Carnegie Mellon University

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

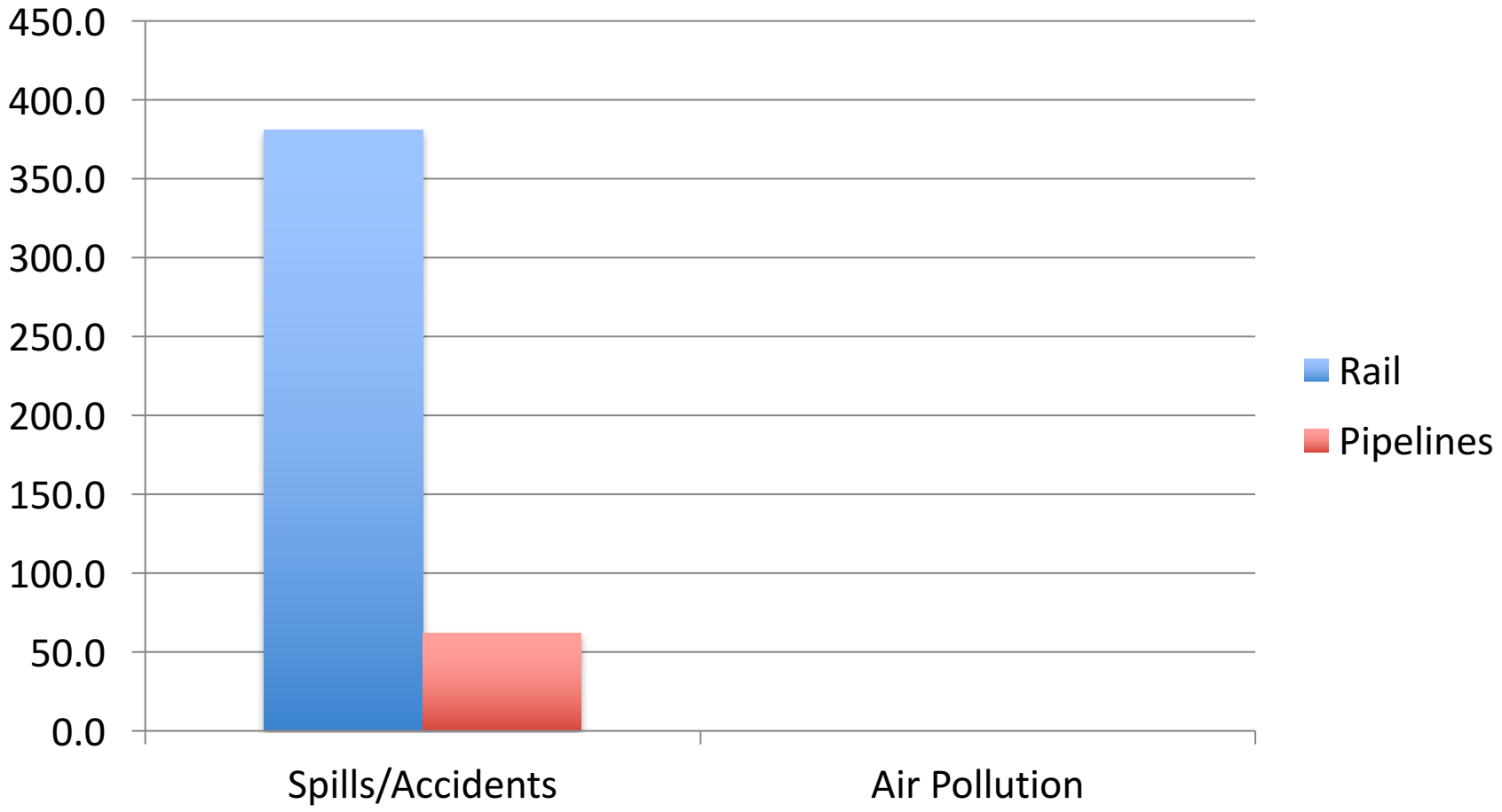
- Long distance transportation of crude oil from North Dakota to refineries in 2014
  - Air pollution (criteria pollutants + CO_2) costs of moving crude oil were 6.7 times larger for rail than for pipelines
    - For rail, 15.7 cents per gallon of crude oil
  - For both rail and pipelines, air pollution 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

