Environmental Science & Technology

# What future for electrofuels in transport?

## analysis of cost-competitiveness in global climate mitigation

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**Reference:** Lehtveer M, Brynolf S, Grahn M (2019). What future for electrofuels in transport? – analysis of cost-competitiveness in global climate mitigation. Environmental Science and Technology 53 (3) 1690–1697. Open access.

# Background

- In the traditional electricity system, power plants are available most of the time and deliver to the grid based on their running cost.
- Electricity from variable renewables (VRE, e.g. wind and solar) do, however, have both daily and seasonal variations.
- Electrofuels could help deal with the variability issue by absorbing excess electricity at windy and/or sunny times, when the price of electricity is low.

**Reference:** Lehtveer M, Brynolf S, Grahn M (2019). What future for electrofuels in transport? – analysis of cost-competitiveness in global climate mitigation. Environmental Science and Technology 53 (3) 1690–1697. .

# Aim

- To investigate the cost-effectiveness of electrofuels from a global energy systems perspective under a climate mitigation constraint.

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# Method

- Global Energy Transition (GET) model. GET 10.0.
- Linear cost-minimizing model.
- Finds the least cost fuel mix, while meeting both a specified energy demand and a $CO_2$ emission constraint.
- New in this model version:
  - Possible to invest in electrofuel production.
  - Possible to capture $CO_2$ from the air.

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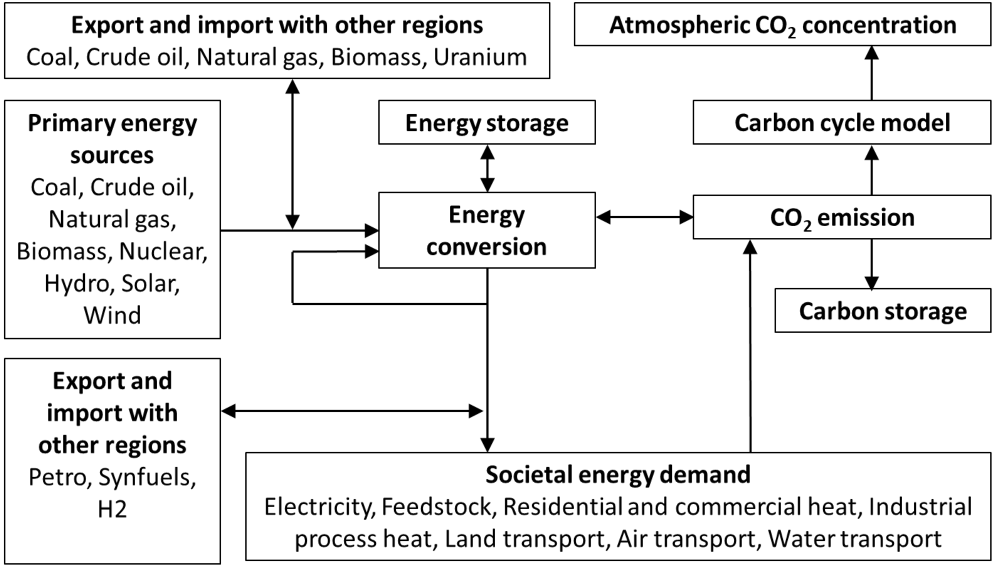
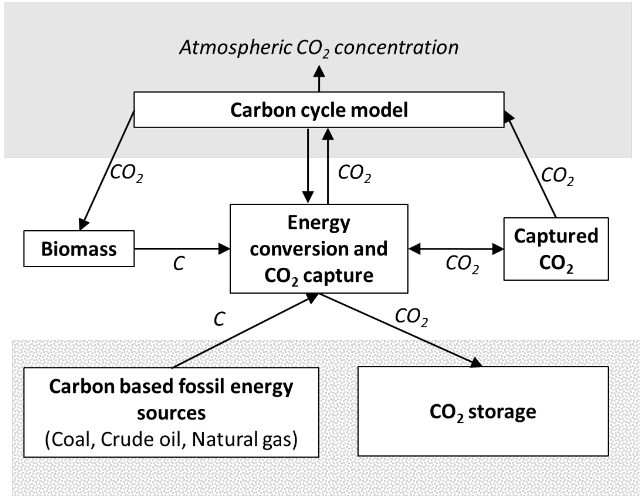
# Energy-economy model Global Energy Transition (GET)

Linearly programmed energy systems cost-minimizing model. Generates the fuel and technology mix that meets the demand (subject to the constraints) at lowest global energy system cost

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# Variable electricity

- The model uses resource-based time slices
  – each time step in the model is divided in slices based on the level of wind and solar generation.
  – Example: a slice called “high solar, medium wind” would aggregate together all hours that are described by this label, irrespective of when during the year they occur.
- To capture the connection between variable electricity and electrofuels, also hydrogen production was sliced in accordance, allowing the model to see differences in electricity prices.

