The race to viability

Biofuels, electrofuels and BEVs as options to decarbonise road transport

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Introduction

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EPRG WORKING PAPER

The race to solve the sustainable transport problem via carbon-neutral synthetic fuels and battery electric vehicles

EPRG Working Paper 1721

Cambridge Working Paper in Economics 1758

Ilkka Hannula and David M Reiner

Abstract Carbon-neutral synthetic fuels (CNSFs) could offer sustainable alternatives to petroleum distillates that currently dominate the transportation sector, and address the challenge of decarbonising the fuel mix. CNSFs can be divided into synthetic biofuels and 'electrofuels' produced from CO_2 and water with electricity. We provide a framework for comparing CNSFs to battery electric vehicles (BEVs) as alternatives to reduce vehicle emissions. Currently, all three options are significantly more expensive than conventional vehicles using fossil fuels, and would require carbon prices in excess of \$250/tCO_2 or oil prices in excess of \$150/bbl to become competitive. BEVs are emerging as a competitive option for short distances, but their competitiveness quickly deteriorates at higher ranges where synthetic biofuels are a lower-cost option. For electrofuels to be viable, the challenge is not simply technological learning, but access to a low-cost ultra-low-carbon electric power system, or to low-carbon electric generators with high annual availability.

Keywords Carbon-neutral synthetic fuels, electrofuels, advanced biofuels, battery electric vehicles, low-carbon transportation alternatives

JEL Classification Q41, Q42, Q55, R41, R48, O33

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Biofuels, electrofuels and BEVs as options to decarbonise road transport

- We focus on
  - Battery Electric Vehicles (BEVs)
  - Internal Combustion Vehicles (ICVs) using Carbon-Neutral Synthetic Fuels (CNSFs)

- CNSFs break down into
  - Advanced biofuels (via gasification)
  - Electrofuels

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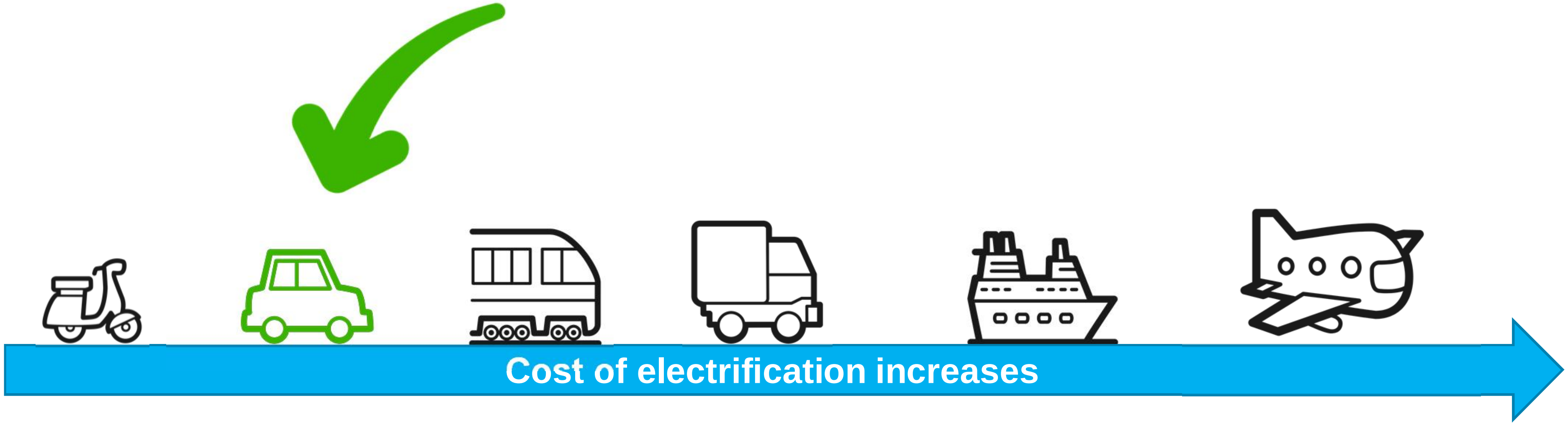
Biofuels, electrofuels and BEVs as options to decarbonise road transport

- Are electrofuels, biofuels and BEVs complementary or competing technologies?
- We choose light-duty vehicles (LDVs) as the hard case for fuels.



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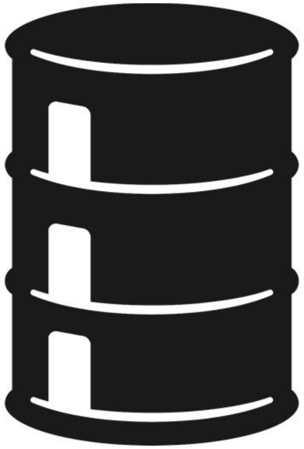
Biofuels, electrofuels and BEVs as options to decarbonise road transport

- We compare
  - Near-term costs from the consumer perspective.
  - Scale-up challenges and impacts from the transport system perspective.

Where are we today?

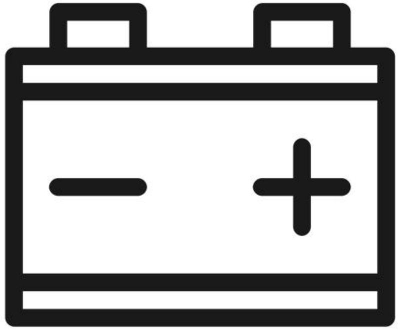
Petroleum

$70/bbl



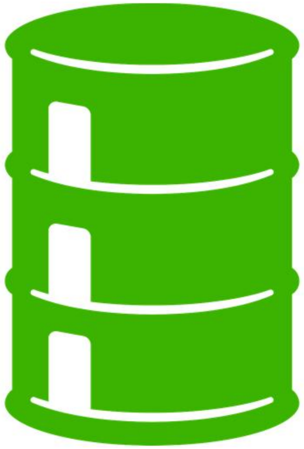
Batteries

$200 - $250/kWh



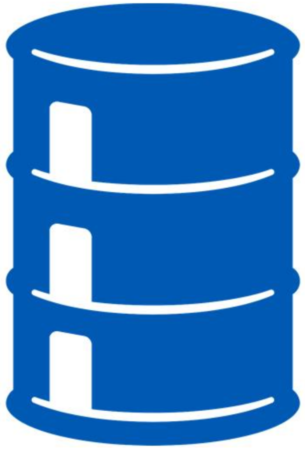
Cellulosic biofuels

?



Electrofuels

?



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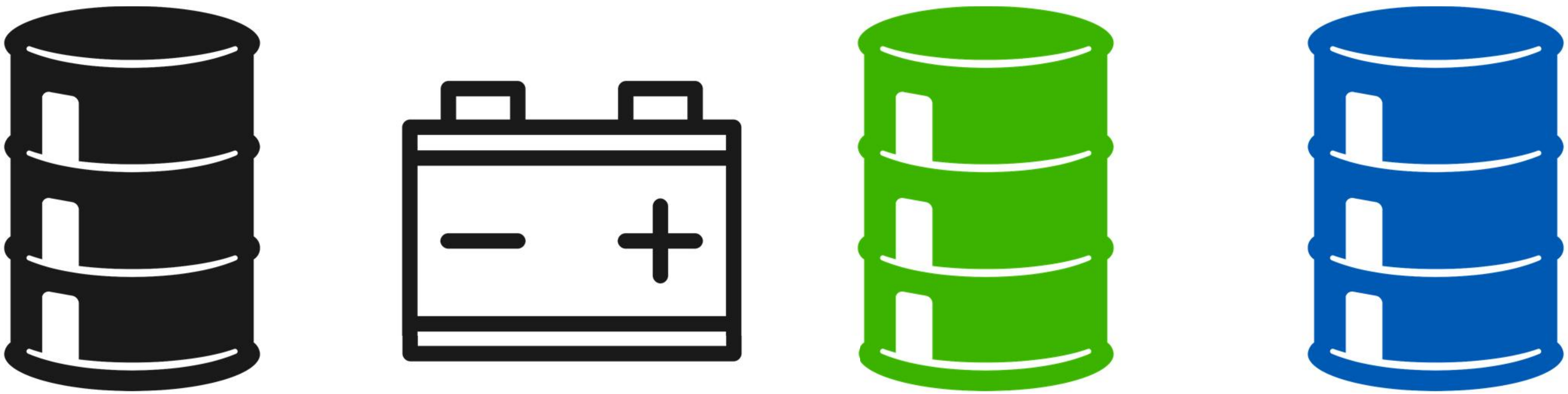
Where are we today?

