Pipelines, Trucks, Buses and Automobiles: Where, When, Which?

Karen Clay, Inês Azevedo, Jeremy Michalek and Fan Tong

Moderated by Deborah Stine

May 3, 2017
"The Good, the Bad and the Ugly: Understanding the Social and Economic Costs of Transporting Crude Oil"

Karen Clay, Ph.D.
Professor of Economics and Public Policy, H. John Heinz III School of Public Policy and Management;
By Courtesy, Tepper School of Business;
Affiliated Faculty, University of Pittsburgh Law School
The Good, the Bad and the Ugly: Understanding the Social and Economic Costs of Transporting Crude Oil
Overview

• Long distance transportation of crude oil from North Dakota to refineries in 2014
  – Air pollution (criteria pollutants + CO\textsubscript{2}) costs of moving crude oil were 6.7 times larger for rail than for pipelines
    • For rail, 15.7 cents per gallon of crude oil
  – For both rail and pipelines, air pollution costs were 9 times spill and accident costs
Policy Implication

• Ideally, impose a pollution tax on movement of crude oil based on county level harms

• Practical Options
  – Diesel tax
  – Support pipeline construction
Social Costs per million barrel miles

- Spills/Accidents
- Air Pollution

Legend:
- Rail
- Pipelines
Crude By Rail Routes

Railroads have become virtual pipelines carrying crude from North Dakota to the East, West and Gulf Coasts.

Weekly average number of crude-oil trains from the Bakken Shale in North Dakota that pass through each county

0 0.1 to 10 10.1 to 25 >25

States that did not disclose data

Note: The Wall Street Journal was able to infer some routes through states that did not provide data based on information from the railroad companies and data provided by neighboring states.

Source: State Emergency Response Commissions
Social Costs
per million barrel miles

Spills/Accidents
Air Pollution

Rail
Pipelines
Movements of Crude Oil and Selected Products by Rail

- U.S. Propane by Rail
- U.S. Crude Oil by Rail
- U.S. Fuel Ethanol by Rail

Source: U.S. Energy Information Administration
Conclusion

• Air pollution costs of moving crude oil were 6.7 times larger for rail than for pipelines
  – For both rail and pipelines, air pollution costs were 9 times spill/accident costs

• Crude by rail is down, but shipments of products that could be shipped by either rail or pipelines remains high
Policy Implication

• Ideally, impose a pollution tax on movement of crude oil based on county level harms

• Practical Options
  – Diesel tax
  – Support pipeline construction
Thank You

For more information, email
Karen Clay
kclay@andrew.cmu.edu
"Should I Stay or Should I Go?: Transportation Fuels and Technologies Across America"

Inês Azevedo, Ph.D.
Co-Director, Climate and Energy Decisionmaking Center;
Associate Professor of Engineering and Public Policy
Should I Stay or Should I Go?
Transportation Fuels and Technologies Across America

Ines Azevedo

Associate Professor
Department of Engineering and Public Policy
Carnegie Mellon University

Co-Director
Climate and Energy Decision Making Center
Take-home messages

• Should we pursue a transition to natural gas use for transportation as a de-carbonization strategy?

**No.** Using natural gas for transportation could only provide emissions reductions for cars if used to produce electricity which will then be used to power electric vehicles. For trucks, buses, etc, using natural gas does not reduce the emissions.

• Is there a fuel-technology transportation choice that is the best at reducing health, environmental and climate change damages across the U.S?

**No.** The lowest damage strategy differs regionally and by vehicle type: there is no one solution fits all.
Should we pursue a transition to natural gas use for transportation as a de-carbonization strategy?
Shale gas revolution

- The availability of shale gas in the United States leads to the question: should we also use natural gas for transportation?
- To understand if that’s a good solution in what concerns climate mitigation, we need to look at the life-cycle emissions of natural gas use for transportation versus using gasoline/diesel.
life-cycle emissions
Examples of key results: tractor-trailer trucks

Life cycle GHG emissions (Unit: g CO₂-eq/km-metric-ton)

Conventional diesel

100-year global warming potential
Examples of key results: tractor-trailer trucks

Natural gas does **NOT** provide a pathway to de-carbonization for long haul trucks

100-year global warming potential
Natural gas transportation pathways have very different consequences for different vehicle classes.