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# Cases

- Base case, assuming input parameters that, to our best knowledge, match current situation as well as data representing mature technology by 2050.
- Monte Carlo analysis (500 model runs) randomly varying data for the 22 most uncertain parameters,
  - including cost of electrolyzers and the size of available carbon storage.
  - See next slide

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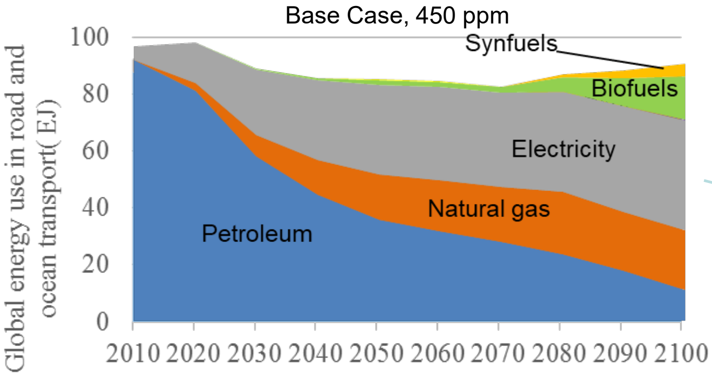
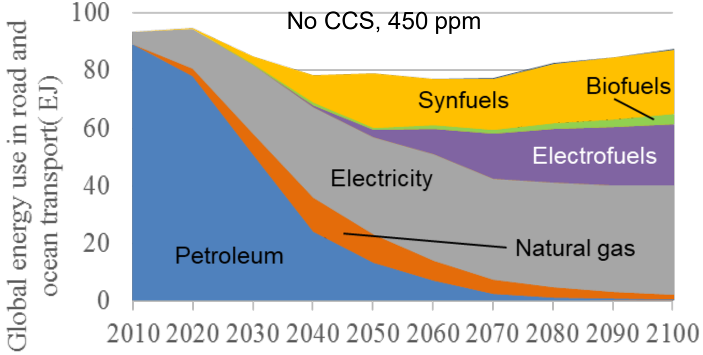
# Monte Carlo analysis

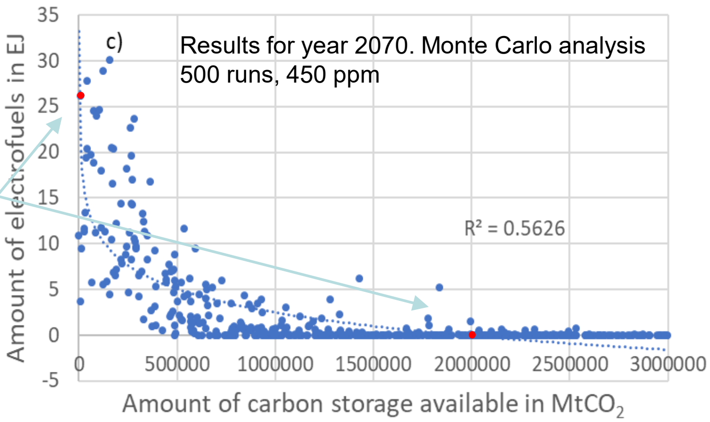
500 model runs, varying 22 parameters with the most uncertain data

