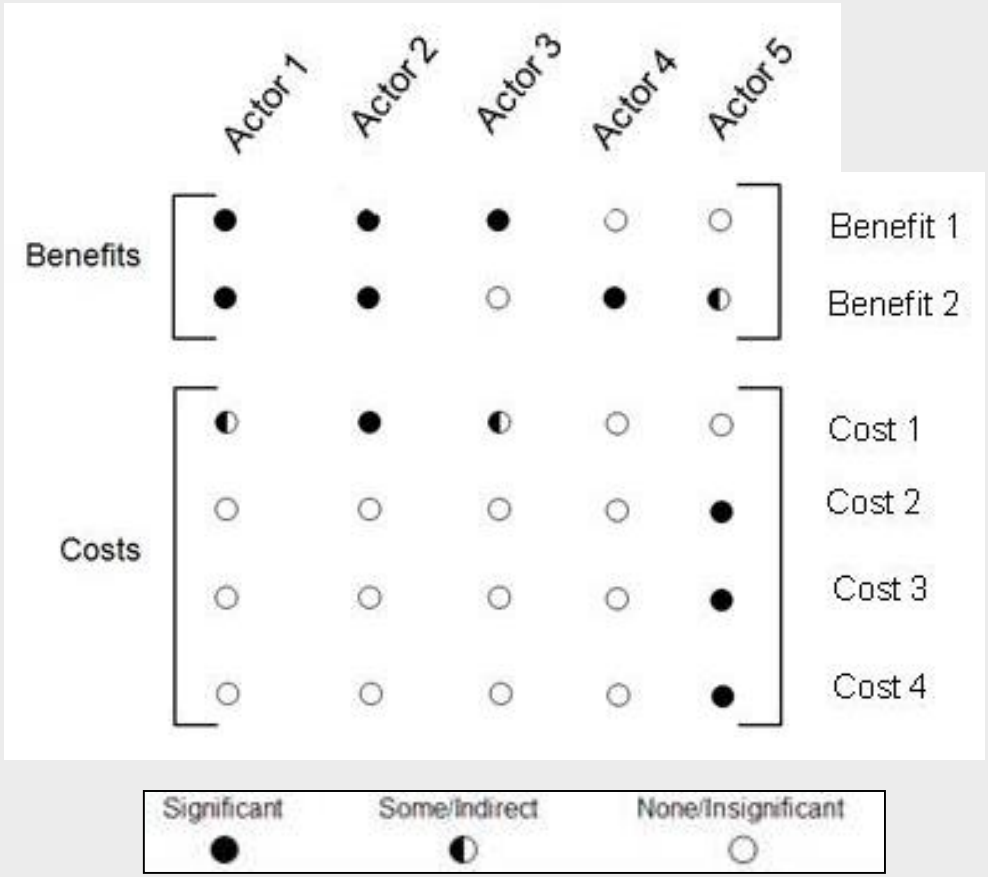
- In the United States, the **aviation** sector is responsible for about **11%** of the total **transportation GHG emissions**.
- Aviation emission reduction goal:
  - carbon neutral growth by 2020
  - GHG emissions reduction by 50% compared to the 2005 baseline level by 2050



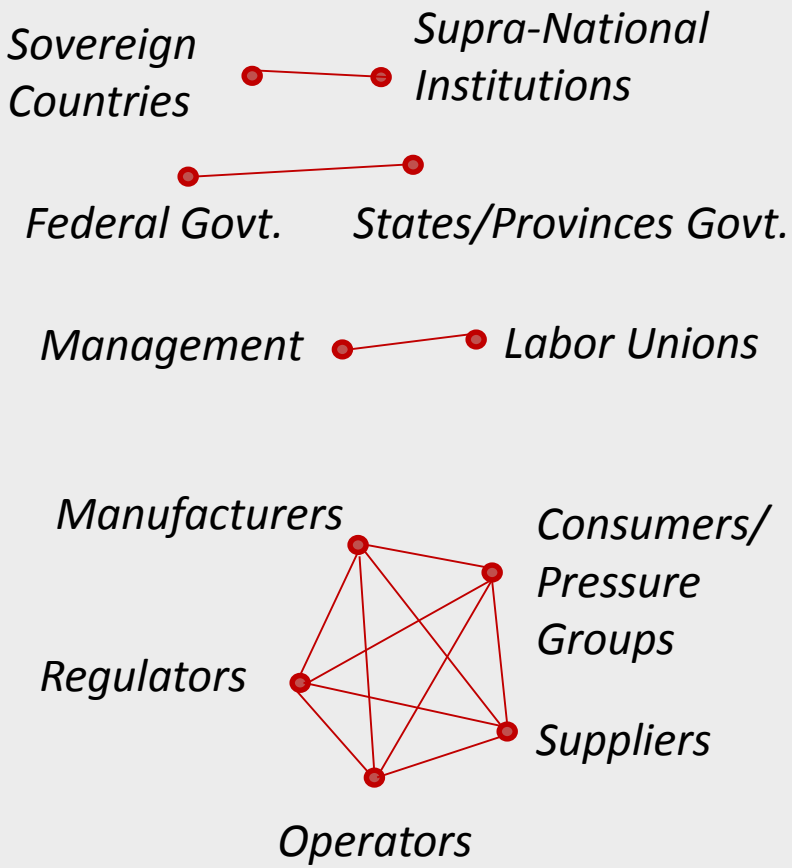
Source: Air Transport Action Group

For biojet fuels to achieve its GHG emission reduction potential, **technical** and **economic** hurdles must be overcome

Observation 3:
Many policymaking efforts on System Change involving multi-actors end up in Delay, Deadlock, or Court