<table>
<thead>
<tr>
<th>Emissions reduction potential</th>
<th>Natural gas pathways</th>
<th>Vehicle types</th>
<th>Insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>✅</td>
<td>Electricity + BEVs</td>
<td>Passenger vehicle, SUVs, and transit buses.</td>
<td>Efficient fuel production, zero tailpipe emissions, and efficient vehicle technologies.</td>
</tr>
<tr>
<td></td>
<td>Gaseous H₂ + FECVs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CNG</td>
<td>All vehicles.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LNG</td>
<td>Heavy-duty trucks.</td>
<td>Simple fuel production, and comparable vehicle technologies.</td>
</tr>
<tr>
<td></td>
<td>Propane</td>
<td>Medium-duty trucks.</td>
<td></td>
</tr>
<tr>
<td>✗</td>
<td>Methanol, Ethanol, and liquid hydrogen</td>
<td>Passenger vehicles</td>
<td>Complex fuel production (penalty), and comparable vehicle technologies.</td>
</tr>
<tr>
<td></td>
<td>Fischer-Tropsch liquids</td>
<td>All vehicles</td>
<td></td>
</tr>
</tbody>
</table>
Key conclusion

- Natural gas pathways provide GHG emissions reductions if the natural gas is used to produce electricity to power BEVs in the passenger vehicle, SUV and transit bus classes.

- For all the other transportation classes, the GHG emissions are either very similar to the incumbent fuel/technology, or even increase the emissions. In those sectors, natural gas does not provide a de-carbonization pathway.
Is there a fuel-technology transportation choice that is the best at reducing health, environmental and climate change damages across the U.S?
Motivation

• The transportation sector...
  – Has recently become the largest contributor to CO$_2$ emissions in the United States (U.S.)
  – Is largest contributor to CO and NOx, and a substantial contributor to other criteria air pollutants (CAPs).

• NRC (2010) shows that on-road vehicles cause $110$ billion air pollution and climate change damages.
What are the climate change and air quality consequences of different technology choices?

Climate change

Air pollution consequences
life-cycle emissions
Here are the car technologies that are the best at reducing damages:

... if you account for climate change damages only

... if you account for air pollution damages only

Climate change + air pollution damages
## Climate change, health, and environmental damages across counties

### Passenger car (\(\epsilon_{m2010}/\text{mile}\))

<table>
<thead>
<tr>
<th></th>
<th>Climate change + air pollution damages</th>
<th>Climate change damages</th>
<th>Air pollution damages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gasoline</td>
<td>Gasoline hybrid</td>
<td>CNG</td>
</tr>
<tr>
<td>Median</td>
<td>1.66</td>
<td><strong>1.31</strong></td>
<td>1.64</td>
</tr>
<tr>
<td>Max</td>
<td>3.02</td>
<td>2.59</td>
<td>3.05</td>
</tr>
<tr>
<td>Min</td>
<td>1.54</td>
<td>1.19</td>
<td>1.42</td>
</tr>
</tbody>
</table>
Policy implications

• Technologies that provide + health, climate changes and environmental benefits differs by vehicle type & region!

• For passenger cars:
  – Battery electric vehicles provide the lasted benefits in the Western U.S. and New England regions
  – Hybrid electric vehicles are the best for remaining regions.
  – We end up with the same technologies if we we consider just climate change or just air pollution consequences, or both.

• For large trucks, diesel hybrid-electric provide the largest benefits in most of the country.

• For buses, local and long-haul tractor trailers, the best technology will differ when considering just air pollution, just climate change or both issues jointly.
  – Policies and incentives should be regionally specific for those vehicle segments
"Where, When, and Which Electric Vehicles are Green?"

Jeremy Michalek, Ph.D.
Director, Vehicle Electrification Group and The Design Decisions Laboratory; Professor of Engineering and Public Policy and Mechanical Engineering
Where, When, and Which Electric Vehicles are Green?

Jeremy Michalek
Professor
Engineering and Public Policy • Mechanical Engineering
Carnegie Mellon University
Two policy briefs

Electric Vehicle Benefits and Costs in the United States

Motivations for vehicle electrification
- Energy Security: Reduce our dependency on foreign oil
- Air Quality: Reduce air pollution and its effects on human health and the environment
- Climate Change: Reduce greenhouse gas emissions to slow climate change
- Economics: Reduce cost of driving, use local energy sources, and lead new technology innovation

Electrification helps achieve these goals sometimes, but not always.