Petroleum	Batteries	Cellulosic biofuels	Electrofuels
$70/bbl	**$200 - $250/kWh**	**?**	**?**



We scale up demonstration plant data (escalated to $2017) to estimate the cost of CNSFs at commercial scale (150 $MW_{synfuel}$)

GoBiGas
30 MW biomass
20 MW synfuel
$180M investment

Audi e-gas
6 MW electricity
3.2 MW synfuel
$27M investment

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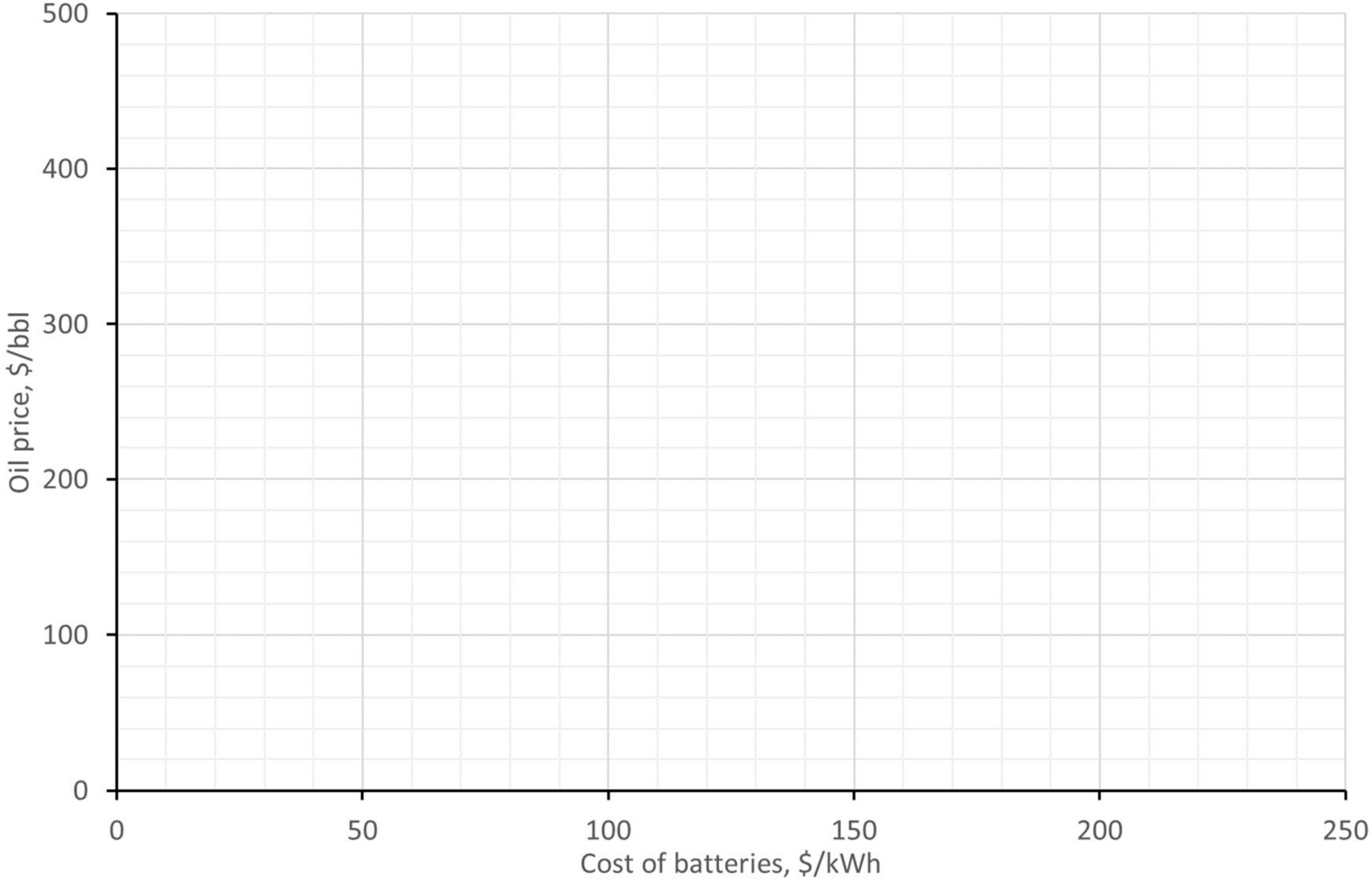
How to compare BEVs and ICVs?

- Various distortions bedevil comparisons between BEVs and ICVs.
- Cost parity (equal-cost) means that, at the very least, the “fuel” cost of the BEV should be no higher than that of comparable ICVs.
  - For a BEV the “fuel” cost includes electricity, but also the interest and depreciation of the battery.
  - This is a minimal requirement since there are additional hurdles that BEVs would need to overcome (e.g. limited range and slow charging rates).
- Also, using efficient rather than tax-inclusive market prices has significant impact on the relative costs of ICVs and BEVs.
- For a list of our assumptions, see “Supplementary material” at the end of the presentation.

Carbon-neutral fuels (CNSF) vs battery electric vehicles



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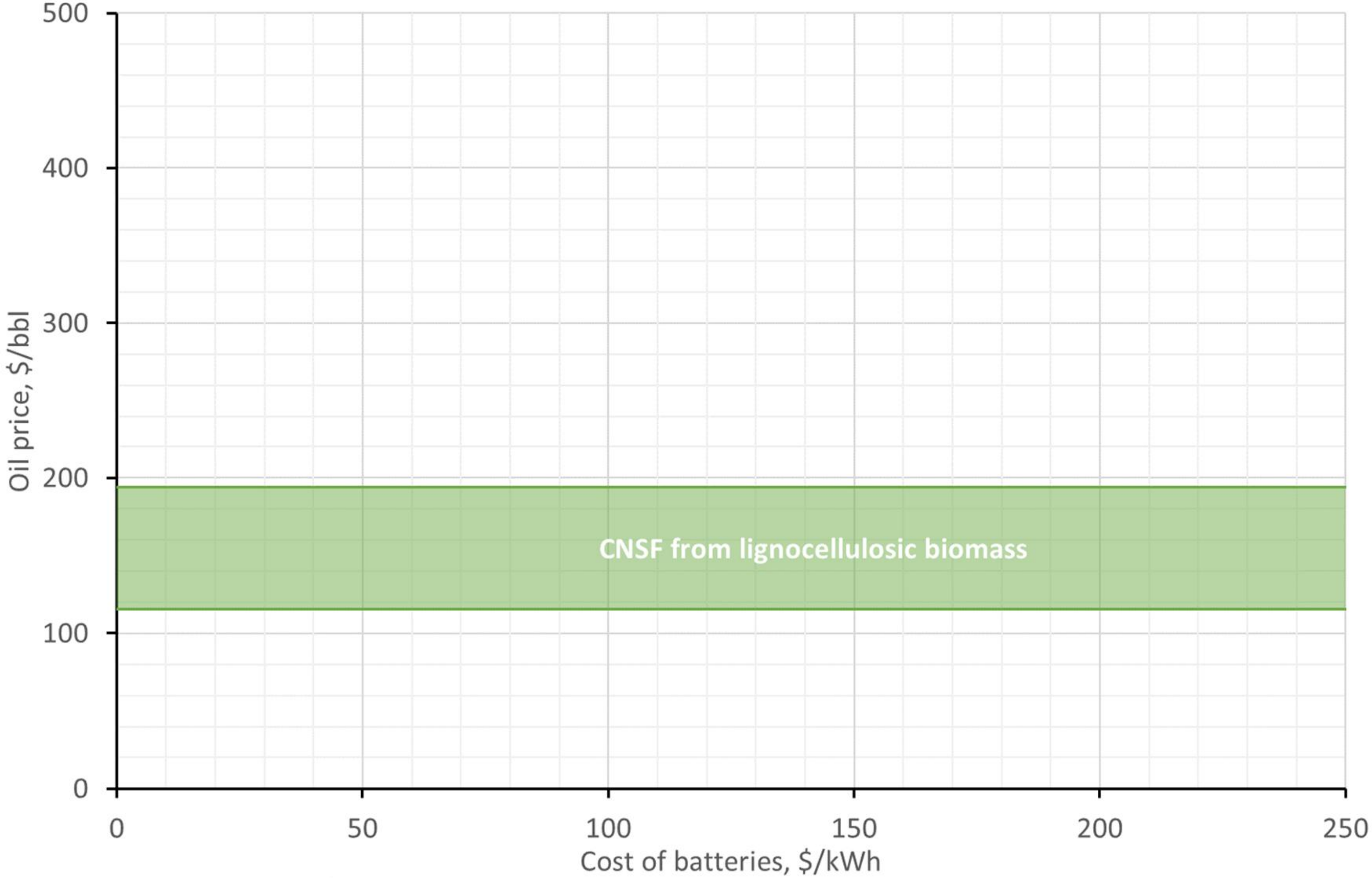