Credit: Mozdzanowska, A., & Hansman, R. J. , 2008

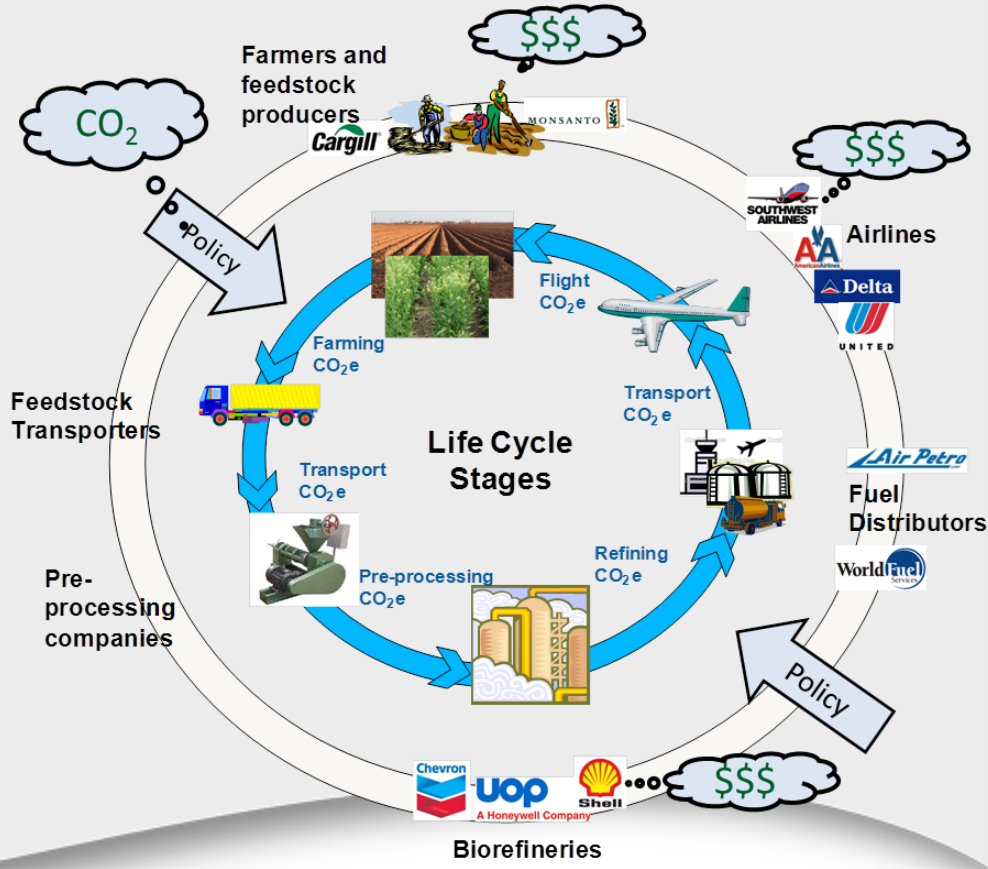


Need for a System Design for Equity/Fairness

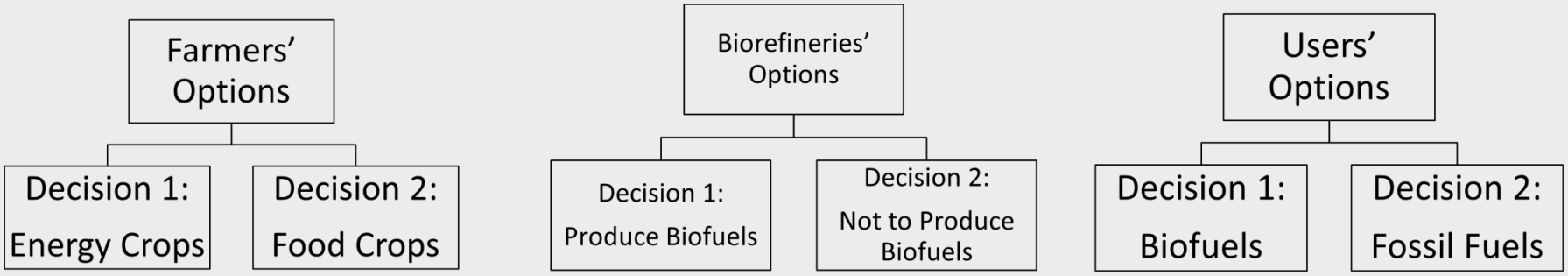
Biofuels production and use = an industrial ecosystems

Features:

- an ecosystem consists of multiple agents or actors
- multiple resources
- decision is based on perceived payoff
- imperfect and obsolete knowledge to base their decisions
- lacks a central controller
- decisions are made in an uncoordinated fashion and asynchronously

