Potential Contribution of Microalgal Biofuels to Long-Term Final Energy Mix in a Carbon-Constrained World

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Outline

1. Introduction
2. Model structure
3. Data and assumptions
4. Simulation results and discussion
   - Competitiveness of microalgal biodiesel under different CO_2 constraints
   - Cost-effective strategy for supplying and using microalgal biodiesel
   - Sensitivity analysis
5. Conclusions

Introduction

Research background

- Criticisms have recently been raised on some biofuels, such as possible competition with food production, increased water consumption, their impacts on land-use patterns, etc.
- Microalgae have several distinctive features providing the possibility of avoiding the above-mentioned criticisms.
- Their distinctive features include: (1) significantly high yields, (2) ability to be cultivated in salt water or wastewater ponds on marginal land, and (3) no competition with food production.
- Microalgae are receiving increasing attention, particularly as a high-potential source for biodiesel production.

Research objective

- To assess the competitiveness of microalgal biofuels under different CO_2 constraints
- To derive the cost-effective strategy for supplying and using microalgal biofuels
- To perform sensitivity analysis with respect to key parameters

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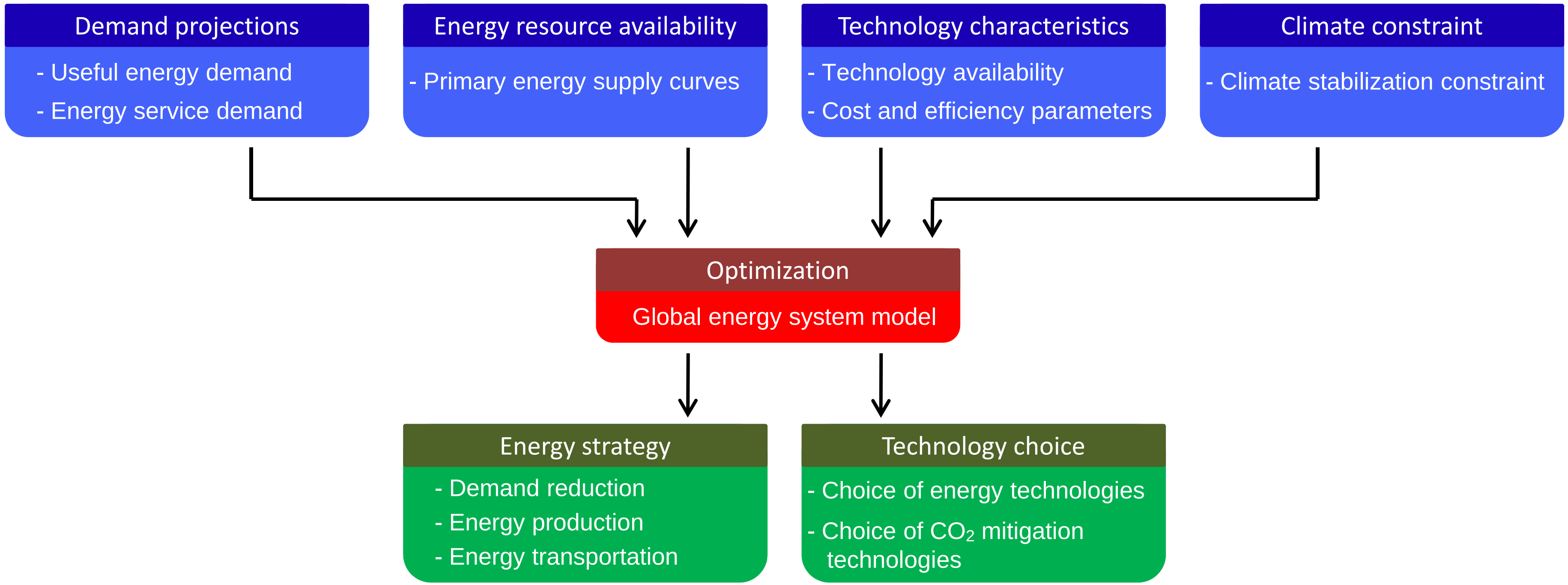
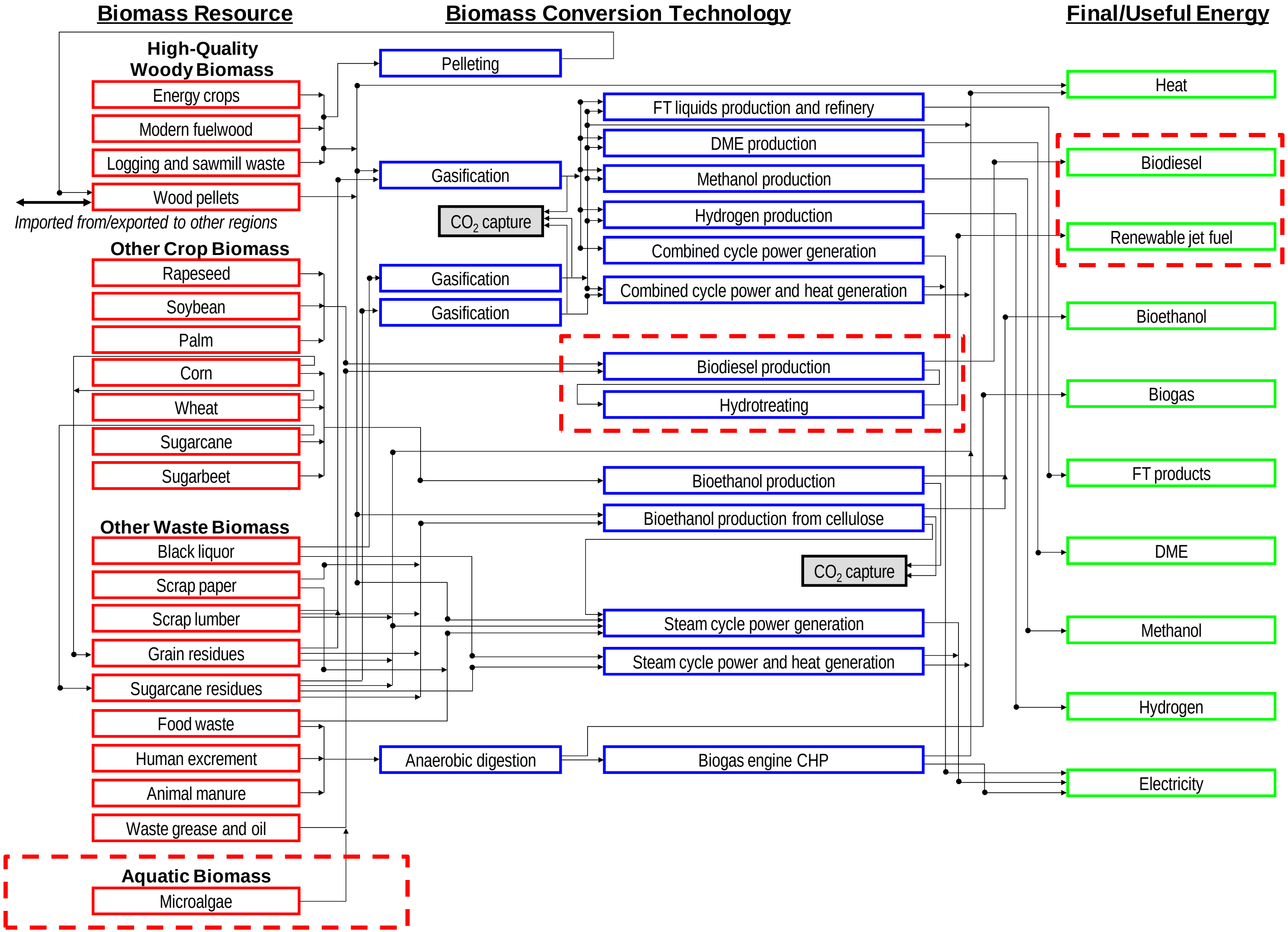
Overview of the Global Energy Model REDGEM70

- Bottom-up type global energy systems optimization model designed to determine the cost-optimal energy strategy and the cost-optimal choice of technology options from 2000 to 2100
- Detailed regional disaggregation (the whole world being divided into 70 regions) enabling the explicit consideration of regional characteristics and interregional energy transportation
- Future socio-economic driving forces based on the IIASA-WEC study's middle-course Case B