Biomass residues:
- $40/dry ton ($8/MWh)*
- Capacity factor 85 %

*USDOE 2016 Billion-ton report figure ES.8

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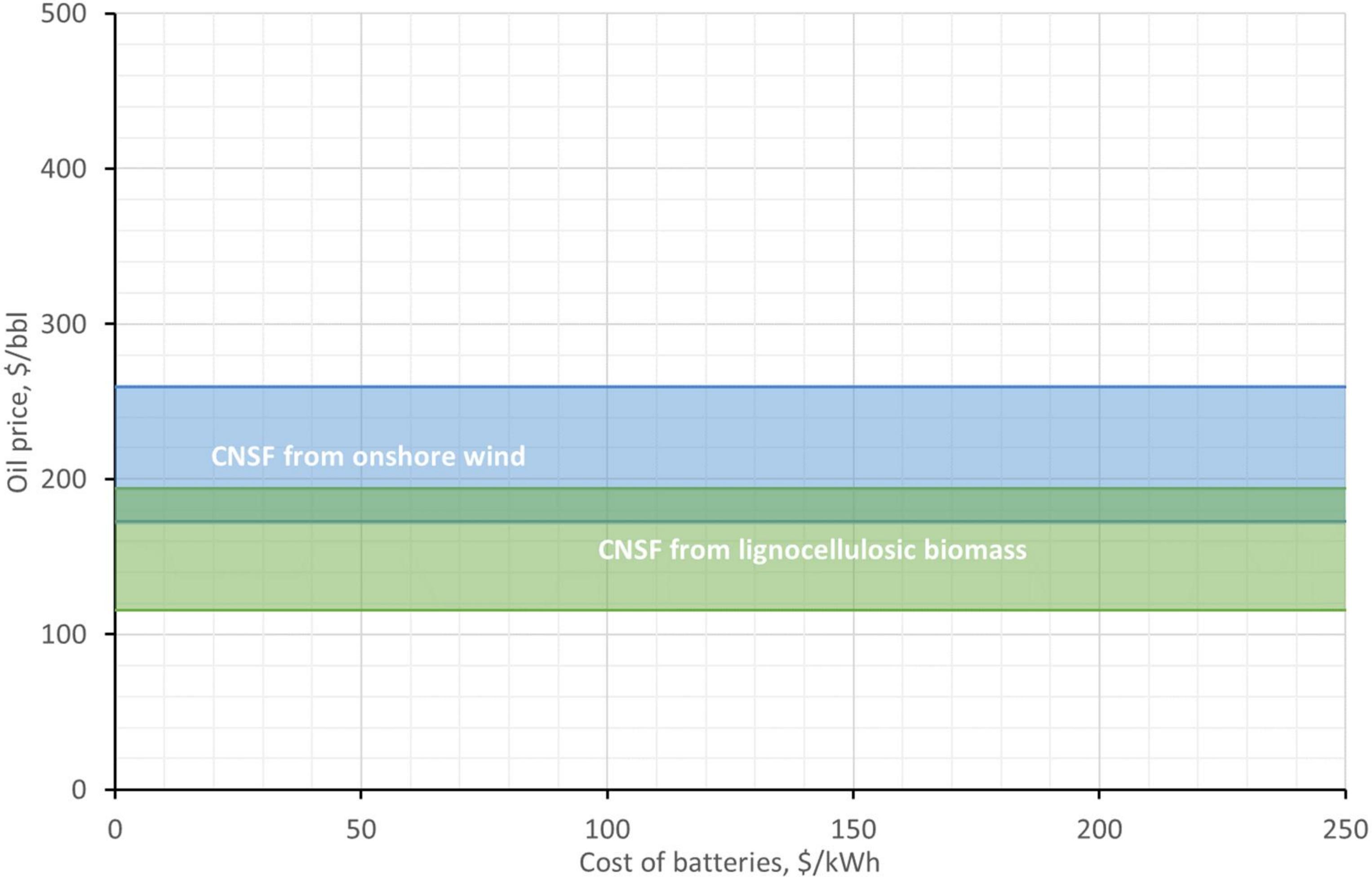

Onshore wind:
- $30/MWh**
- Capacity factor 55 %**

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**USDOE 2016 Billion-ton report figure ES.8*
***Lazard's Levelized cost of energy analysis – version 11.0 (2017)*

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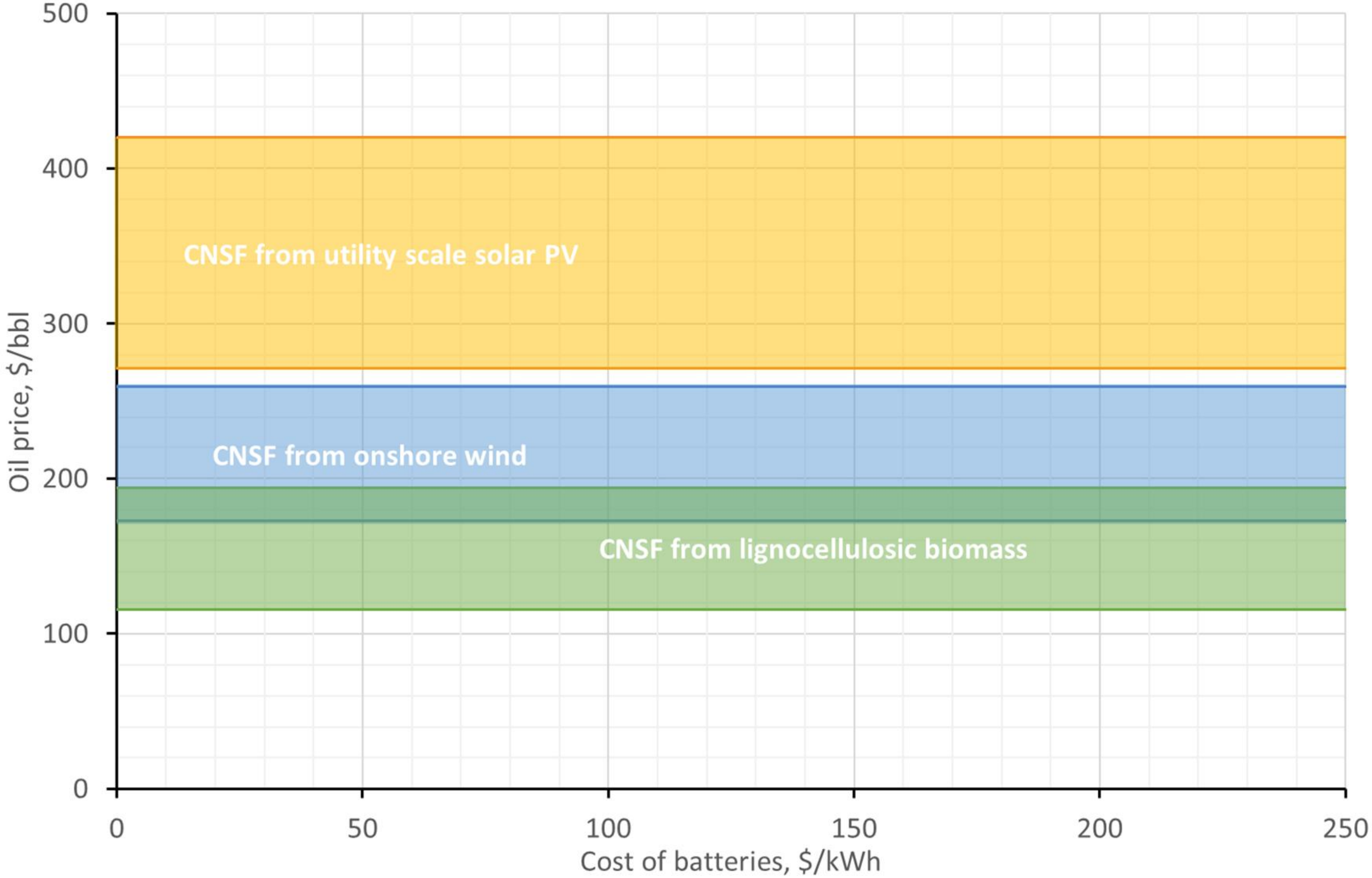