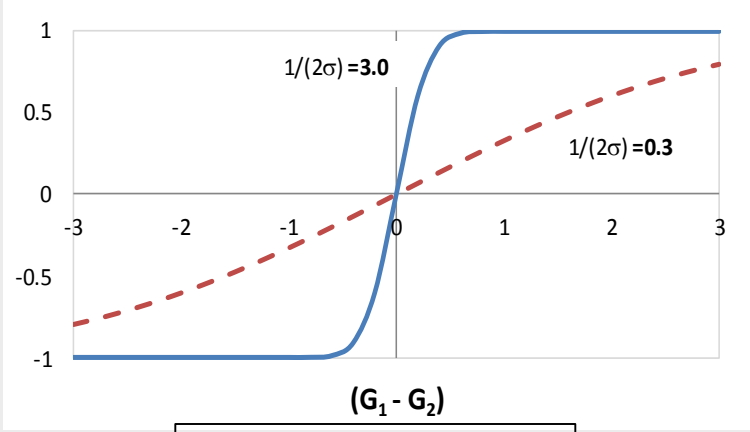


Dynamics of Biofuels Supply Chain Network



$$\frac{df}{dt} = \alpha\,[\rho(f(t-\tau) - f(t)]$$

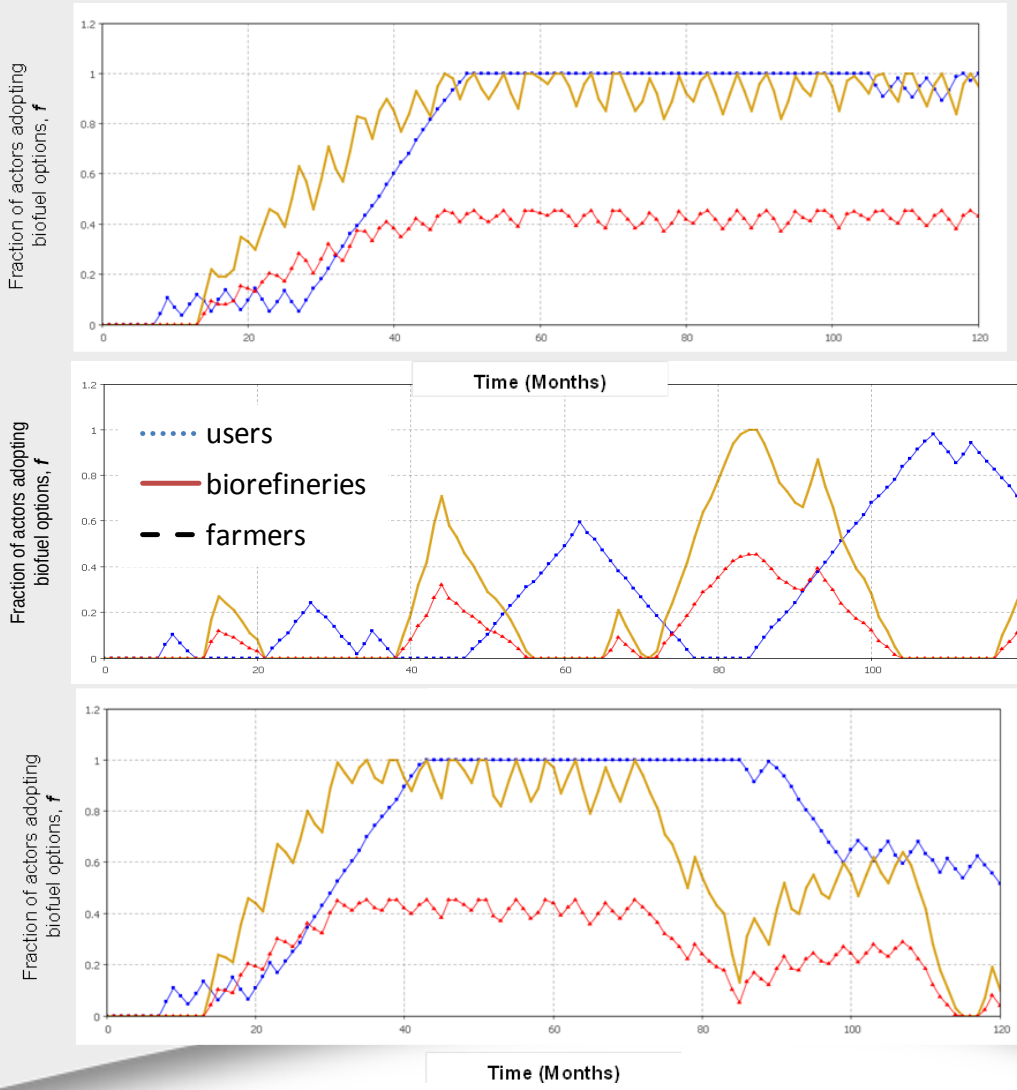
f : fraction of agents taking *Decision 1*
α : evaluation rate
ρ : **preference probability** function
G_1 : payoff from taking *Decision 1*
G_2 : payoff from taking *Decision 2*
σ : payoff uncertainty
τ : time delay



Error Function, erf

$$\rho = \frac{1}{2}\left[1 + \text{erf}\left(\frac{G_1(f) - G_2(f)}{2\sigma}\right)\right]$$

Behavior of Supply Chain Network



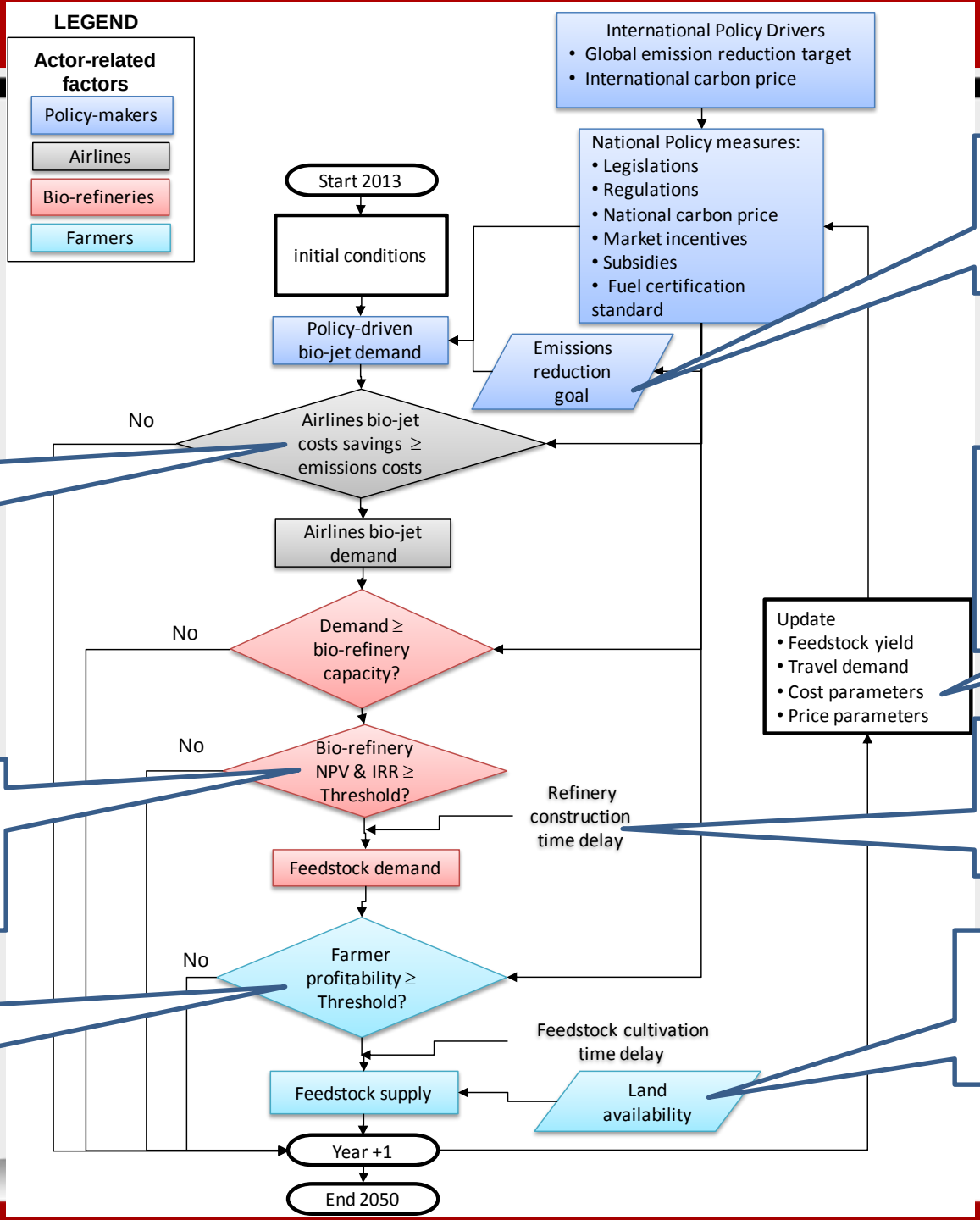
Agusdinata, D.B., Lee, S., and Zhao, F., Thissen, W., "Agent-based Simulation Modeling Framework for Uncovering System Behaviors in Biofuels Supply Chain Network, "*Simulation: Transactions of the Society for Modeling and Simulation International*, (forthcoming)