Structure of the Bioenergy Submodel



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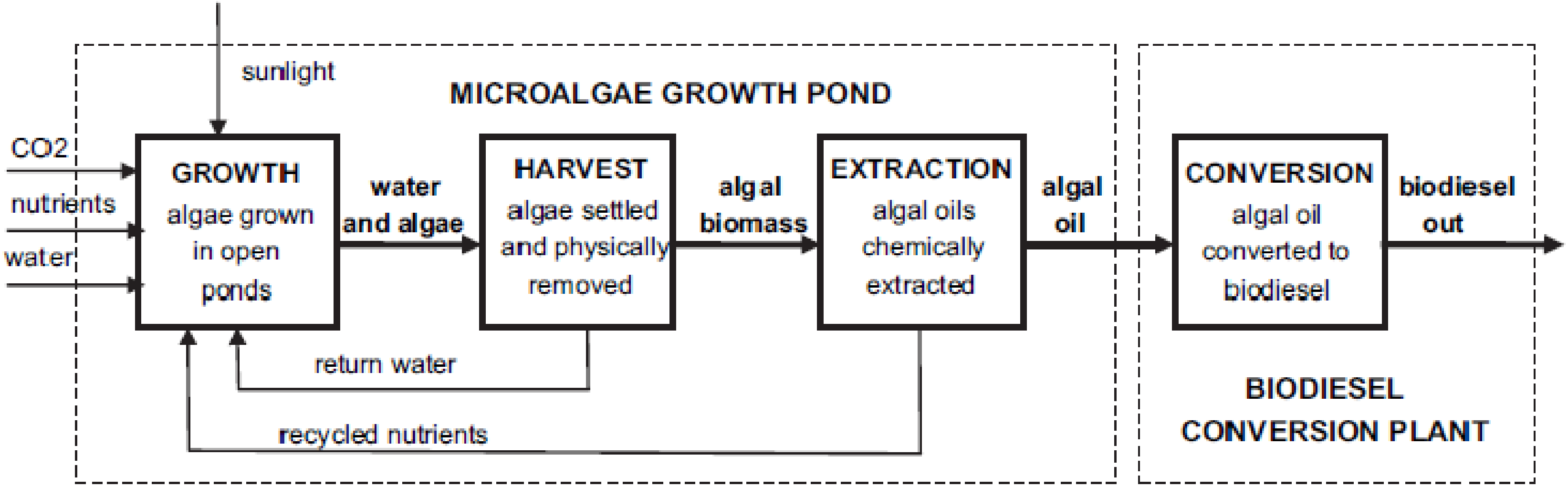
Assumptions on Microalgal Biodiesel Production Systems

- Microalgae are cultivated continuously in open ponds equipped with paddle wheels.
- Seawater and pure CO_2 captured from stationary sources are used for microalgal production.

Figure: Typical process of producing biodiesel from microalgae using open pond systems