Thin film PV:
- $43/MWh**
- Capacity factor 32 %**

Onshore wind:
- $30/MWh**
- Capacity factor 55 %**

Biomass residues:
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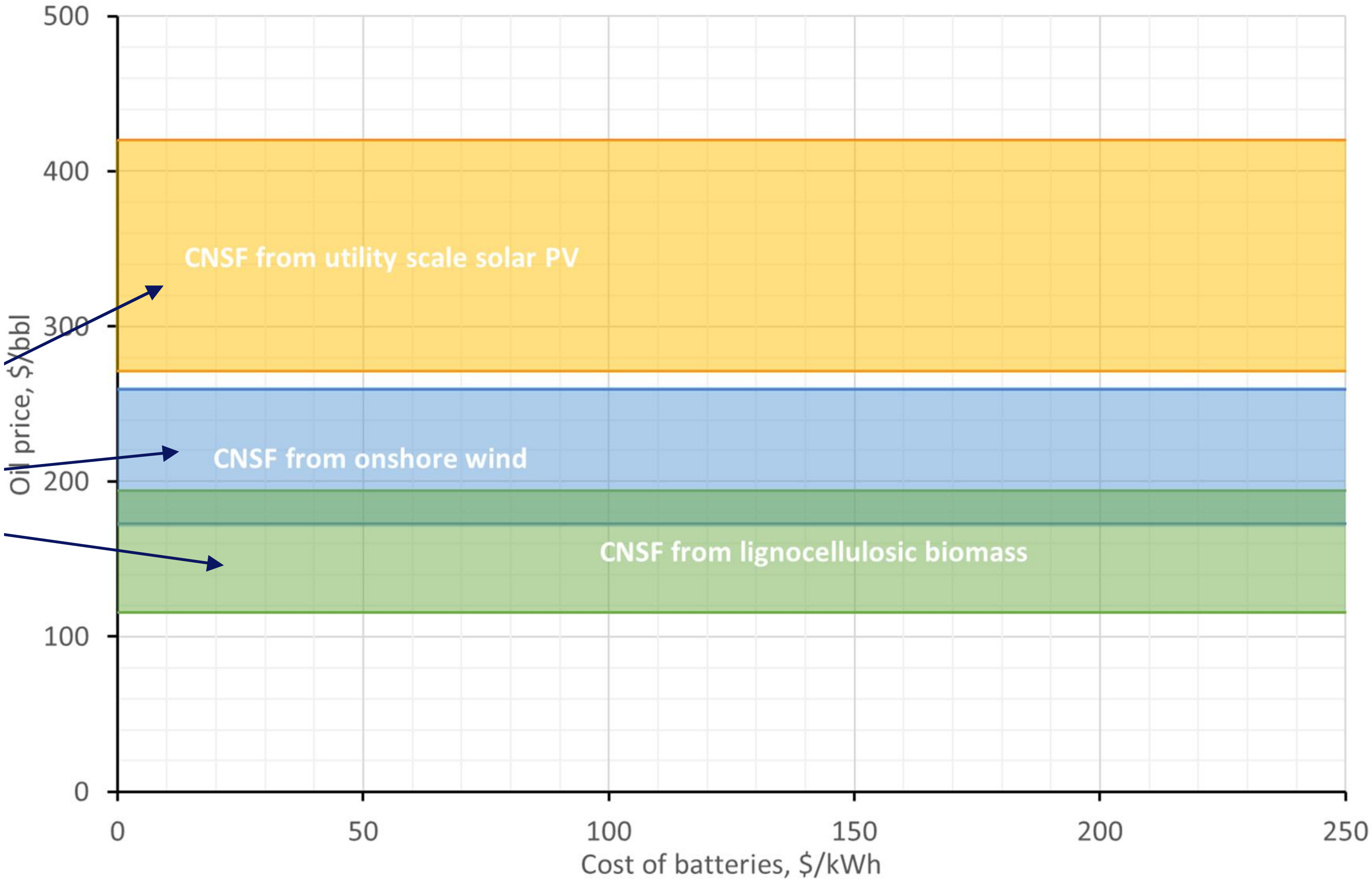
Carbon-neutral fuels (CNSF) vs battery electric vehicles

Prospective production cost estimates ($2017) based on demonstration plant data (ranges due to uncertainty of cost scaling exponents) for First-of-a-Kind plants at 150 $MW_{synfuel}$ scale, if built **today** to **best resource locations** in the U.S.



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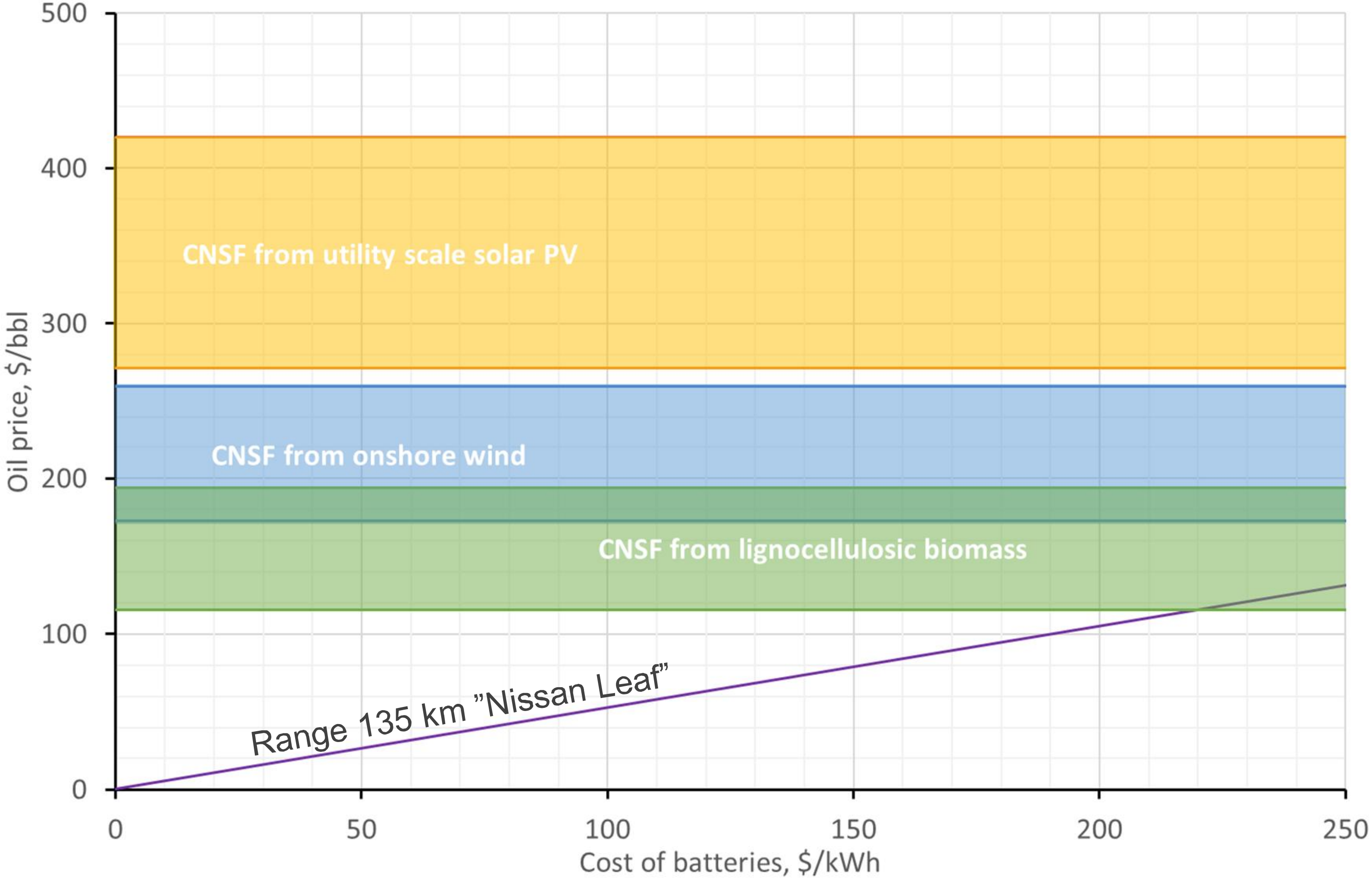