Multi-Actor Life Cycle Assessment

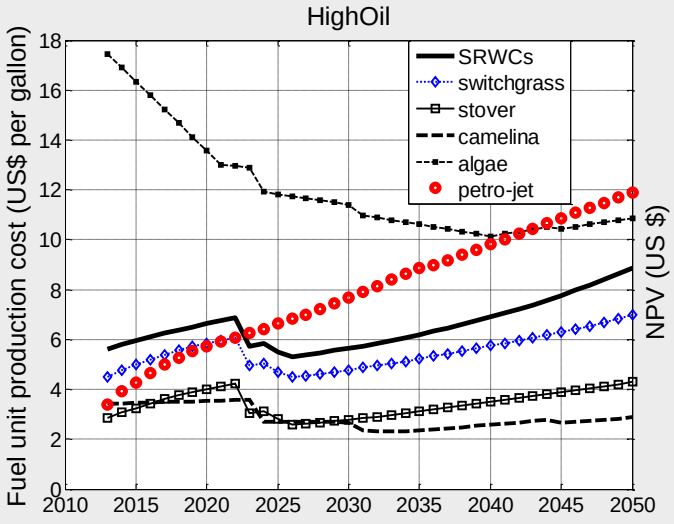
- **Traditional LCA studies focus:**
  - mostly on the environmental performance of technology options
  - largely left out the economic aspect of the system in question
  - or at most include economic performance as a separate part

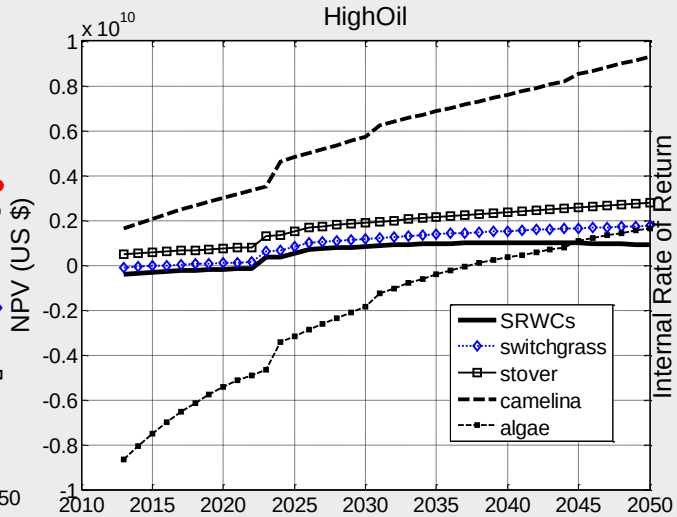
- **Multi-Actor LCA:**
  - Explicit consideration of supply chain actors

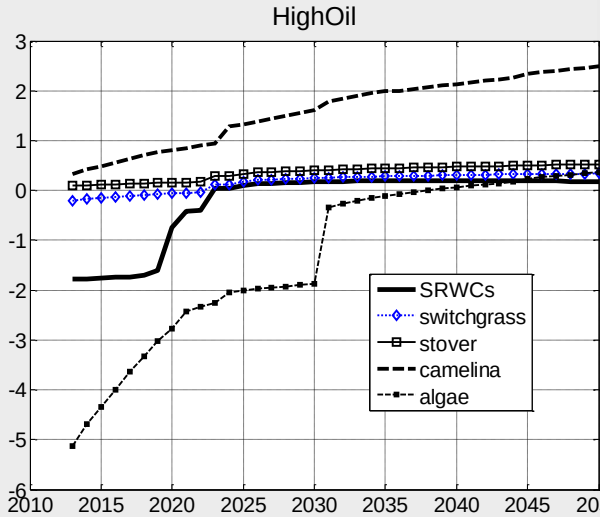
- **Expected Results:**
  - Better estimate of feedstock penetration level and life cycle emissions impact


LEGEND
Actor-related factors
Policy-makers
Airlines
Bio-refineries
Farmers
International Policy Drivers
• Global emission reduction target
• International carbon price
National Policy measures:
• Legislations
• Regulations
• National carbon price
• Market incentives
• Subsidies
• Fuel certification standard
Start 2013
initial conditions
Policy-driven bio-jet demand
Emissions reduction goal
No
Airlines bio-jet costs savings ≥ emissions costs
Airlines bio-jet demand
No
Demand ≥ bio-refinery capacity?
No
Bio-refinery NPV & IRR ≥ Threshold?
Refinery construction time delay
Feedstock demand
No
Farmer profitability ≥ Threshold?
Feedstock cultivation time delay
Feedstock supply
Land availability
Year +1
End 2050
Update
• Feedstock yield
• Travel demand
• Cost parameters
• Price parameters
Emission reduction goal
Airlines' cost savings
Effect of technological learning curve on costs
Biorefineries' investment criteria
Construction time delay
Farmers' profitability criteria
Land constraints