| Parameter randomly varied in the Monte Carlo runs | Base: Starting data 2010 | Base: Mature data 2050 | Min | Max |
|---|---|---|---|---|
| CSP + storage investment cost ($USD_{2010}$/kW) | 7000 | 4500 | 0.5 x base | 1.5 x base |
| Wind onshore investment cost ($USD_{2010}$/kW) | 2000 | 1500 | 0.5 x base | 1.5 x base |
| Wind offshore investment cost ($USD_{2010}$/kW) | 5000 | 3000 | 0.5 x base | 1.5 x base |
| Solar PV rooftop investment cost ($USD_{2010}$/kW) | 4000 | 1600 | 0.5 x base | 1.5 x base |
| Solar PV plant investment cost ($USD_{2010}$/kW) | 3700 | 1250 | 0.5 x base | 1.5 x base |
| Solar $H_2$ investment cost ($USD_{2010}$/kW) | 4200 | 2500 | 0.5 x base | 1.5 x base |
| **Electrolyser investment cost ($USD_{2010}$/kW)** | **1300** | **500** | **0.6 x base** | **1.4 x base** |
| Electrolyser efficiency (%) | 80 | 80 | 65 | 85 |
| Synthesis reactor investment cost ($USD_{2010}$/kW) | 625 | 375 | 0.66 x base | 1.33 x base |
| Synthesis reactor efficiency (%) | 89 | 89 | 69 | 95 |
| Bioenergy availability (EJ/year) | 134 | 134 | 0.5 x base | 1.5 x base |
| **Global carbon storage capacity (Gtonne $CO_2$)** | **2000** | **2000** | **0** | **3000** |
| $CO_2$ storage cost ($USD_{2010}$/tonne) | 10 | 10 | 0.5 x base | 1.5 x base |
| Direct air capture cost ($USD_{2010}$/tonne) | 500 | 500 | 0.06 x base | 1.8 x base |
| Fuel cell investment cost (cars. trucks. buses) ($USD_{2010}$/kW) | 97.5 | 65 | 0.69 x base | 1.31 x base |
| Fuel cell investment cost (shipping) ($USD_{2010}$/kW) | 1335 | 890 | 0.56 x base | 1.44 x base |
| Fuel cell investment cost (stationary sector) ($USD_{2010}$/kW) | 1200 | 800 | 0.5 x base | 1.5 x base |
| $H_2$ in transport ($USD_{2010}$/kW) | Possible | Possible | Not possible | Possible |
| Infrastructure cost for road transport with synfuels ($USD_{2010}$/kW) | 1200 | 1200 | 800 | 1600 |
| Infrastructure cost for road transport with $H_2$ ($USD_{2010}$/kW) | 2700 | 2700 | 2500 | 3100 |
| Infrastructure cost for ocean transport with synfuels ($USD_{2010}$/kW) | 200 | 200 | 100 | 300 |
| Infrastructure cost for ocean transport with $H_2$ ($USD_{2010}$/kW) | 2100 | 2100 | 1800 | 2400 |

# Results, two scenarios showing different amount of electrofuels




- Two examples from the 500 runs to illustrate differences on global fuel mix, depending on CO2 storage capacity.
- Electrofuels are shown in the fuel mix when assuming low carbon storage capacity and most often zero electrofuels assuming carbon storage capacity lager than 500 GtCO2.
- Synfuels are in these runs first and foremost fuels produced from hydrogen and carbon dioxide where the hydrogen is produced from concentrated solar power (high temperature heat+water+CO2) whereas electrofuels are produced from electricity+water+CO2.