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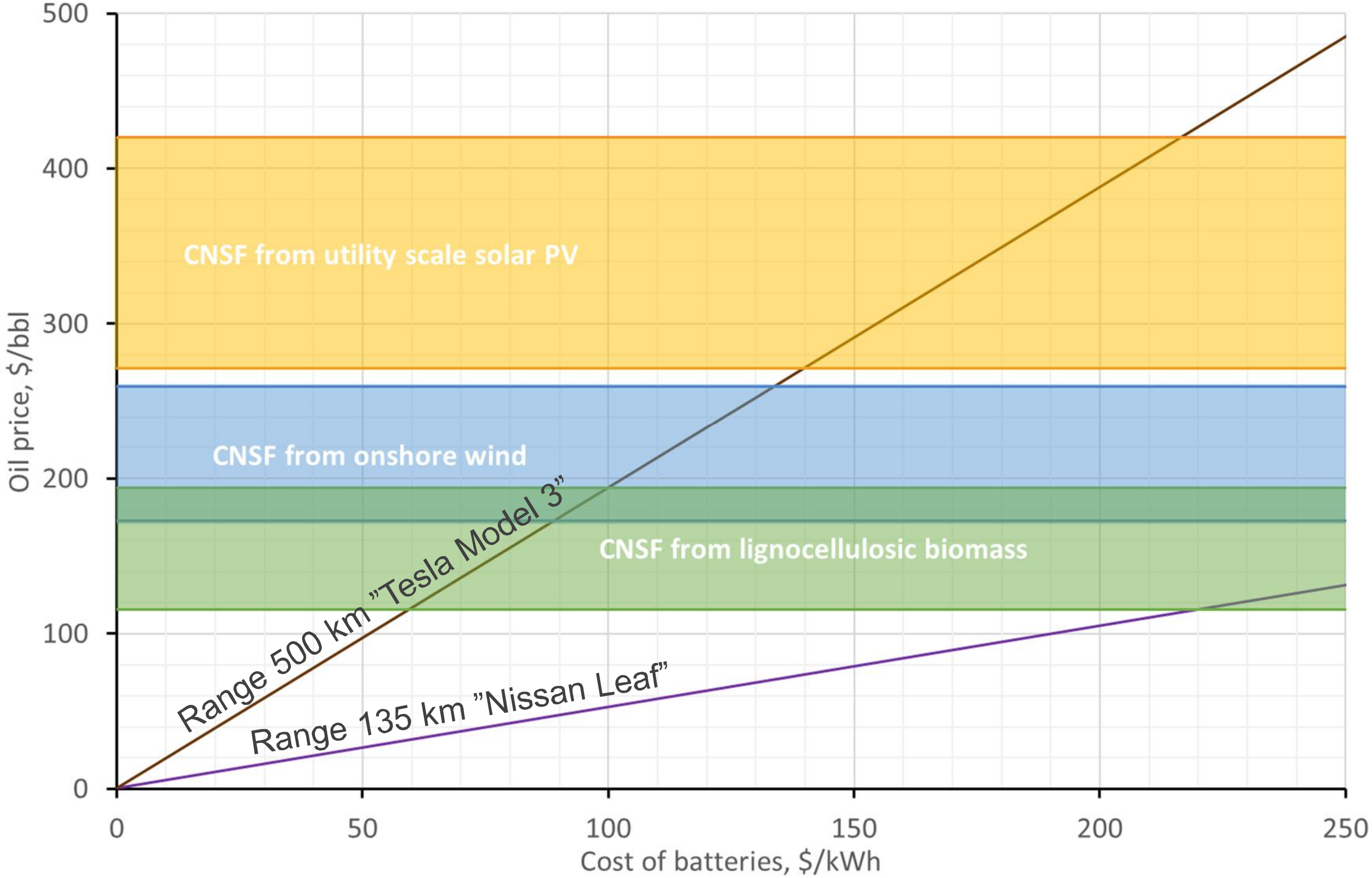

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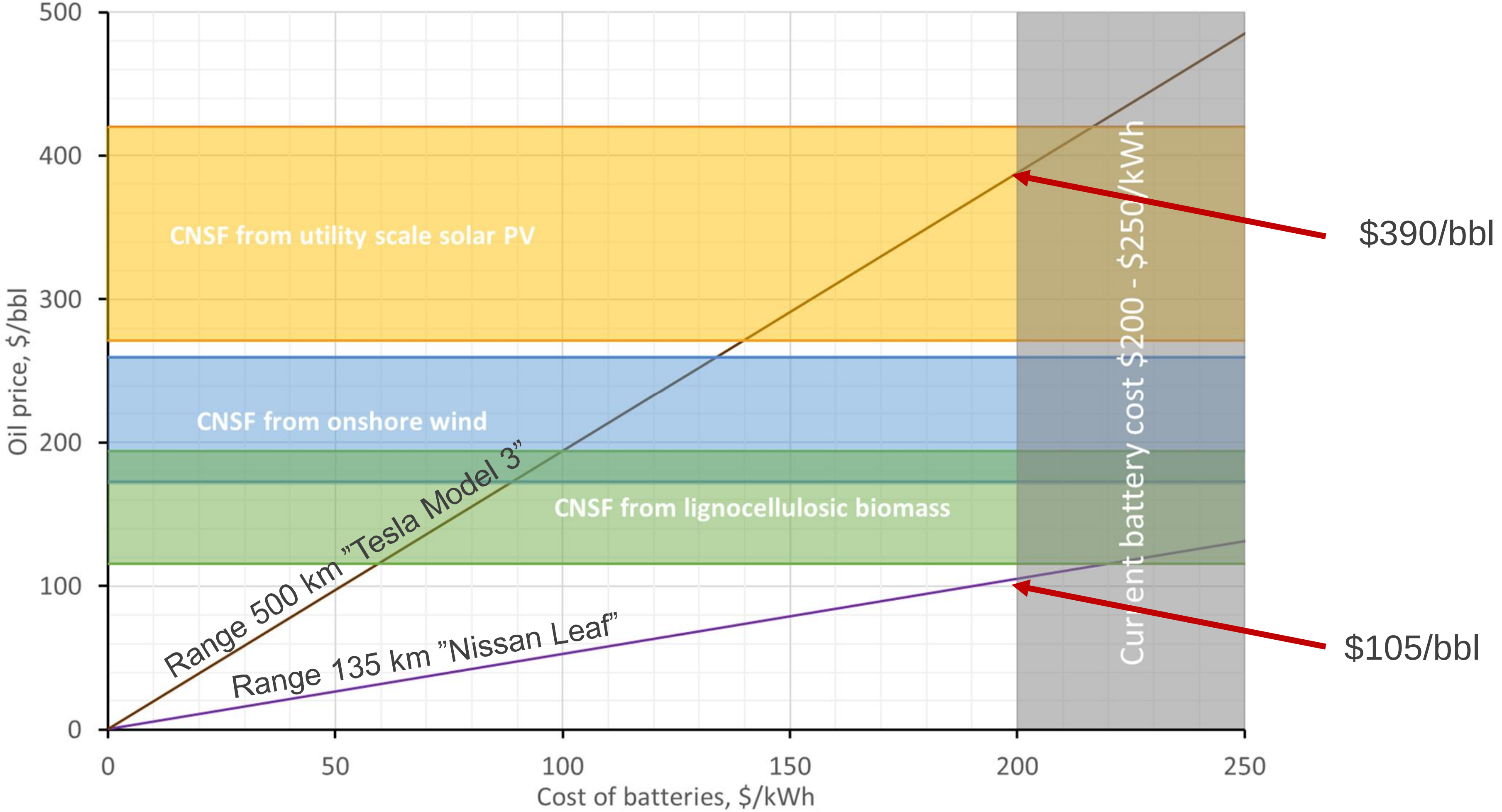

*USDOE 2013 Fiscal Year 2012 Annual Progress Report for Energy Storage R&D

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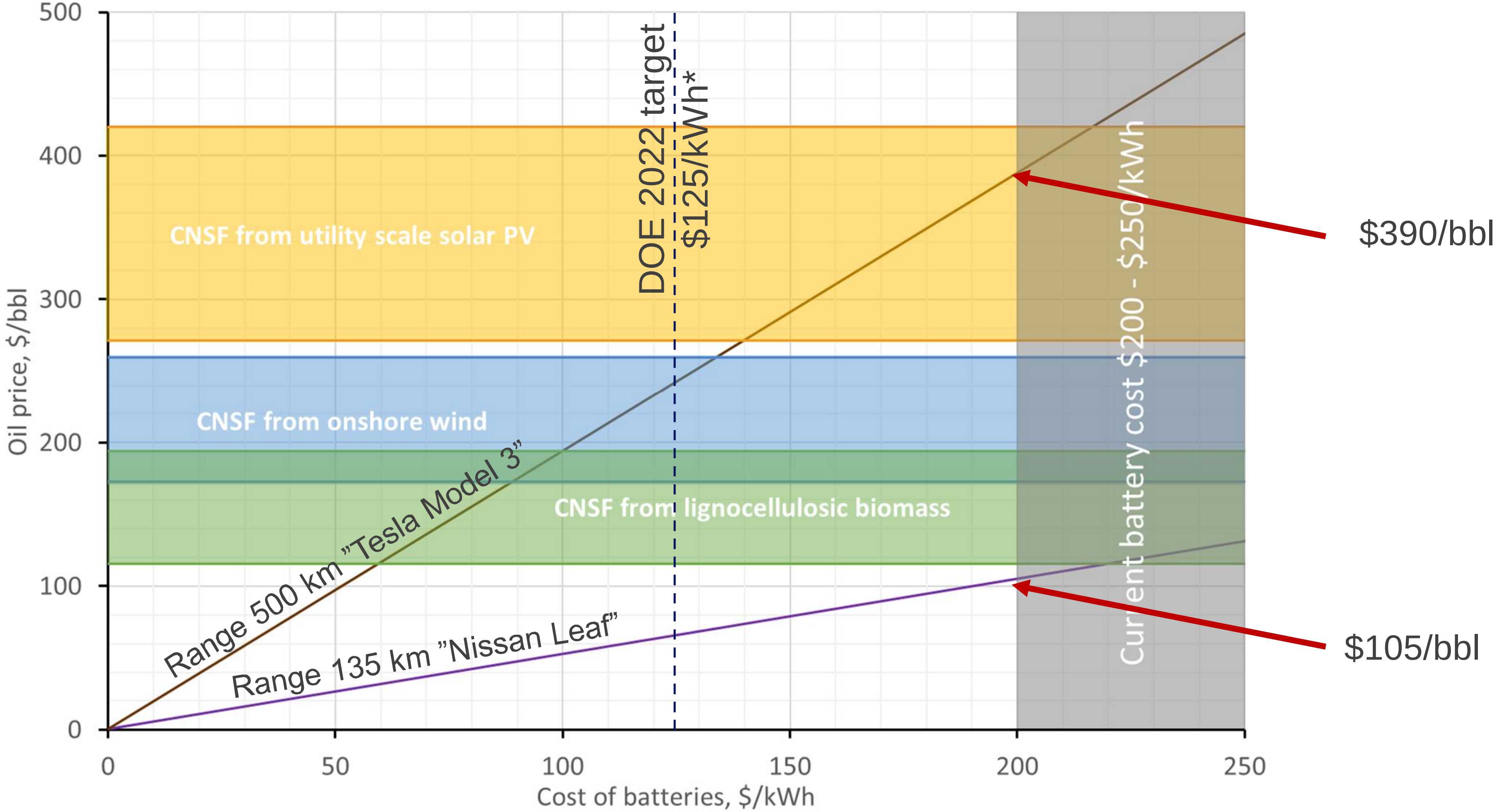