Result: production cost, NPV, IRR





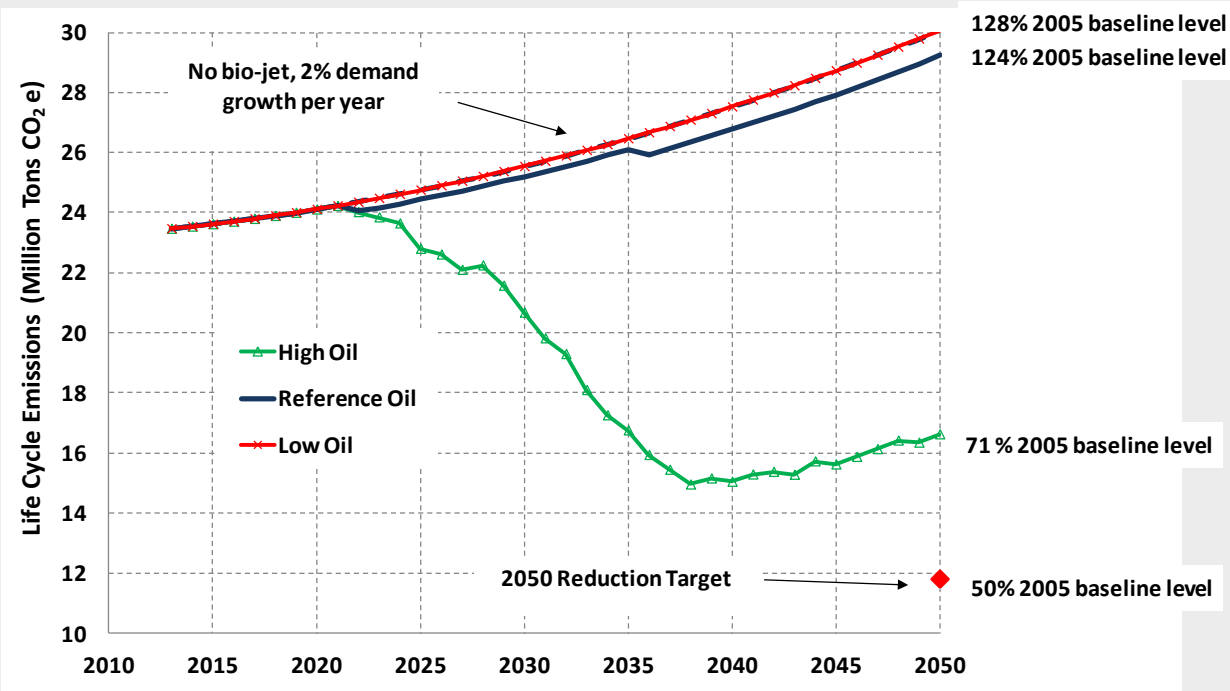


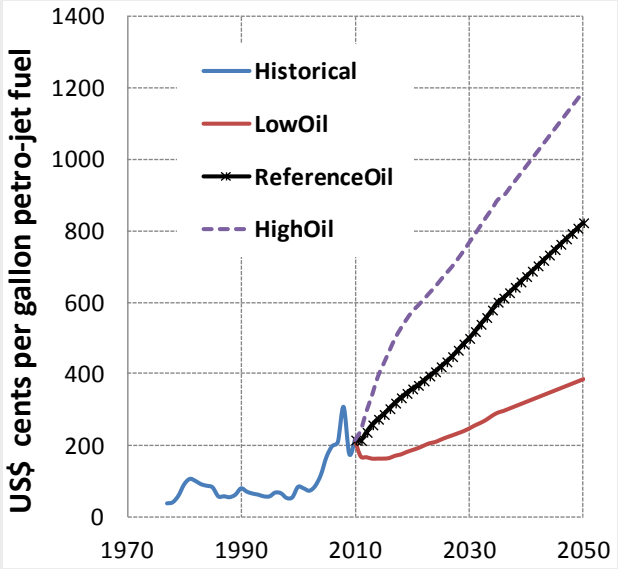
Camelina **Corn Stover**

Algae **Switchgrass** **Woody Crops**

Reference: Agusdinata, D.B., Zhao, F., Ileleji, K.E. and DeLaurentis, D.A. "Life Cycle Assessment of Potential Bio-jet Fuel Production in the United States", *Environmental Science and Technology*, vol. 45 (21), pp. 9133–9143, 2011