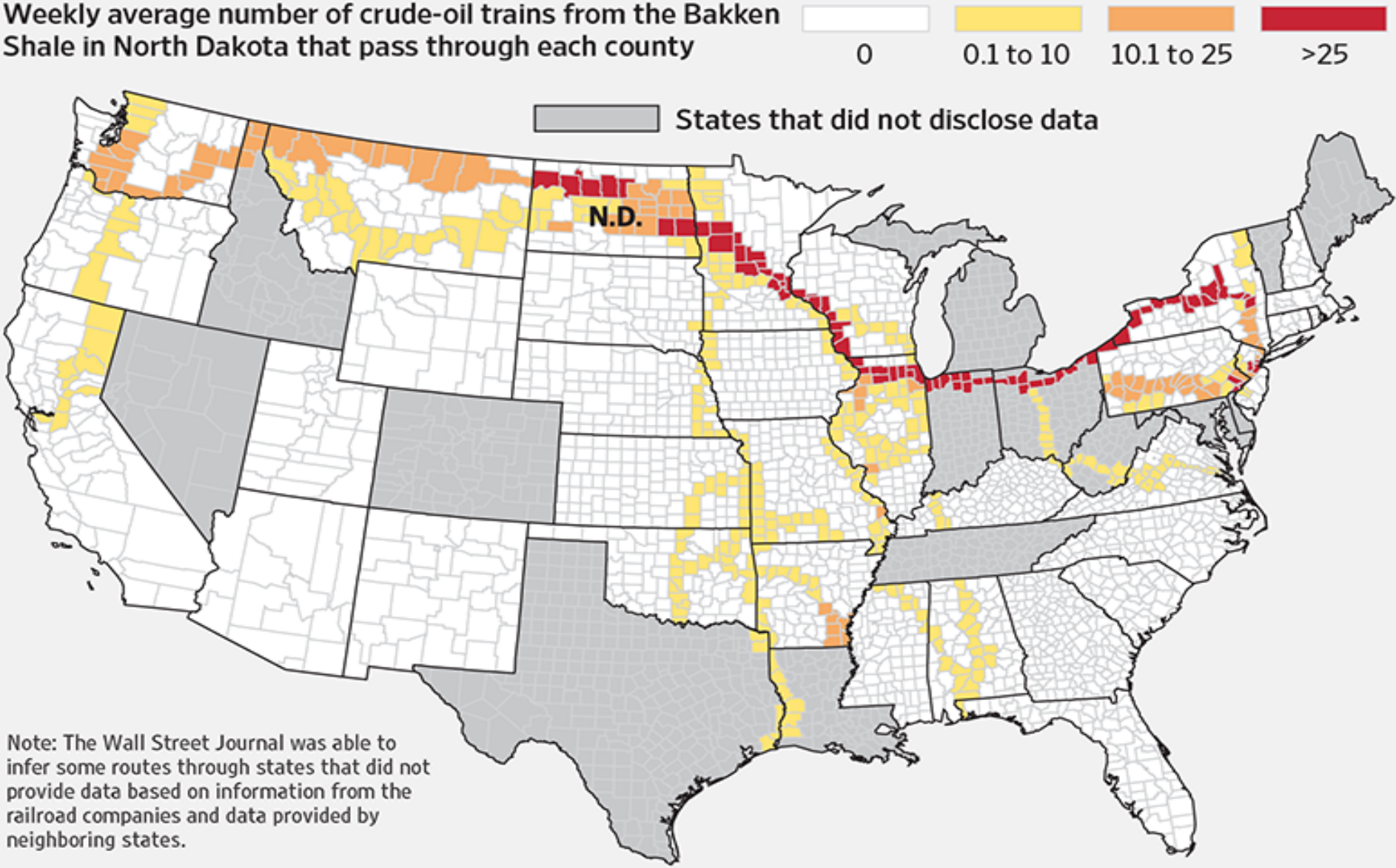

4685
4685
BNSF

Social Costs
per million barrel miles



Crude By Rail Routes