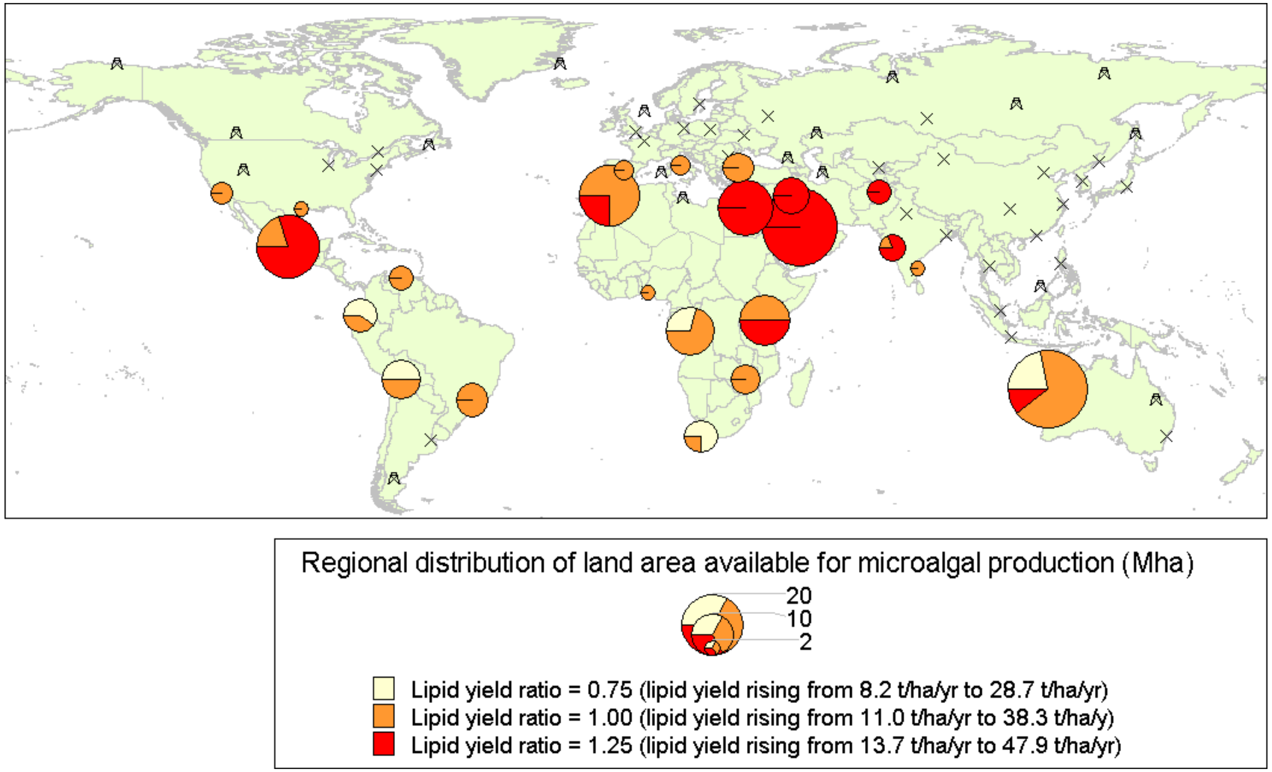


Source: Gallagher (2011).

Microalgal Supply Potential by World Region

- The global land area that can be used for microalgal production was estimated at 130 Mha (Florentinus et al., 2008).
- A large microalgal supply potential was estimated to exist in regions with high temperature, abundant sunlight, and large arid (or semi-arid) areas.

Figure: Regional distribution of land area that can be used for microalgal production

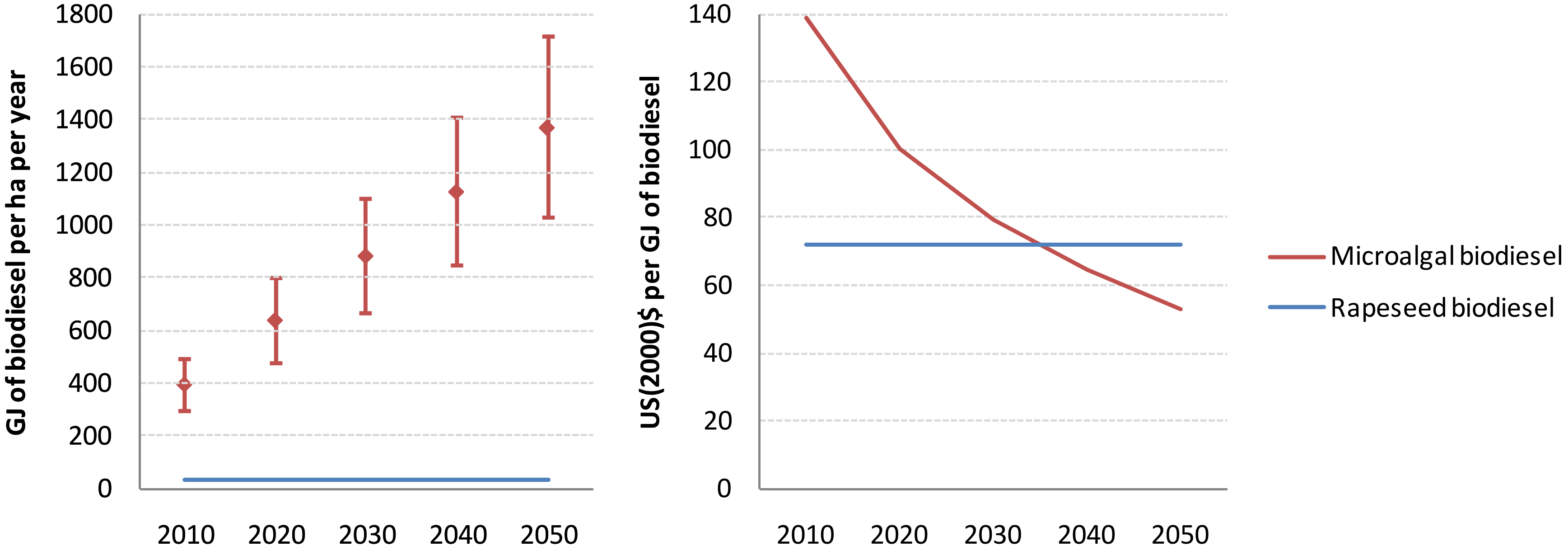


Source: Takeshita (2011).