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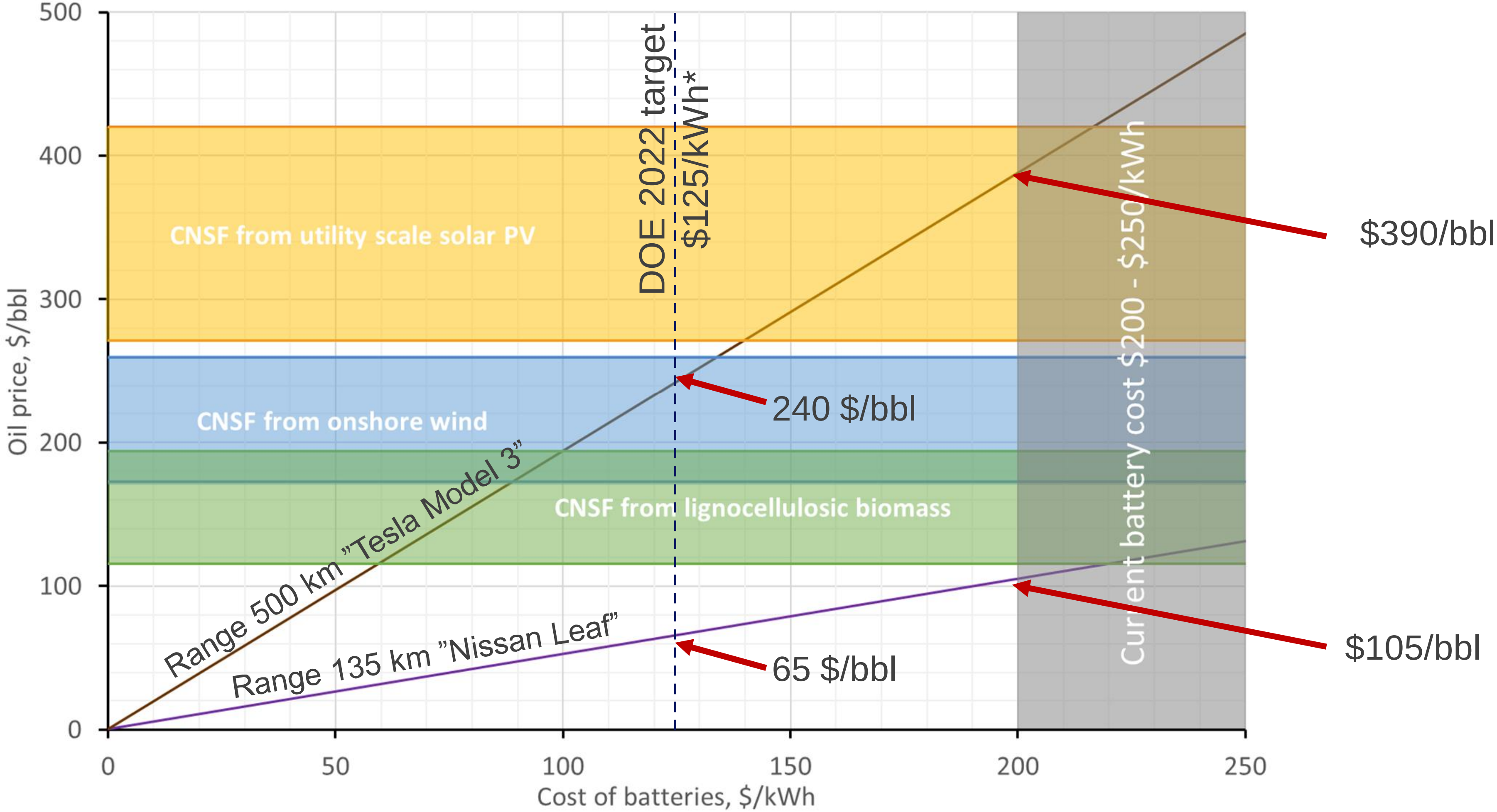

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*USDOE 2013 Fiscal Year 2012 Annual Progress Report for Energy Storage R&D

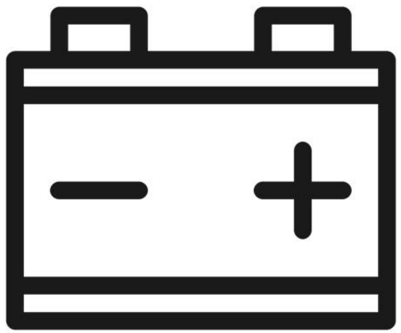
Setting cost targets for carbon-neutral synthetic fuels

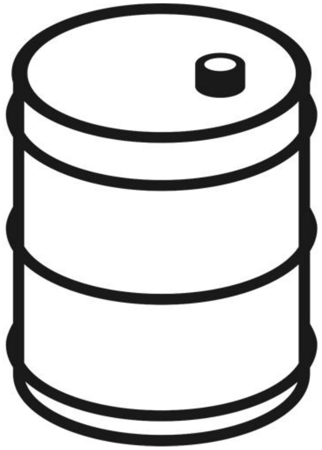
At **today**'s battery cost:

- Short-range BEV < $105/bbl
- Long-range BEV < $390/bbl

At **2022** DOE target cost:

- Short-range BEV < $65/bbl
- Long-range BEV < $240/bbl





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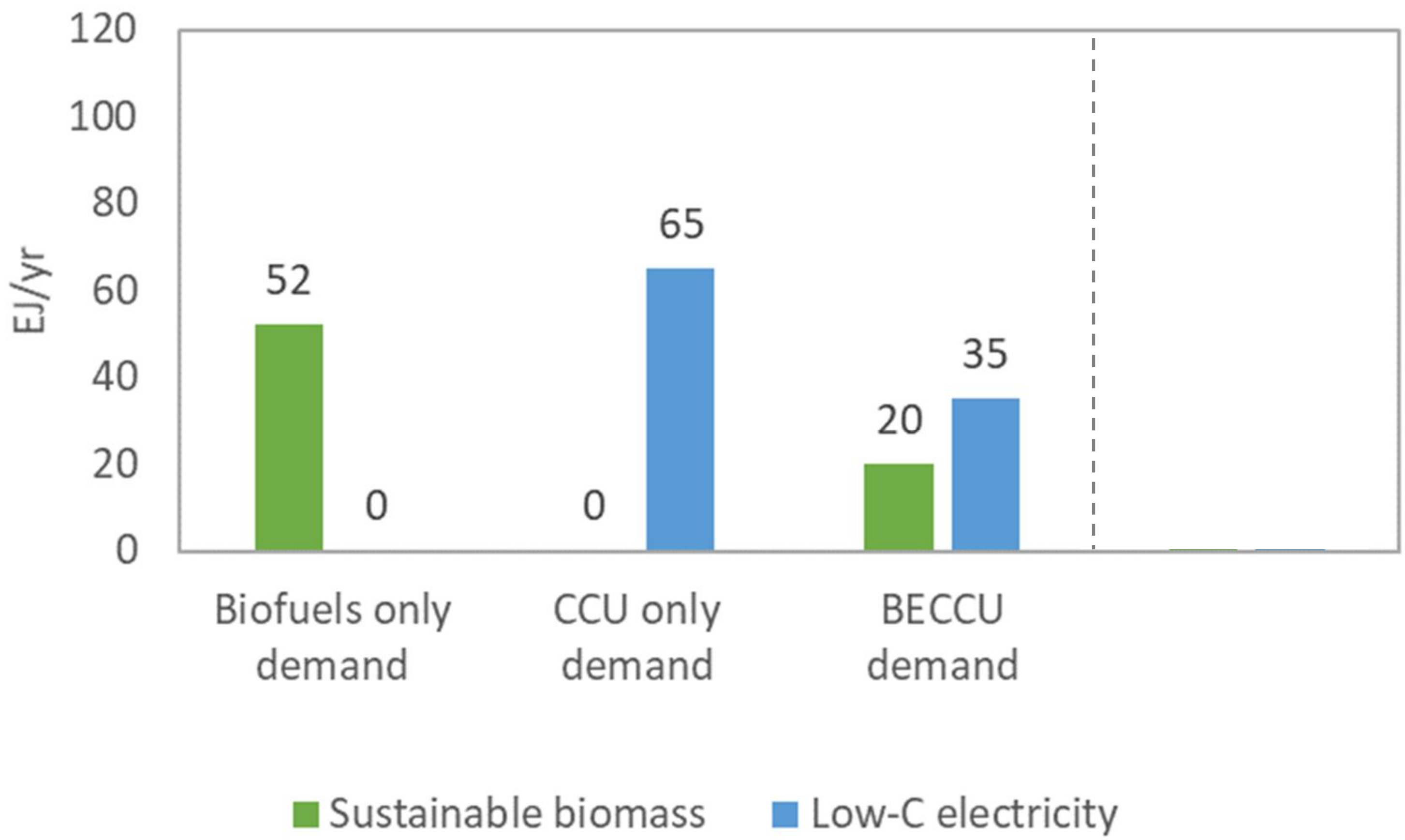
Resource needs for supplying 26 EJ/yr CNSF in 2050