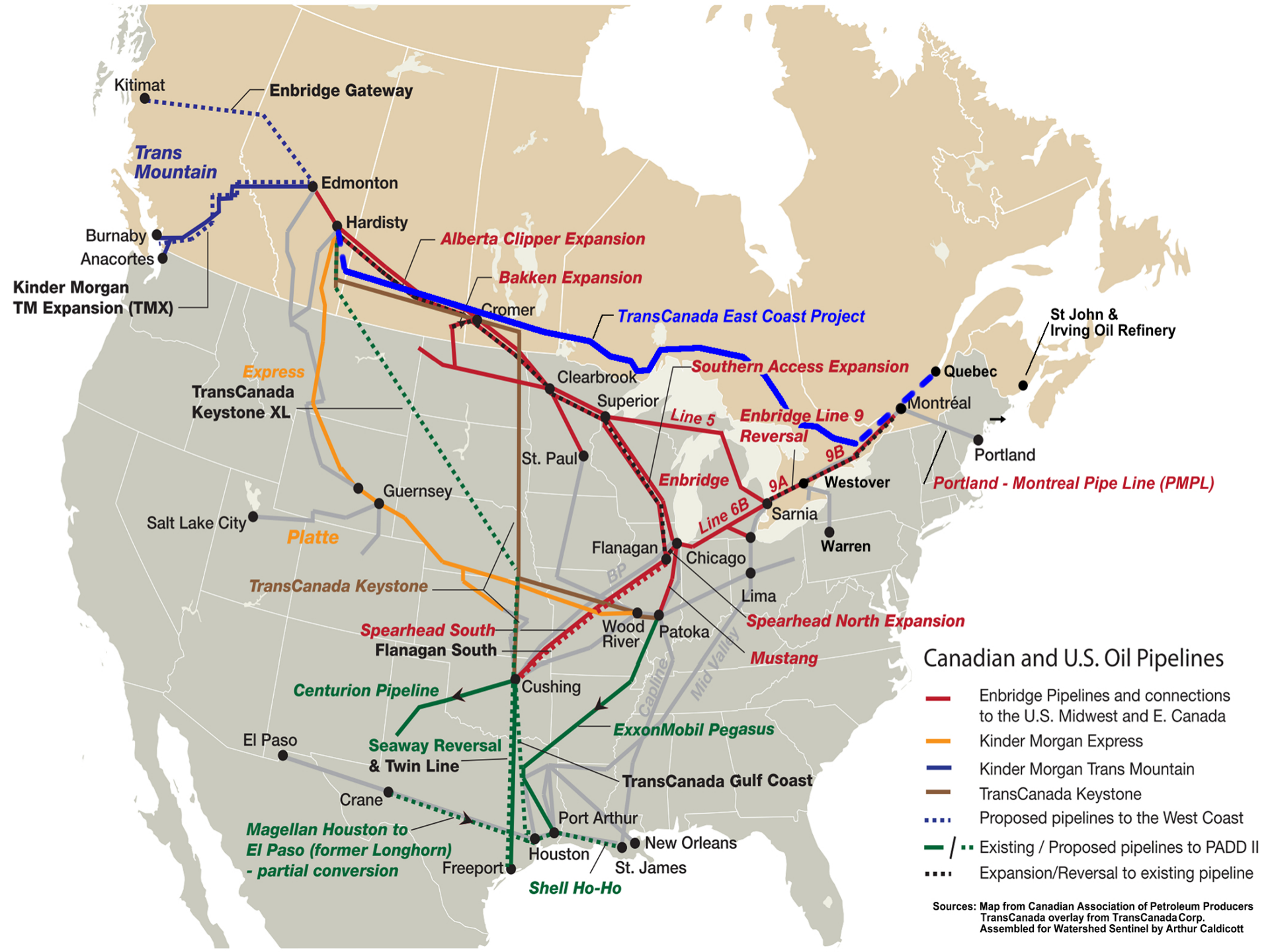
Railroads have become virtual pipelines carrying crude from North Dakota to the East, West and Gulf Coasts.