Benefits vary based on...

Vehicle Type
- A typical gasoline vehicle may generate around $4,000 of costs to society over its life, in the form of human health costs, environmental damages, and other air pollution costs.
- A hybrid electric (HEV) or plug-in hybrid electric (PHEV) vehicle could lower these costs by 10-30%, depending on the electricity source.
- A pure battery electric vehicle (BEV) could lower costs even more, since they have no tailpipe emissions at all, depending on the electricity source.
- HEVs and PHEVs tend to offer more air emissions and fuel displacement benefits per dollar spent from pure BEVs with comparable range.

Electric Vehicle Adoption Potential in the United States

Key Factors in PEV Adoption
- Charging infrastructure
- Public chargers could make EVs more attractive, but they’re public charging investment is an expensive way to lower the price of gasoline per gallon saved.
  - Generally, it is less expensive to add battery capacity to PHEVs and to make widespread electric vehicle charging stations.
- Range
  - PEV range can drop by 40% or more in the hottest or coldest regions of the U.S., growing regional challenges to adoption.
  - EVs are no more likely to be used as much as gasoline vehicles that can travel longer distances.
- Parking
  - Most U.S. households have some off-street parking, and many have readily available parking.
  - In many cases, however, electrifying off-street parking is not as straightforward as electrifying in-vehicle adoption.

Electric vehicles can only make impact to the extent that consumers adopt them.
Key message #1:

Electric vehicles are important:

- One of the few technologies capable of near-zero emission transportation

But are they greener than gasoline vehicles today?

- Depends on location, use conditions, and specific vehicle designs

Implication:

- Best policies target end goals directly (e.g.: emissions, oil consumption) rather than favoring specific technologies
Electric vehicle benefits depend on...

**Electricity source:** Charging in the N-Midwest can produce 2-3x as much CO$_2$ as charging on West Coast.

**Your climate:** Electric vehicles consume 15% more electricity in hot/cold regions on average. Range drops 40% or more on hottest/coldest days.

**How you drive:** In stop-and-go driving, hybrid & electric vehicles cut GHG emissions 50%. For cruising they cost more with marginal environmental benefit.

**What time you charge:** In places like D.C., cheap coal plants are available at night. Charging at night creates more health costs than it saves in operation cost.

**Vehicle design:** Electric vehicles are diverse, and so are gasoline vehicles. It’s not right to think of the technology as just one thing.
GHG benefits of Leaf vs. Prius vary regionally

- Leaf produces lower greenhouse gas emissions than Prius in urban counties of the southwest, TX, & FL
- Prius better in midwest, south, and most rural counties
Pairwise comparison of 3 plug-in electric vehicles (PEVs) to 2 gasoline vehicles

- PEVs sometimes cleaner than gasoline vehicles but not always
  - PEVs typically best in urban counties of the southwest, TX, FL
  - PEVs typically worse in midwest, south, and rural counties
- Grid expected to get cleaner over time, reducing PEV emissions
Alternative Fuel Vehicles (AFVs)

Vehicles that run on fuels other than gasoline or diesel (electricity, ethanol, hydrogen, etc.)
Key message #2: AFV policy interactions increase emissions

1. Federal light-duty vehicle fleet standards
   - Greenhouse gas standards regulated by EPA under the Clean Air Act and
   - Fuel economy standards regulated by DOT under the Energy Policy and Conservation Act
   - Both policies allow automakers that sell AFVs to meet less-stringent fleet standards

2. Federal and state policies encourage AFV sales
   - E.g.: Up to $7,500 tax credit per electric vehicle sold from American Recovery and Reinvestment Act of 2009

3. So, as more AFVs are sold, net emission limits increase

Implications:
- Fleet greenhouse gas standards are important, but they may not be the best place to incentivize AFV sales
Take away:

1. **Electric vehicles** important long term
   - To get there most efficiently:
     - Target end goals *(carbon price, gas tax, feebates)*
     - rather than favoring specific technologies *(EV subsidies & mandates)*