Global transport energy use in 2050 according to IEA (2017) 2DS modelling:

- 59 EJ/yr of petroleum fuels,
- **26 EJ/yr of biofuels**, and
- 17 EJ/yr of electricity.



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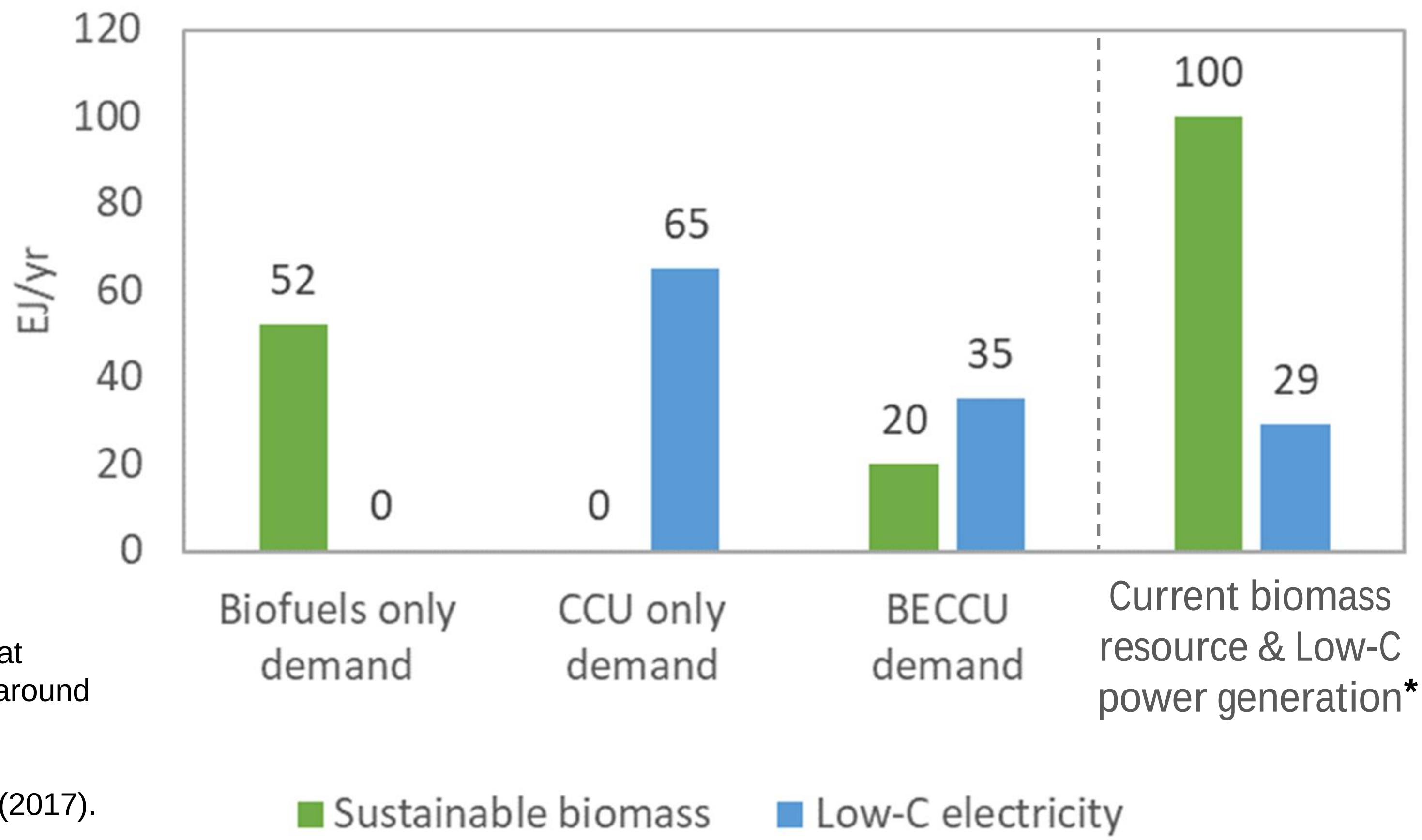


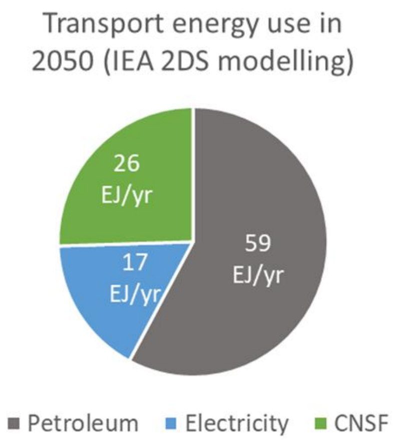
*Biomass resource from AR5 (IPCC, 2014) that "agrees on a technical bioenergy potential of around 100 EJ, and possibly 300 EJ and higher".

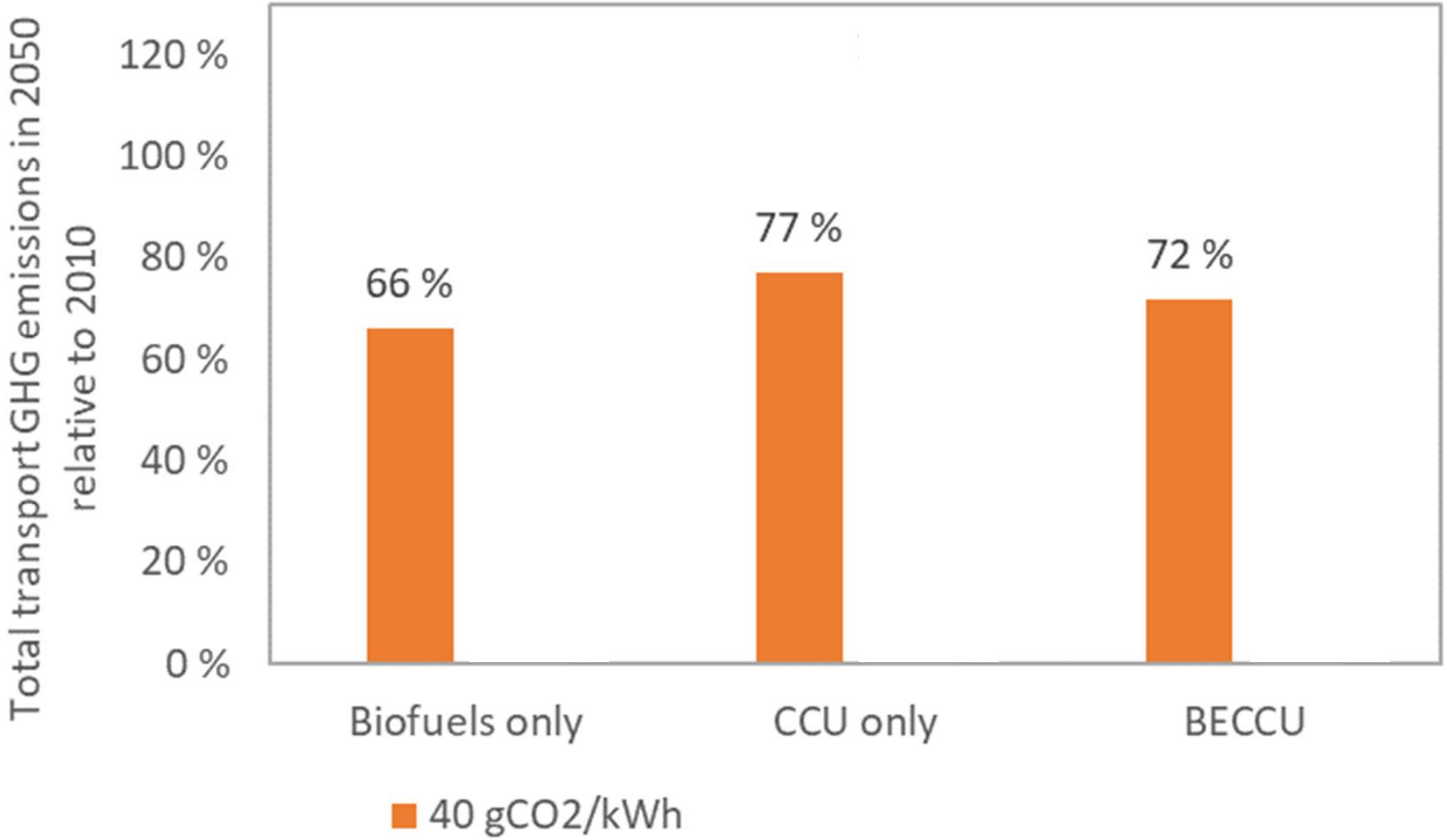
Low-C power generation calculated from EIA (2017).

