The Future of Fuels:
Meeting Global Decarbonization Goals

CSIS: Innovation in Transportation Fuels

John Farrell
National Renewable Energy Laboratory
September 30, 2020
Today’s Transportation System

Energy Source
- Fossil Petroleum

Energy Pathway
- Fuels Production

Energy Carrier
- Liquid Fuels

Transportation Sectors
- Aviation
- Marine
- Rail
- HD/MD Vehicles
- LD Vehicles*

* A small percentage of light-duty vehicles are currently powered by electricity.
Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California’s Fight Against Climate Change

Published: Sep 23, 2020

Executive order directs state to require that, by 2035, all new cars and passenger trucks sold in California be zero-emission vehicles

SACRAMENTO – Governor Gavin Newsom today announced that he will aggressively move the state further away from its reliance on climate change-causing fossil fuels while retaining and creating jobs and spurring economic growth – he issued an executive order requiring sales of all new passenger vehicles to be zero-emission by 2035 and additional measures to eliminate harmful emissions from the transportation sector.

Following the order, the California Air Resources Board will develop regulations to mandate that 100 percent of in-state sales of new passenger cars and trucks are zero-emission by 2035 – a target which would achieve more than a 35 percent reduction in greenhouse gas emissions and an 80 percent improvement in oxides of nitrogen emissions from cars statewide. In addition, the Air Resources Board will develop regulations to mandate that all operations of medium- and heavy-duty vehicles shall be 100 percent zero emission by 2045 where feasible, with the mandate going into effect by 2035 for drayage trucks. To ensure needed infrastructure to support zero-emission vehicles,
Phase-out of fossil fuel vehicles

From Wikipedia, the free encyclopedia

The **phase-out of fossil fuel vehicles** is one of the two most important parts of the general fossil fuel phase-out process, the other being the phase-out of fossil fuel power plants for mains electricity.

More than 14 countries and over 20 cities around the world have proposed banning the sale of passenger vehicles (primarily cars and buses) powered by fossil fuels such as petrol, liquefied petroleum gas and diesel at some time in the future. Synonyms for the bans include phrases like "banning gas cars", "banning petrol cars", "the petrol and diesel car ban", or simply "the diesel ban". Another method of phase-out is the use of zero-emission zones in cities.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>2025</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2030</td>
</tr>
<tr>
<td>India</td>
<td>2030</td>
</tr>
<tr>
<td>Scotland</td>
<td>2032</td>
</tr>
<tr>
<td>France</td>
<td>2040</td>
</tr>
<tr>
<td>Britain</td>
<td>2040</td>
</tr>
<tr>
<td>Germany</td>
<td>TBD</td>
</tr>
<tr>
<td>China</td>
<td>TBD</td>
</tr>
</tbody>
</table>
NREL’s Vision for a Decarbonized Transportation Sector

Illustration by Josh Bauer, NREL
What fuels will meet vehicle use requirements?

Vehicle Weight

- Internal combustion engines
- low-carbon, high energy-density fuels
- Fuel cell
- hydrogen
- electrons
- Heavy battery electrification

Daily Miles Traveled

The Real Challenge: Low-Carbon Fuels for Large Vehicles
More than 1 billion tons of biomass could be domestically converted into biofuels and products.

Biomass could displace up to 25% of U.S. petroleum use annually by 2030, keeping revenues in the United States, adding jobs, and reducing annual CO₂ emissions.

e-fuels

Syn fuels

e-ethanol

e-diesel

e-gasoline

Fischer-Tropsch fuels

FT fuels

Power to fuel

CO$_2$-based fuels
What are e-fuels?

Electrofuels ("e-fuels") are hydrocarbon or oxygenate fuels synthesized primarily using a carbon source and electricity.
The diagram shows a process involving hydrogen and carbon dioxide to produce methane and water with the assistance of a biocatalyst and heat. The reactions are as follows:

\[ 4H_2 + CO_2 \xrightarrow{\text{Biocatalyst}} CH_4 + 2H_2O + \text{Heat} \]
e-fuels: are they feasible technically?

• Some technologies (water electrolysis, CO$_2$ ➔ CO conversion, Fischer-Tropsch) are technically mature

• Hydrogen at scale (H$_2$@Scale) is a key foundational technology

• New, exciting bio-electrochemical conversion routes are at a very early research stage
  – Many technical challenges must be overcome for commercial viability
Are e-fuels low-GHG fuels?

Lifecycle carbon intensity of electro-diesel

```
<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂e/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum-derived gasoline</td>
<td>300</td>
</tr>
<tr>
<td>Petroleum-derived diesel</td>
<td>275</td>
</tr>
<tr>
<td>56% renewable, 44% natural gas</td>
<td>110</td>
</tr>
<tr>
<td>Natural gas CCGT</td>
<td>290</td>
</tr>
<tr>
<td>EU mix mid-voltage</td>
<td>300</td>
</tr>
<tr>
<td>Natural gas CCGT with CC</td>
<td>150</td>
</tr>
<tr>
<td>Zero-carbon renewable</td>
<td>0</td>
</tr>
</tbody>
</table>
```

“What role is there for electrofuel technologies in European transport’s low carbon future?”
How much electricity is required?

Future WTW Energy Requirement to convert 100% of Germany’s LD and HD Fleet
(electrical energy required for PtX production or BEV charging)

Energy (TWh/year)

- BEV
- H₂ (FCEV) local (DE)
- H₂ (FCEV) central
- DME (CI)
- OME (CI)
- CH₄ (SI-DI)
- CH₄ (SI-DI) (CI-HPDI)
- Methanol
- Gasoline (SI-DI) FT
- Diesel (CI) FT
- LPG (SI-DI) FT

Germany’s current annual electricity production

Summary/Conclusions

• Abundant sources of low-carbon fuels for IC engines are needed to meet global decarbonization goals
• Advanced biofuels can supply some of this need
• e-fuels could be a longer-term technology that provides low-GHG option for hard-to-electrify transportation needs
  o Need at least ~70% renewable electricity in grid mix for better carbon footprint than conventional fuels
  o A transition to e-fuels would require massive amounts of electricity (~4× more than direct electrification)
• We need to use our renewable electrons wisely
Thank You