2. **Light-duty vehicle fleet standards** important
   - But not the best place to incentivize alternative-fuel vehicle sales because these incentives increase overall emissions
   - While these AFV incentives are in place (through 2025), efforts to increase AFV sales will increase emissions
For more information

Jeremy Michalek
jmichalek@cmu.edu

Vehicle Electrification Group
www.cmu.edu/cit/veg

Publications:


Backup
Terminology

Vehicle Electrification Comparison

- **CV**: Conventional
- **HEV**: Hybrid Electric
- **PHEV**: Plug-in Hybrid Electric
- **BEV**: Battery Electric

Plug-in Electric Vehicles (PEVs)

- **Increasing electrification**

<table>
<thead>
<tr>
<th>Battery</th>
<th>Power Converter</th>
<th>Electricity</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMALL</td>
<td>ENGINE</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>ENGINE &amp; MOTOR</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>LARGE</td>
<td>MOTOR</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

**DRIVETRAIN**

**SOURCE**
“Which Alternative Fuel Technology is Best for Transit Buses?”

Fan Tong, Ph.D.
Postdoctoral Research Associate, Engineering and Public Policy
Which Alternative Fuel Technology is Best for Transit Buses?

Fan Tong, Chris Hendrickson, Al Biehler, Paulina Jaramillo, Stephanie Seki

Department of Engineering and Public Policy & Heinz College

Carnegie Mellon University
Which Alternative Fuel Technology is Best for Transit Buses?

Conventional Alternatives

- **Diesel**
  - Produced from crude oil.
  - Conventional diesel buses comprise 60% of the existing fleet. Diesel hybrid electric buses have better fuel economy.

- **Biodiesel**
  - Biodiesel is typically made from vegetable oils, animal fats or recycled restaurant grease. Currently, producing biodiesel is expensive and the supply might be limited.

- **Electricity**
  - Battery electric buses have electric motors and batteries that charge en route (rapid, medium battery) or overnight (slow).

- **Natural Gas**
  - Requires dedicated refueling infrastructure, modifications to garages and special onboard tanks.

**Battery Range**

- **Conventional Diesel**
  - $5.00
- **Biodiesel 20% Blend**
  - $4.60
- **Biodiesel 100%**
  - $4.70
- **Electricity Battery Electric Bus (Rapid-Charge)**
  - $5.80
- **Electricity Battery Electric Bus (Slow-Charge)**
  - $4.70
- **Natural Gas**
  - $6.30
  - $7.70

**Agency Cost**

- **Conventional Diesel**
  - $59.40
- **Biodiesel 20% Blend**
  - $56.50
- **Biodiesel 100%**
  - $64.90
- **Electricity Battery Electric Bus (Rapid-Charge)**
  - $59.60
- **Electricity Battery Electric Bus (Slow-Charge)**
  - $68.00
- **Natural Gas**
  - $68.00

**Finding**

- Battery electric buses have the lowest overall life cycle cost, particularly when support from federal funding is available. However, they also have the shortest driving range, which will need to improve before they are widely adopted.
Key messages

#1. Among the choices available to transit agencies, battery electric buses are the best option due to low life cycle agency costs and environmental and health impacts from greenhouse gas and air pollutant emissions.

#2. Although there are still some barriers, such as low range, to their adoption, electric buses should be considered in both short-term experimentation and long-term planning for public transit agencies.
Battery Electric Buses Ready for Planning and Testing But Not Yet Full Implementation

**Short-Term Strategies**

WAIT AND OBSERVE.
Bus agencies should learn from the implementation experience of alternative fuel buses, particularly battery electric buses operated by early-adopter bus agencies.

PLAN AHEAD.
The investment in alternative fuel buses likely requires changes to the garage infrastructure and may require changes to operation scheduling. Anticipating and planning for these changes could help with the transition to alternative fuel buses.

TEST THE OPTIONS.
Before making the investment, plan on testing the buses and the potential infrastructure to ensure it meets agency needs. Update studies.

As more and better emissions data becomes available, update these studies to ensure that decisions are based on the most current information.

**Long-Term Strategies**

INVEST IN BATTERY ELECTRIC BUSES.
In the long term, battery electric bus batteries should become less expensive and have longer range. The benefits of reduced emissions and the use of external funding for capital investments make this an attractive option.