Per Unit Area Yield and Production Cost of Biodiesel

- Microalgal biodiesel yield per unit area was estimated to be higher by a factor of about 12 in 2010 and about 38 in 2050 compared with that of rapeseed biodiesel.
- Microalgal biodiesel production cost per unit area remains higher by a factor of over 20 compared with that of rapeseed biodiesel over the time horizon.
- However, microalgal biodiesel production cost per unit output was estimated to ultimately becomes lower than that of rapeseed biodiesel.

Figure: Techno-economic parameters for producing biodiesel from microalgae and rapeseed



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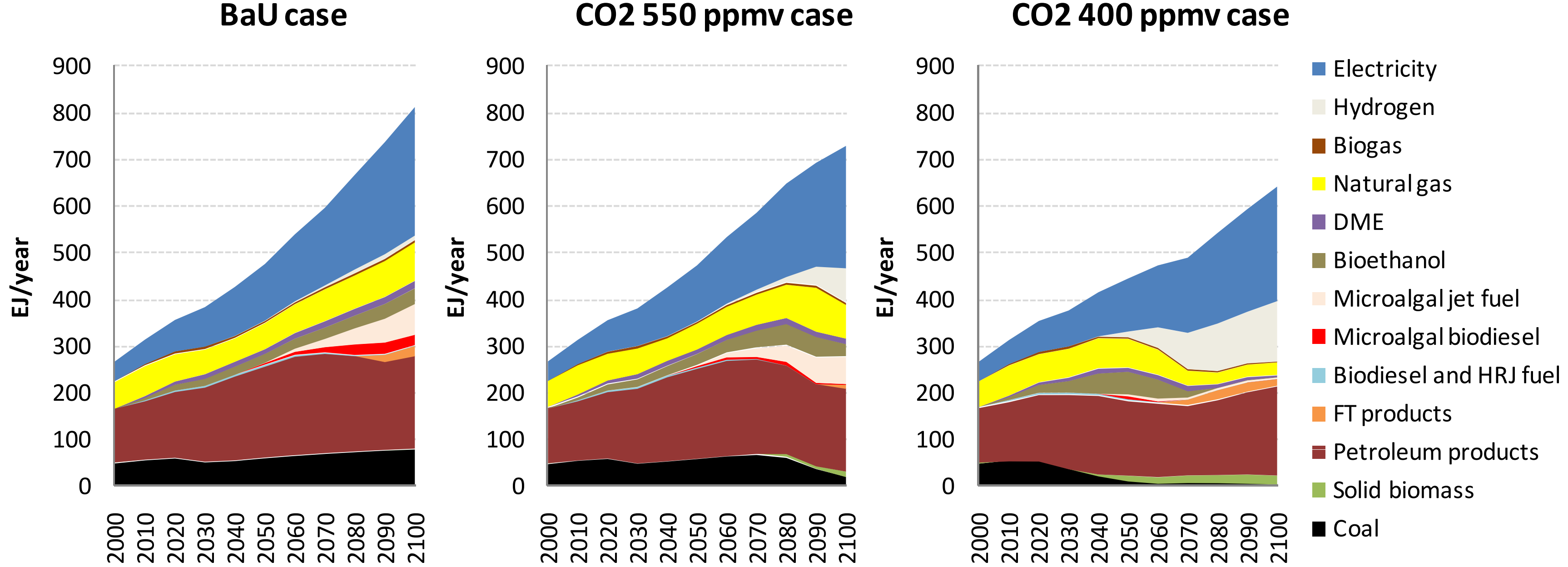
Competitiveness of Microalgal Biofuels

- Microalgal biofuels enter the global final-energy mix in all the three cases.
- As the CO_2 stabilization constraint is more stringent, microalgal biofuels are less attractive.
  - Combustion of microalgal biofuels adds new CO_2 to the atmosphere.
  - Release of captured CO_2 makes it difficult to meet stringent climate stabilization constraints.
  - CO_2 prices rise as the CO_2 stabilization constraint is more stringent.
- Microalgal biofuels are introduced because they are carbon neutral and because introducing them reduces the consumption of other forms of final energy to satisfy the energy demand.