Evolution of US Aviation Life Cycle Emissions

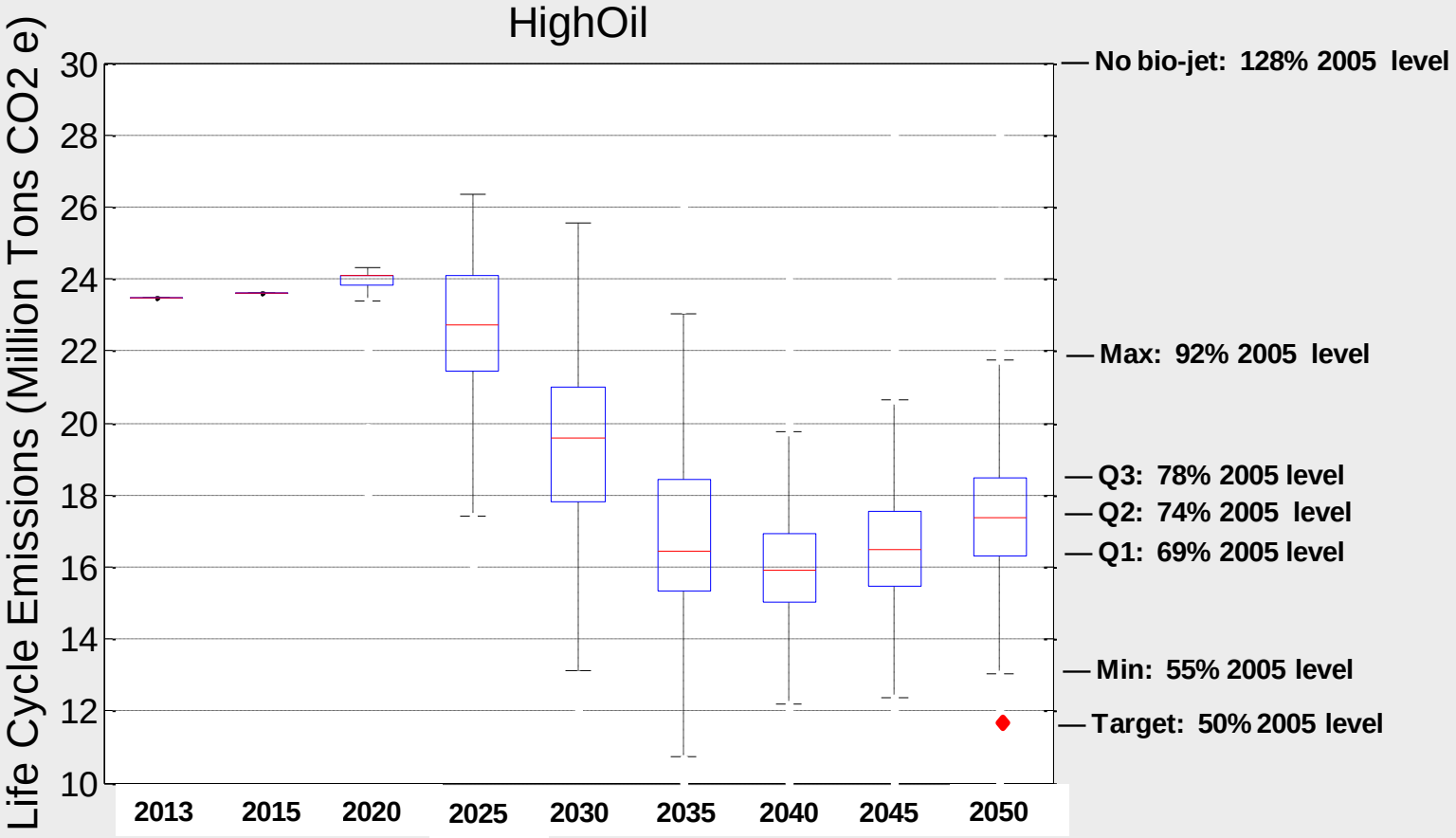




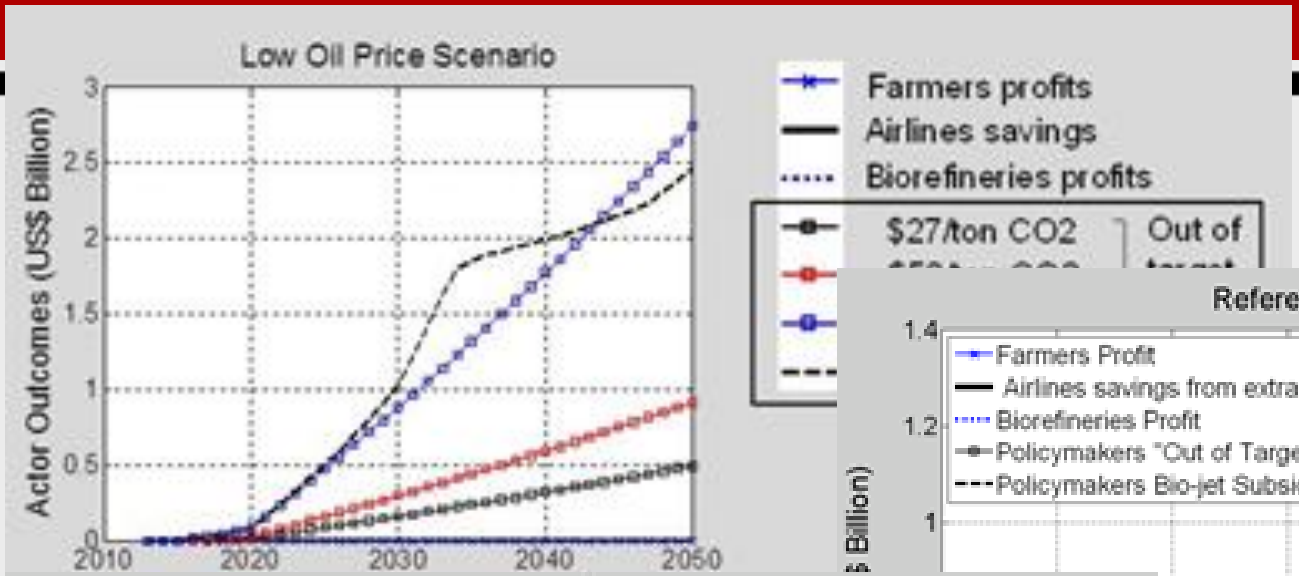
Source:

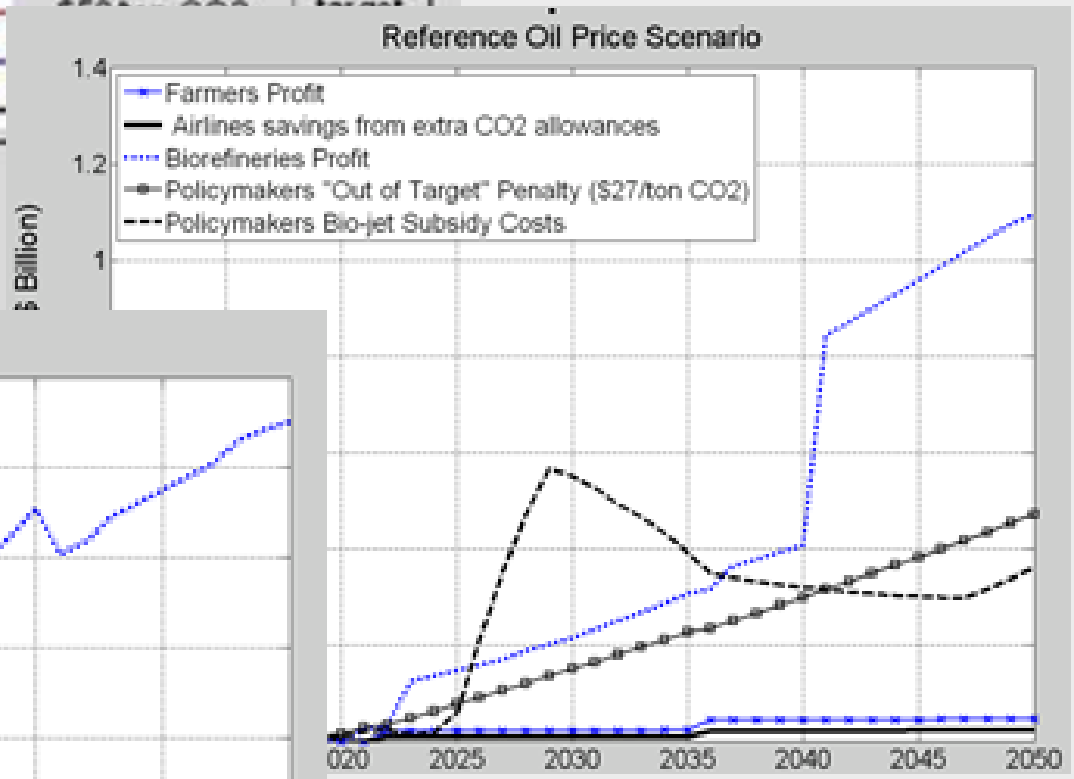
Lignocellulosic derived liquid fuels can only become competitive under high oil price scenario