Relationship of power and transport sector emissions for supplying 26 EJ/yr CNSF

Transport emissions were 6.79 Gt CO_2 in 2010.

IEA 2DS modelling:
Power sector carbon intensity is 40gCO2/kWh in 2050.





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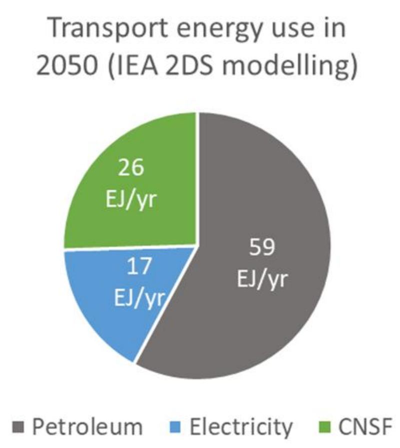

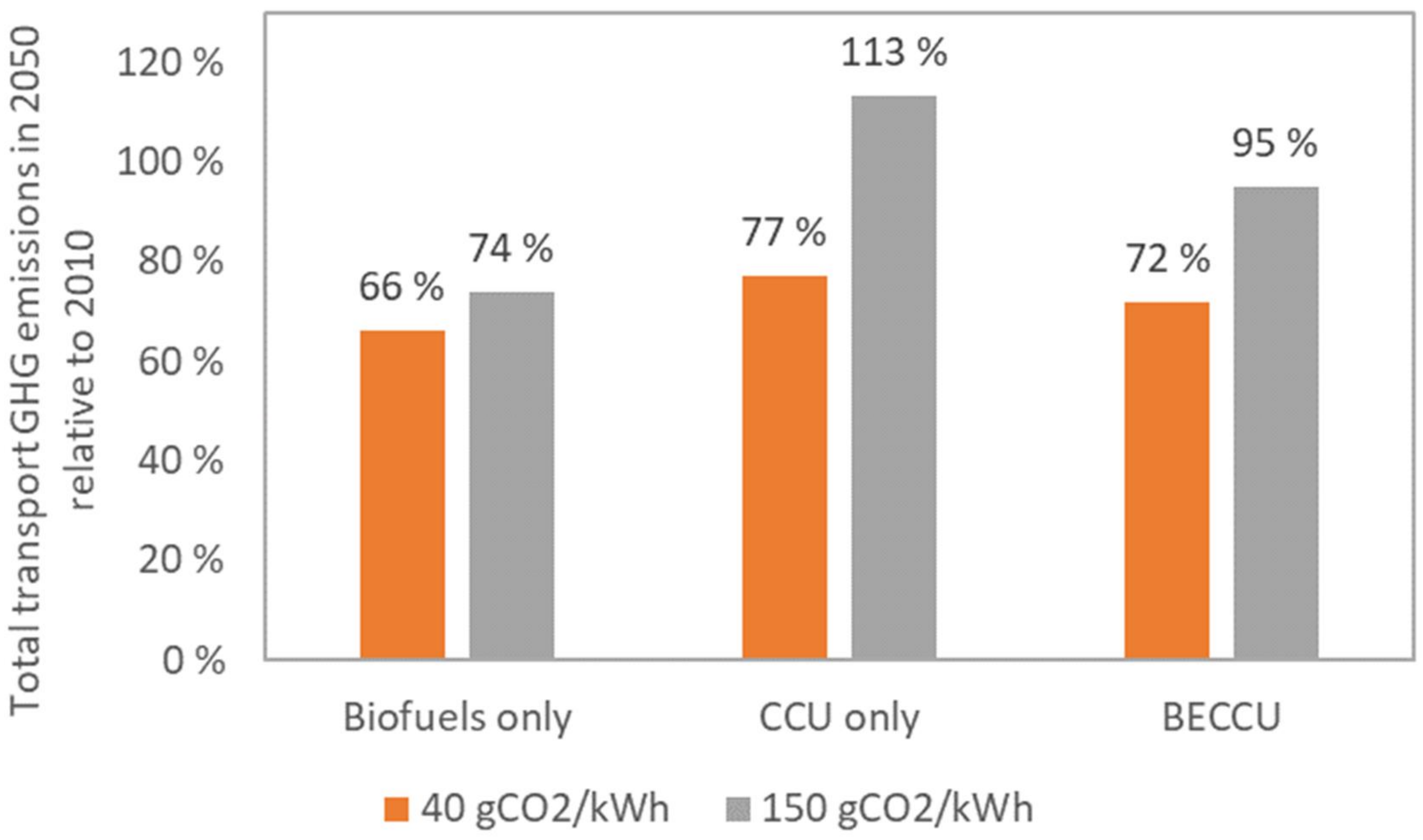

Conclusions

- At today's battery costs, all sustainable gasoline substitutes that can be produced roughly below $400/bbl are competitive against a long-range BEV.
  - Even $125/kWh would not outcompete CNSF including electrofuels.
- However, short-range BEVs competitive with CNSFs already today and may become out of reach if the DOE target is achieved.
- VRE reaching grid parity with fossil energy in some locations does NOT mean electrofuels will soon be reaching parity with petroleum.
- Near-term learning potential limited for electrofuels as costs governed by electricity price?
  - In the longer term solid-oxide electrolyser technology possibly an option to reduce costs and resource requirements.
- The viability of electrofuels is governed by the prospects of future power markets:
  - A dramatic expansion of cheap low-carbon electricity is needed,
  - Ties the fate of transport sector emissions closely with the power sector.

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Supplementary material 1/2

To calculate the equal-cost curves in CNSF vs BEV figure we adopt an approach similar to that developed in Newbery and Strbac (2016), which seeks to strip out the various distortions that bedevil comparisons between battery electric vehicles (BEVs) and internal combustion vehicles (ICVs).

Our assumptions:

We use \$0/tCO2 as emission costs, 1.26 for the wholesale gasoline price multiplier (1.18 for diesel), \$0.07/l gasoline retail margin (\$0.09/l for diesel), 2.36 gCO2/l gasoline carbon content (2.68 gCO2/l for diesel), and \$0.033/l gasoline pollution cost (\$0.099/l for diesel).

The BEV battery is sized to allow either 135 or 500 km single-charge range, while assuming 10-year vehicle life and 170,000 km lifetime battery range (17,000 km annual distance travelled).

Electric motors convert 75% of the energy supplied into the batteries to power the wheels and move the vehicle 5 km per every kWh supplied. For gasoline vehicles, 30 % efficiency is assumed (35 % for diesel vehicles).

We assume savings from a BEV drivetrain relative to ICV to be \$1232, while a home charger costs \$1130.

The cost of electricity is 14 dollar cents per kWh assuming smart charging (70% off-peak & 30% peak), and the discount rate is 8%. For currency conversions, we use 1.13 EUR to USD exchange rate (average for 2017).

Supplementary material 2/2

Assumptions used to calculate the break-even oil price for first-of-a-kind CNSF plants:

- Delivered cost of biomass feedstock $40 - $120/dry ton (assuming 19 MJ/kg lower heating value) from US DOE 2016 Billion-ton report figure ES.8.
- Electricity generation data for different energy sources from Lazard's Levelized cost of energy analysis – version 11.0 (2017).
- Assumptions used for all plants: 150 MW (LHV) liquid hydrocarbon output, wholesale fuel price multiplier 1.22 (average for gasoline and diesel), 20 yr economic life, 8% Weighted Average Cost of Capital (WACC).
- For an electrofuel plant producing liquid hydrocarbons, we assume: 40 % (LHV) fuel efficiency, central estimate for total capital investment (TCI) $583 million with a range of $407 - $834 million, annual operating and maintenance cost 2% of TCI.
- For a biofuel plant producing liquid hydrocarbons, we assume: 50 % (LHV) fuel efficiency, central estimate for TCI $845M with a range of $626 - $1140 million, annual operating and maintenance cost 4% of TCI.