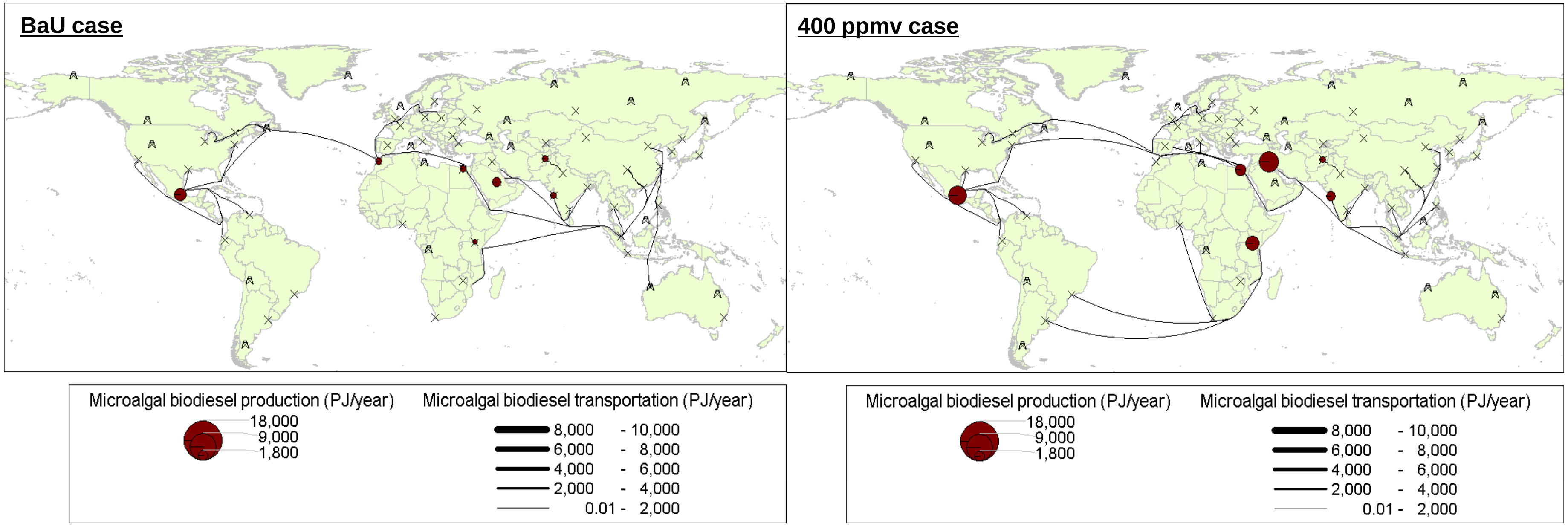
Figure: Global final energy consumption in the BaU, CO_2 550 ppmv, and CO_2 400 ppmv cases



Strategy for Supplying Microalgal Biodiesel in 2050

- Some similarities can be found in the results of the two cases.
- Microalgal biodiesel is produced mainly in the Middle East, Central America, northern and central-eastern Africa, and western Asia, from which it is exported widely to regions such as North and Latin America, Europe, and eastern Asia.