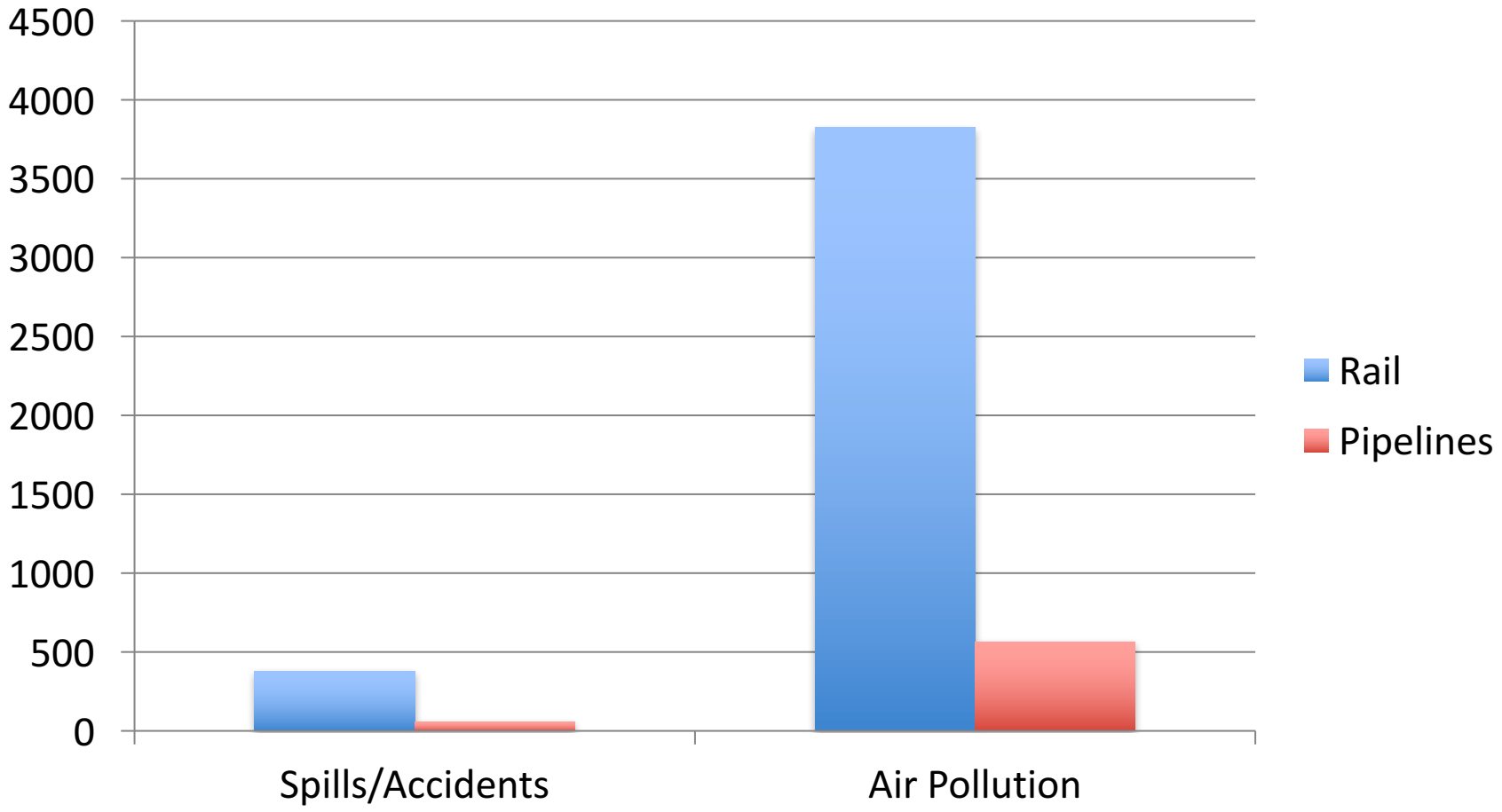
Note: The Wall Street Journal was able to infer some routes through states that did not provide data based on information from the railroad companies and data provided by neighboring states.