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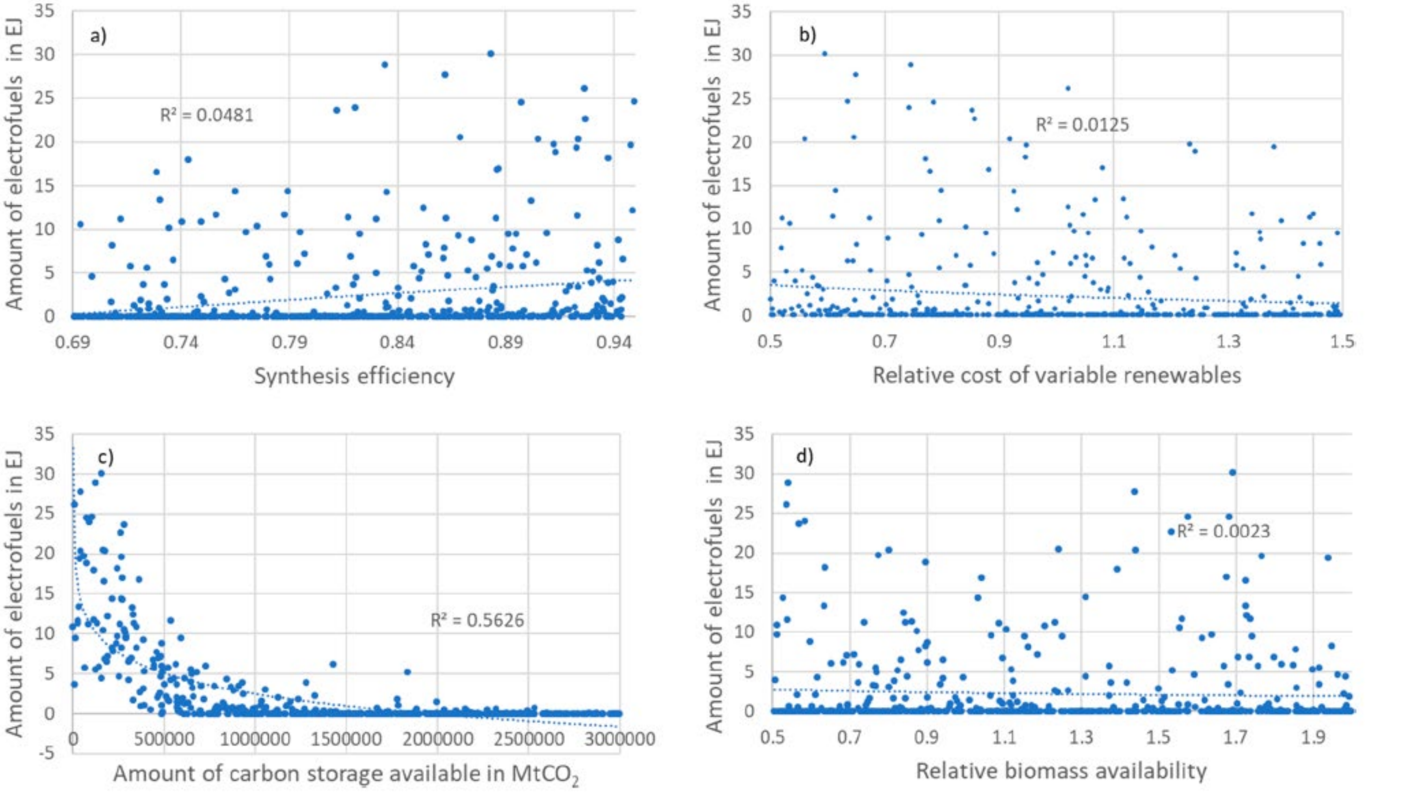


Figure 2. Monte Carlo analysis showing the potential for cost-effective use of electrofuels in the global transport sector in 2070 for 500 runs plotted against (a) the synthesis efficiency, (b) the relative cost of variable renewables, (c) the availability of carbon storage, and (d) the relative biomass availability.

- No significant correlation, except for carbon storage availability.
- Plus-minus 50% in electricity cost show minor changes in electrofuels.
- Electrofuels always below 35 EJ/yr (approx 15% of global fuel mix). Most often zero.