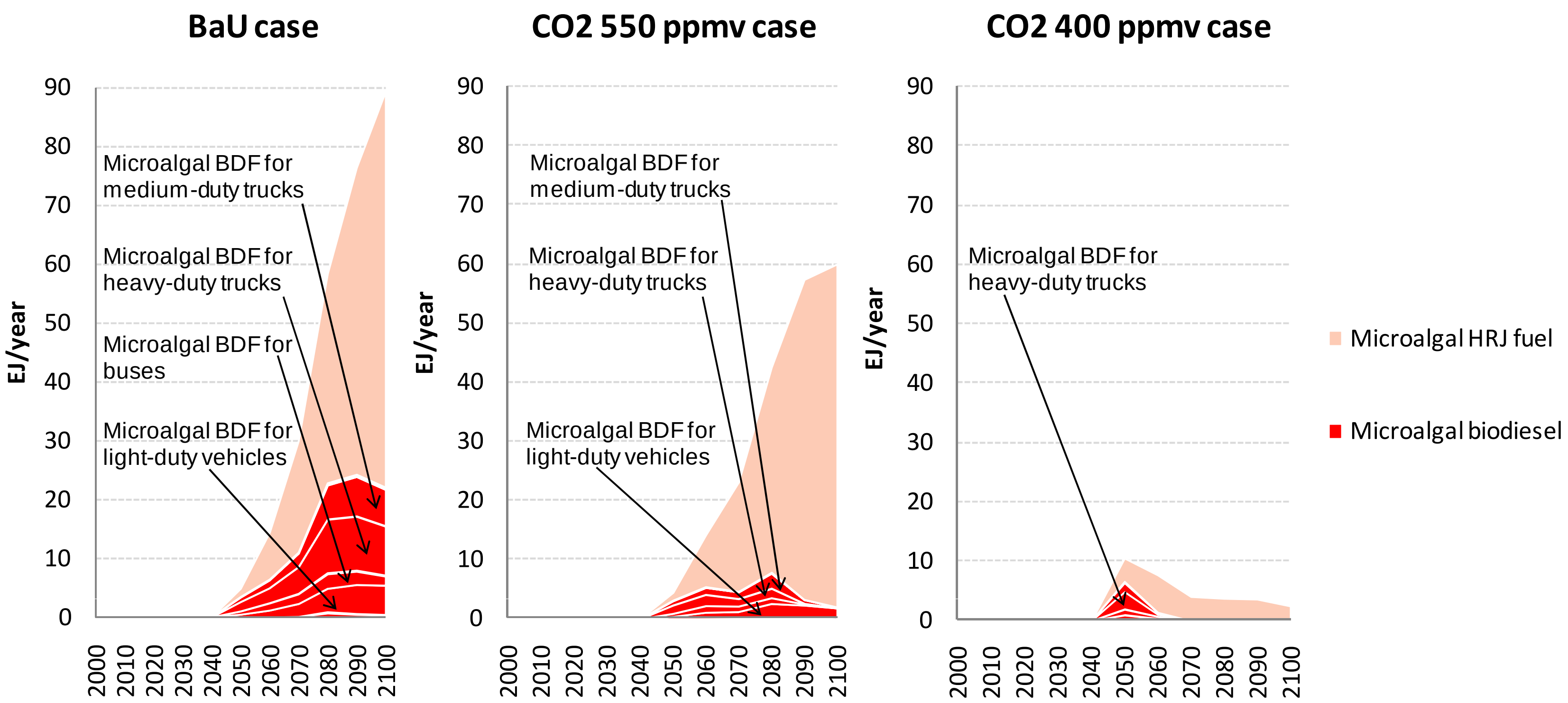
Figure: Microalgal biodiesel production and transportation in the BaU and CO_2 400 ppmv cases in 2050



Strategy for Using Microalgal Biofuels

- Almost all microalgal biodiesel and HRJ fuel are used to satisfy the energy demand in the transport sector.
- An increasing portion of microalgal biodiesel is hydro-treated to produce a HRJ fuel, which is supplied for the rapidly growing aviation sector in the second half of the century.

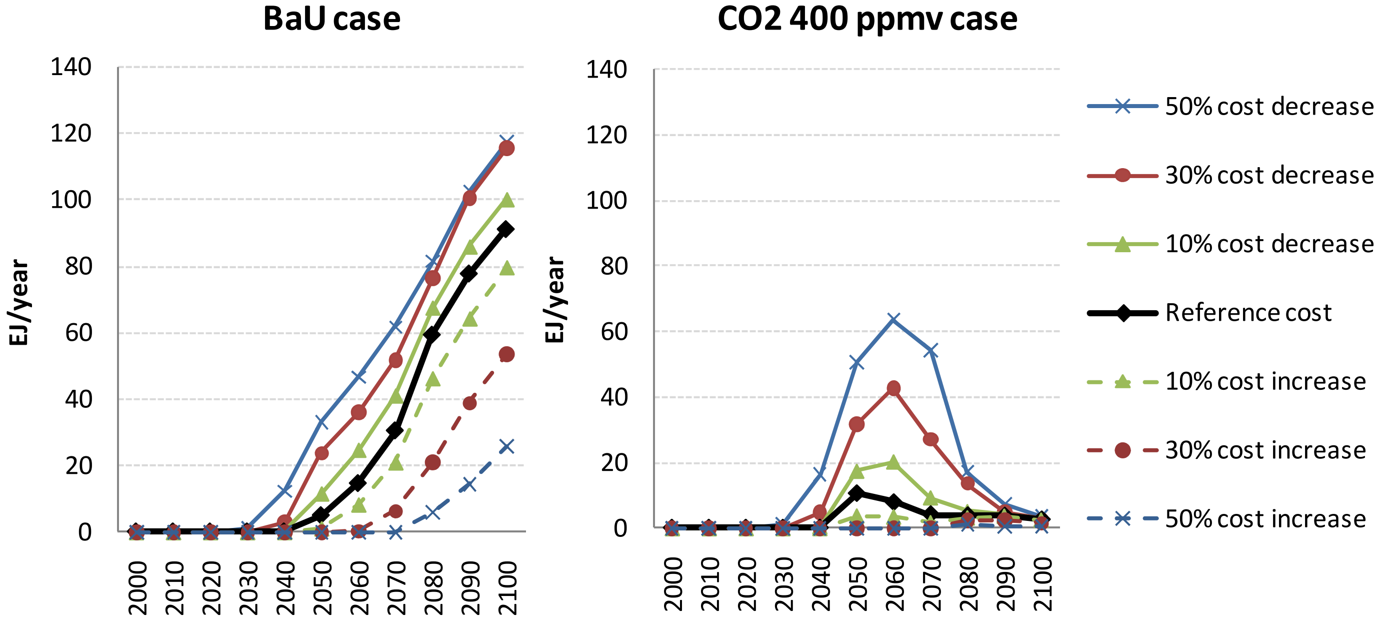
Figure: Global final consumption of microalgal biofuels by purpose in the three cases