INVESTIGATE RENEWABLE ENERGY SOURCES.
With a switch to battery electric buses, a large contributor to the life cycle emissions is from grid electricity. Although the grid in Pennsylvania is likely to become cleaner, having independent, renewable energy sources at Port Authority facilities could be a cost-effective option from an emissions standpoint.
Variety of Bus Fueling Options Available

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Diesel</td>
<td>Diesel</td>
</tr>
<tr>
<td>Diesel Hybrid-Electric Bus</td>
<td>Electricity via regenerative braking</td>
</tr>
<tr>
<td>BEB Rapid-charging</td>
<td>BEB Slow-charging</td>
</tr>
<tr>
<td>BEB</td>
<td>Electricity via grid</td>
</tr>
<tr>
<td>CNG</td>
<td>Natural Gas</td>
</tr>
<tr>
<td>LNG</td>
<td>Biodiesel</td>
</tr>
<tr>
<td>B20 20% biodiesel, 80% diesel</td>
<td></td>
</tr>
<tr>
<td>B100 100% biodiesel</td>
<td></td>
</tr>
</tbody>
</table>

Produced from crude oil. Diesel hybrid-electric buses have smaller diesel tanks than conventional diesel buses.

Regenerative braking systems recover energy from the vehicle's mechanical systems, which is then stored or used. Diesel hybrid-electric buses have smaller batteries than BEBs.

BEBs are battery electric buses with electric motors and batteries that charge en route (rapid, medium battery) or overnight (slow, large battery).

CNG is compressed natural gas and LNG is liquefied natural gas; both require processing and special onboard tanks.

Typically made from vegetable oils, animal fats or recycled restaurant grease.

ACRONYM KEY:

- **B20**: A blend of 20% biodiesel and 80% petroleum diesel
- **B100**: Biodiesel (pure)
- **BEB**: Battery electric bus
- **CAP**: Criteria air pollutant
- **CNG**: Compressed natural gas
- **GHG**: Greenhouse gas
- **HEB**: Hybrid-electric bus
- **LNG**: Liquefied natural gas
- **O&M**: Operation and maintenance
Transit Agencies Need to Consider Both Agency Costs and Social Costs Caused by Air Emissions

Agency costs

- Transit bus – purchase costs, operation & maintenance costs.
- Infrastructure – refueling station, garage, and parking lot.

Social costs caused by air emissions

- Greenhouse gas emissions – climate change impacts
- Criteria air pollutants – health impacts
Battery Electric Buses Have Zero Tailpipe Emissions

Transit buses contribute to 1% of direct PM$_{2.5}$ emissions from mobile sources in Allegheny County.

Diesel particulate matter is the leading additive cancer risk air toxics in Downtown Pittsburgh and in Allegheny County.

Battery electric buses have zero tailpipe emissions.
Battery Electric Buses Cannot Go Far Before Needing to Recharge Relative to Alternatives

Transit buses run on average 100 miles per day according to Port Authority in Pittsburgh and several transit agencies in California.
Battery Electric Buses are Improving in Cost and Performance

More adoption leads to increasing technology maturity level. Less than 100 battery electric buses in the U.S. now (~40 in CA).

Battery costs and performance are improving fast, suggesting better economics and longer range for battery electric buses in the near future.

Cleaner electricity grid results in lower social costs.

Left: DOE (2014); right: EIA (2016)
For more information

• Contact for research team
  • Fan Tong, fantong@cmu.edu
  • Chris Hendrickson, cth@cmu.edu.
  • Traffic21 Institute, http://traffic21.heinz.cmu.edu/.

*Its goal is to design, test, deploy and evaluate information and communications technology based solutions to address the problems facing the transportation system of the Pittsburgh region and the nation.*

• Scott Institute for Energy Innovation.

• Publication
  • The policymaker guide and policy brief are available at http://www.cmu.edu/energy/public-policy/guides.html.
Moderator

Deborah Stine, Ph.D.
Associate Director for Policy Outreach
Wilton E. Scott Institute for Energy Innovation
Professor of the Practice, Engineering and Public Policy
For More Information

**Deborah Stine, PhD**
Associate Director for Policy Outreach
Professor of the Practice, Engineering and Public Policy
Wilton E. Scott Institute for Energy Innovation
dstine@andrew.cmu.edu

www.cmu.edu/energy
www.emissionsindex.org