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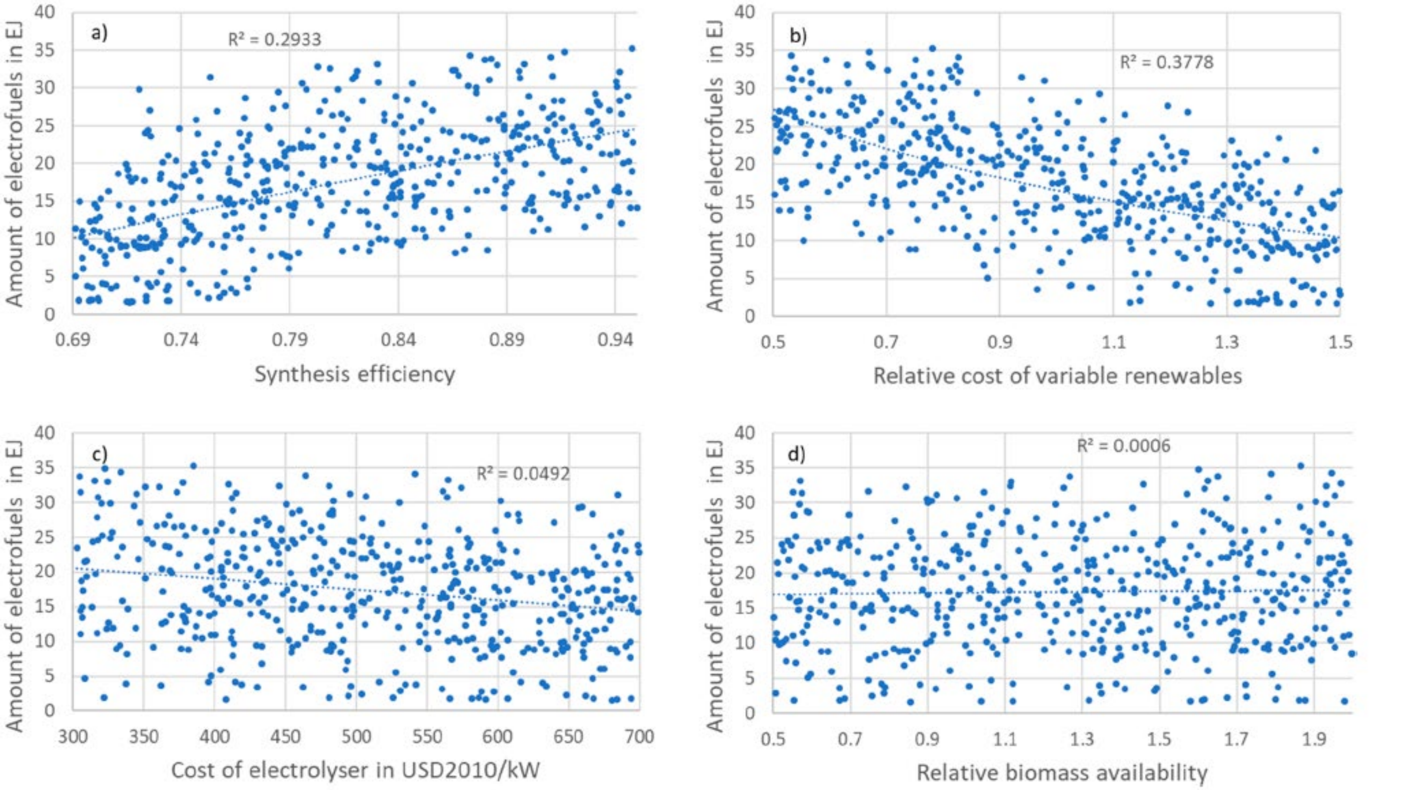


**Figure 3.** Monte Carlo analysis showing the potential for cost-effective use of electrofuels in the global transport sector in 2070 in *No storage* (no carbon storage) for 500 runs plotted against (a) the synthesis efficiency, (b) the relative cost of variable renewables, (c) the electrolyzer cost, and (d) the relative biomass availability.

- Results from assuming **no carbon storage**
- No run show zero electrofuels.
- Higher efficiency as well as cheaper electricity show more electrofuels.
- No correlation for electrolyser cost nor biomass potential.

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# Main findings 1

- First half of the century, there are less expensive options for balancing the grid, such as flexible gas generation.
- At the end of the century
  - when emissions need to be close to zero, natural gas can no longer be used to balance the system.
  - the share of VRE increases at the end of the century, increasing the number of overproduction hours.
  - Thus, investing in electrolyzers to produce electro-hydrogen (base for electrofuels) becomes profitable.

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# Main findings 2

- Significant correlation between the availability of carbon storage and the amount of electrofuels.
  - When storage availability is low (below 500 $GtCO_2$) electrofuels are present in all runs
  - When storage availability is higher than 500 $GtCO_2$ almost no electrofuels enter the scenarios (base case assume 2000 $GtCO_2$).
  - All other studied parameters show no (or weak) correlation.
- Recall that
  - the relatively large amount of fossil fuels seen in the transport sector is a result of the energy systems modelling approach where the climate target are met at lowest cost, regardless of in which sectors the CO2 reductions are made (model results show a fast phase out of fossil fuels from the electricity, heat and feedstock sectors). In reality, policies may steer towards a more equal burden sharing between sectors and thereby force a more rapid phase out of fossil fuels from the transport sector.

# Conclusions

- Electrofuels are not a cost-effective option to mitigate climate change if $CO_2$ can be stored underground
  - Electrofuels are relatively expensive and other options out-compete electrofuels when there is room for carbon emissions.
  - With a limited carbon budget, emitting becomes expensive, the climate goal can be met at a lower cost if $CO_2$ can be stored, rather than reused.
- If carbon storage is limited (for technical reasons, or due to public opinion), electrofuels can become cost-effective as a complement.
  - Most favorable cases show 35 EJ globally in 2070, (approx. 15% of energy demand for transport).
  - The cost of the electrolyzer, cost of direct air capture, or increased availability of VRE appear not to be key factors in whether electrofuels enter the transport system, in contrast to findings in previous studies.

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