Sensitivity Analysis

- Changes in microalgal production cost have a large impact on the competitiveness of microalgal biofuels.
- In particular, under the 400 ppmv CO_2 stabilization constraint, lowering microalgal production cost remarkably increases the competitiveness of microalgal biofuels.

Figure: Total global microalgal biodiesel production in the BaU and CO_2 400 ppmv cases as a function of microalgal production cost



Conclusions

1. Microalgal biofuels could competitively enter the global energy market regardless of CO_2 abatement policy. However, its competitiveness decreases as the CO_2 stabilization constraint becomes more stringent.

2. The Middle East, North Africa, and Central America might become the leading producers and exporters of microalgal biodiesel, while North and Latin America, Europe, and eastern Asia might become their major importers.

3. Microalgal biofuels play an important role in satisfying the energy demand in the transport sector. An increasing proportion of microalgal biodiesel is converted into a HRJ fuel over time to be used as a fuel for aircraft.

4. Changes in microalgal production cost have a large impact on the competitiveness of microalgal biofuels. This implies that R&D efforts aimed at improving microalgal production cost should be enhanced to receive the benefits of microalgal biofuels.

For details please see:

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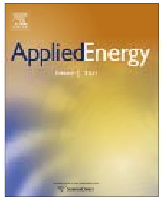

Competitiveness, role, and impact of microalgal biodiesel in the global energy future

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A B S T R A C T

This paper examines the competitiveness, role, and impact of microalgal biodiesel in the 21st century using a global energy system model with a detailed technological representation. The major conclusions are the following. First, the competitiveness of microalgal biodiesel decreases as CO_2 stabilization constraints become more stringent. The share of microalgal biodiesel and renewable jet fuel produced from it in total global final energy consumption over the time horizon 2010–2100 is 5.1% in the case without CO_2 constraints compared with 3.9% and 0.7% in the case of CO_2 stabilization at 550 ppmv and 400 ppmv, respectively. This is because production and combustion of microalgal biodiesel release as much CO_2 as is captured from anthropogenic sources and assimilated by microalgae and because CO_2 prices raised by stringent CO_2 stabilization constraints make the economics of microalgal biodiesel unattractive. Second, the competitiveness of microalgal biodiesel is also greatly affected by microalgal production cost and microalgal lipid yield. Under a 400 ppmv CO_2 stabilization constraint, a 50% microalgal production cost decrease leads to increase in total global microalgal biodiesel production over the time horizon by a factor of 6.5, while a 50% microalgal lipid yield increase leads to increase in it by a factor of 4.5. Third, microalgal biodiesel plays an important role in satisfying the energy demand in the transport sector, thereby replacing petroleum products and Fischer–Tropsch synfuels. An increasing proportion of microalgal biodiesel is converted into renewable jet fuel over time to be used as a fuel for aircraft. Fourth, either without CO_2 constraints or under the 550 ppmv CO_2 stabilization constraint, the participation of microalgal biodiesel in the global energy market would have a large impact on the global energy supply and consumption structure. This is not only because of its substitution for other forms of final energy, but also because of the need to satisfy the demand for CO_2 for microalgal production.