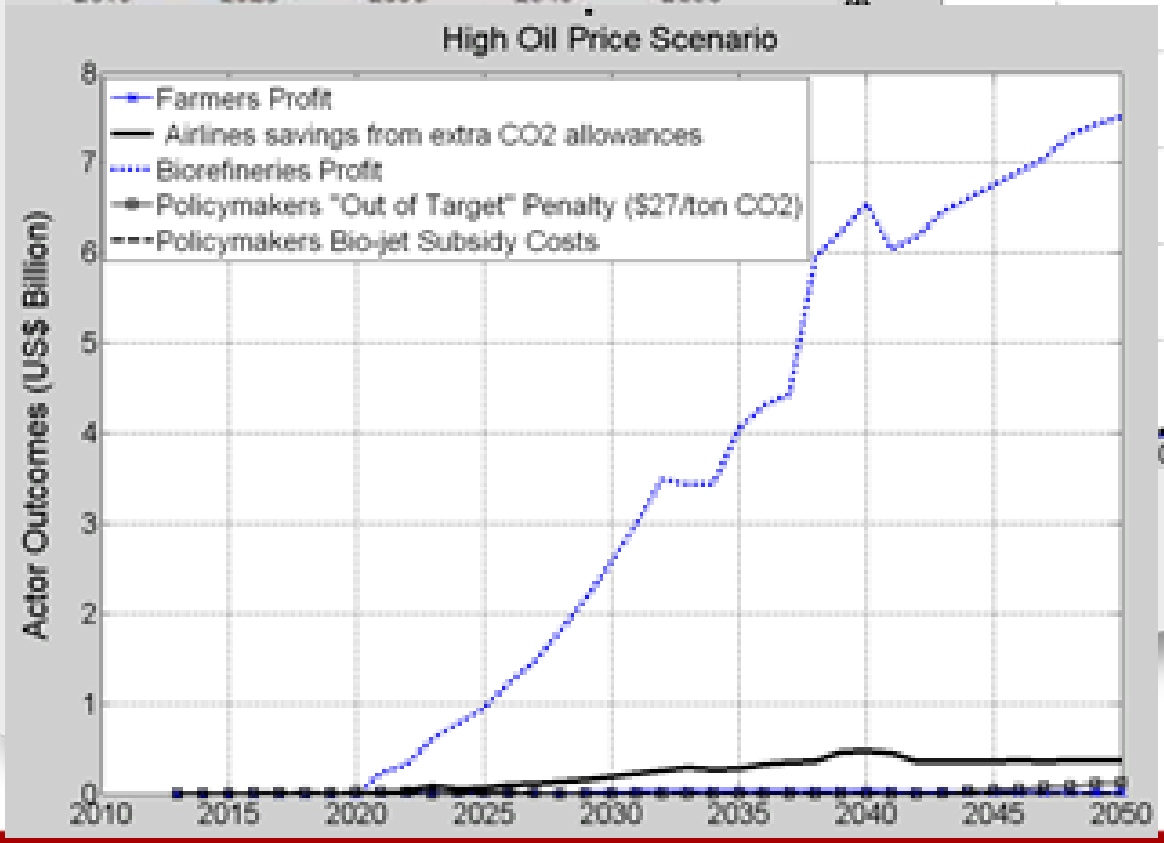
Taking uncertainties into account



RESULTS: BIOFUELS EQUITY ISSUE


Low Oil Price Scenario
Actor Outcomes (US$ Billion)
Farmers profits
Airlines savings
Biorefineries profits
$27/ton CO2
Out of


Reference Oil Price Scenario
Farmers Profit
Airlines savings from extra CO2 allowances
Biorefineries Profit
Policymakers "Out of Target" Penalty ($27/ton CO2)
Policymakers Bio-jet Subsidy Costs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Farmers Profit
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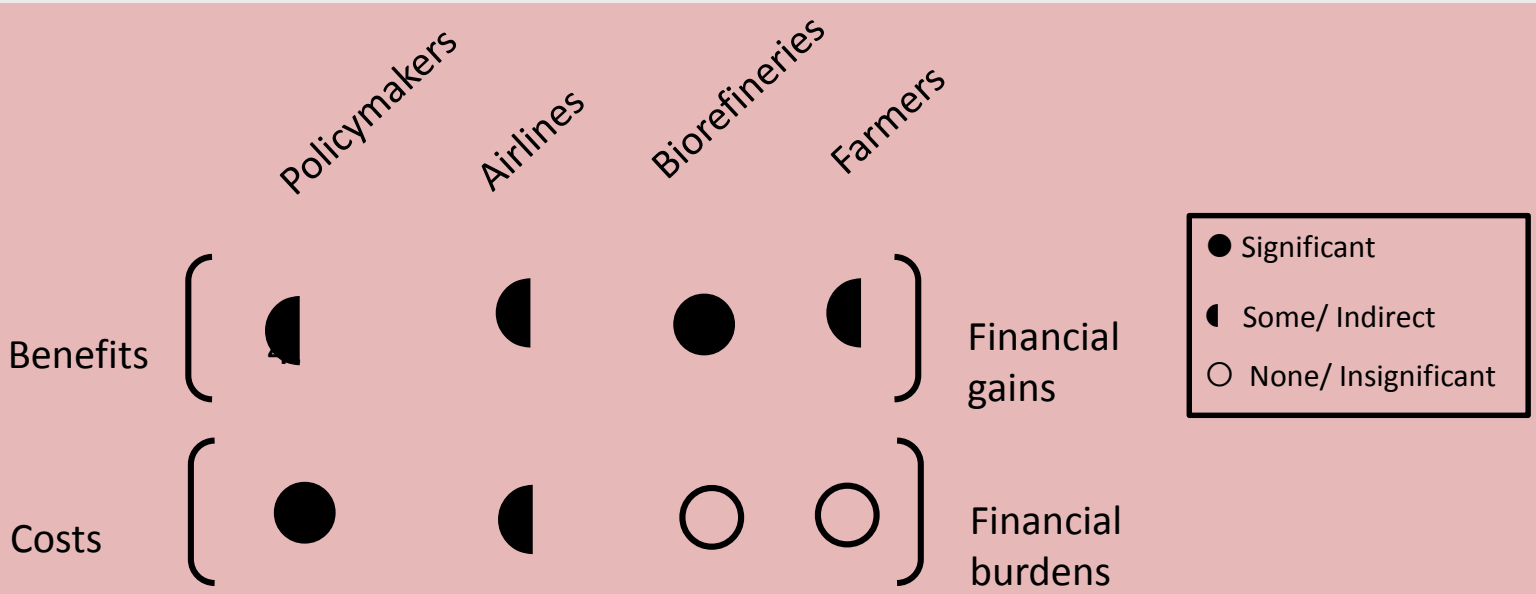
Preliminary Result (2)



- **Biorefineries will be main beneficiaries**
  - But are exposed to financial risks
- **Policymakers (incl. consumers and taxpayers) will bear most the financial burdens**

Agusdinata, D.B., "System Design Framework for Equity/ Fairness among Actors, " Procedia Computer Science, Volume 16, , Pages 1122-1131, 2013

Concluding Remarks

- **Added values of the multi-actor system approach:**
  - Insights:
    - Understanding of **collective behavior** resulting from **decisions of individual actors**
    - A decision may perfectly be **rational** from an actor perspective but could be **detrimental** from the view of overall system
  - Policy implications:
    - **Policy design** more aligned to actors' interests
    - **Quantitative** basis for negotiation and compromise

- **Challenges:**
  - **Calibration** of the parameter space
  - **Validation** of the overall system behavior with empirical data or expert opinion

EXTRA SLIDES

Exploring the Meaning of Fairness

Equity Principles
Egalitarianism
Spoiler of equilibrium pays
Ability to pay
Grandfathering
Merit

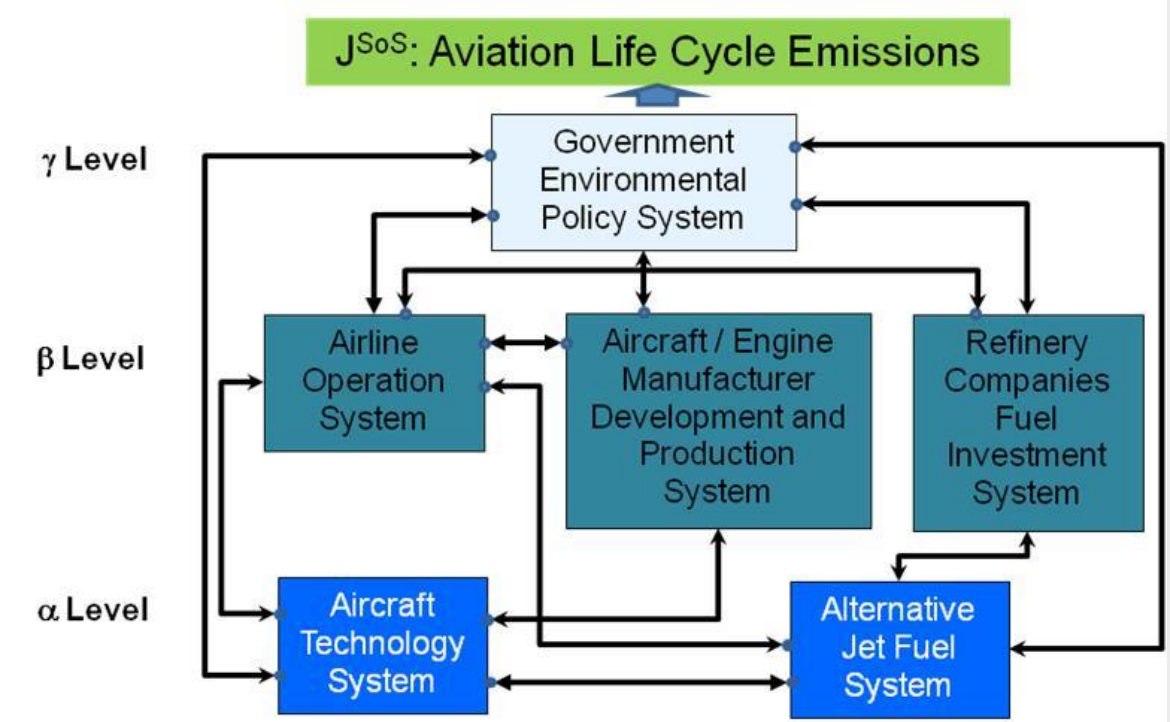
Approach

- most biofuel supply chain studies to date take the bio-refinery as the default customer under the assumption that the bio-refinery is in control of the entire supply chain.
- Most of these studies adopted the classical production/distribution MIP approach in order to design a network that maximizes bio-refinery profits

- As the SC network consist of a large number of firms from multiple interrelated industries, a complex adaptive system (CAS) perspective allows a supply network manager to make local decisions while considering the complexity of the overall system.
- Furthermore, it is argued that due to the prevalence of the use of information technology, supply chains have greatly increased in complexity almost to the level of biological system.
- In this environment there is a need for coordination strategies among supply chain actors to achieve an adaptive collective behavior.

SYSTEM DESIGN FOR EQUITY/FAIRNESS AMONG ACTORS

A System-of-Systems Definition for the Sustainability of Aviation Biofuels



The common system objective, J_z^{SOS} transcends all individual objectives of actors, $J_z^{Actor\ i}$.

Agusdinata, D.B. and DeLaurentis, D.A.,"Addressing Equity Issues in Multi-Actor Policymaking via a System-of-Systems Approach: A Case Study in Aviation Emissions Reduction ", Journal of Systems Science and Systems Engineering, vol. 20(1), pp. 1-24, 2011