Source: State Emergency Response Commissions

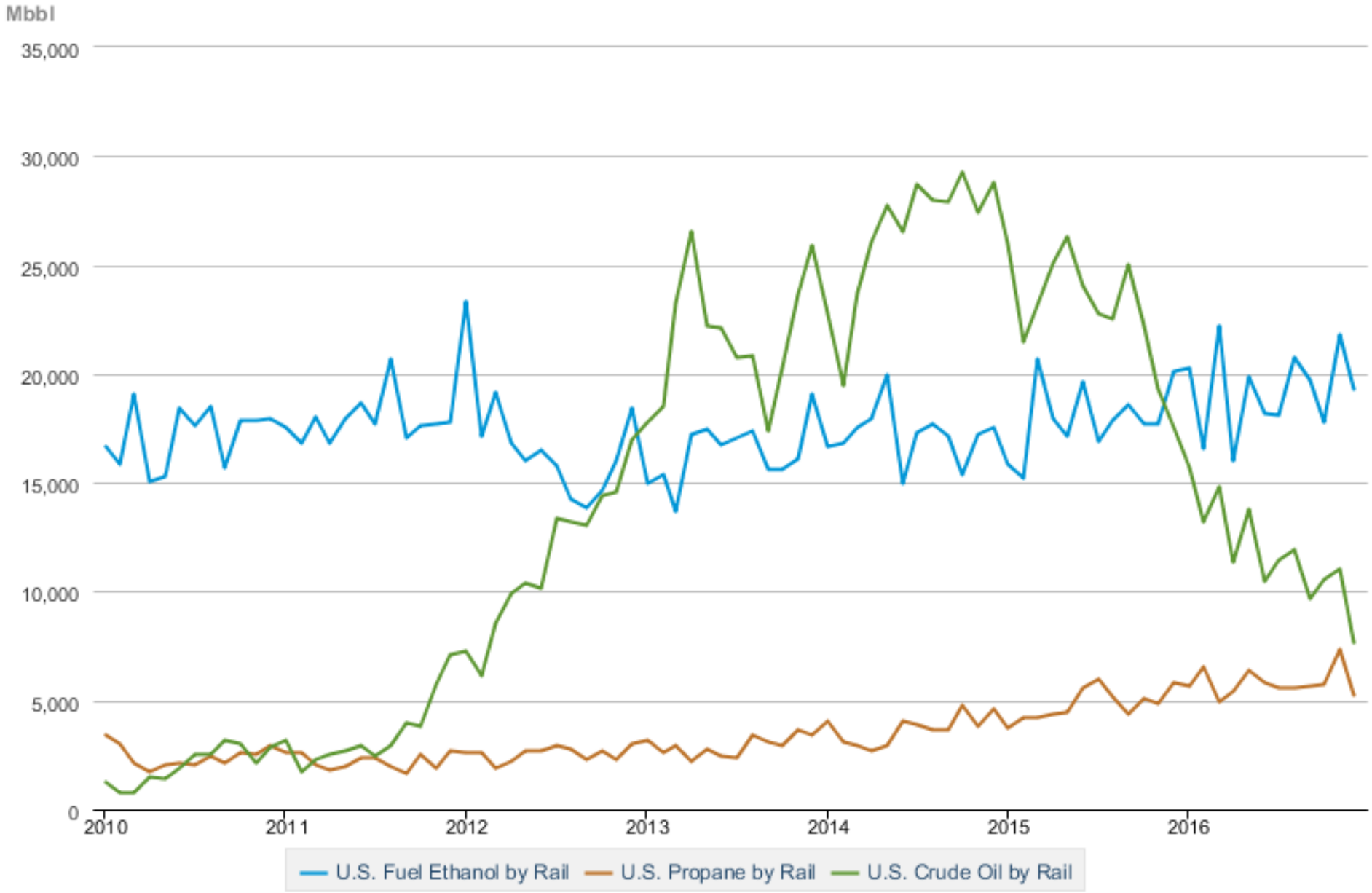
The Wall Street Journal


Kitimat
Enbridge Gateway
Trans Mountain
Edmonton
Hardisty
Burnaby
Anacortes
Kinder Morgan TM Expansion (TMX)
Alberta Clipper Expansion
Bakken Expansion
Cromer
TransCanada East Coast Project
St John & Irving Oil Refinery
Express TransCanada Keystone XL
Clearbrook
Southern Access Expansion
Quebec
Superior
Line 5
Enbridge Line 9 Reversal
Montréal
9B
Portland
St. Paul
Enbridge
9A
Westover
Portland - Montreal Pipe Line (PMPL)
Guernsey
Line 6B
Sarnia
Salt Lake City
Platte
Flanagan
Chicago
Warren
BP
TransCanada Keystone
Lima
Spearhead North Expansion
Spearhead South
Flanagan South
Wood River
Patoka
Mustang
Centurion Pipeline
Cushing
Capline
Mid Valley
ExxonMobil Pegasus
El Paso
Seaway Reversal & Twin Line
TransCanada Gulf Coast
Crane
Port Arthur
New Orleans
Magellan Houston to El Paso (former Longhorn) - partial conversion
Houston
Freeport
St. James
Shell Ho-Ho
Canadian and U.S. Oil Pipelines
Enbridge Pipelines and connections to the U.S. Midwest and E. Canada
Kinder Morgan Express
Kinder Morgan Trans Mountain
TransCanada Keystone
Proposed pipelines to the West Coast
Existing / Proposed pipelines to PADD II
Expansion/Reversal to existing pipeline
Sources: Map from Canadian Association of Petroleum Producers
TransCanada overlay from TransCanada Corp.
Assembled for Watershed Sentinel by Arthur Caldicott

Social Costs
per million barrel miles



Movements of Crude Oil and Selected Products 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?**

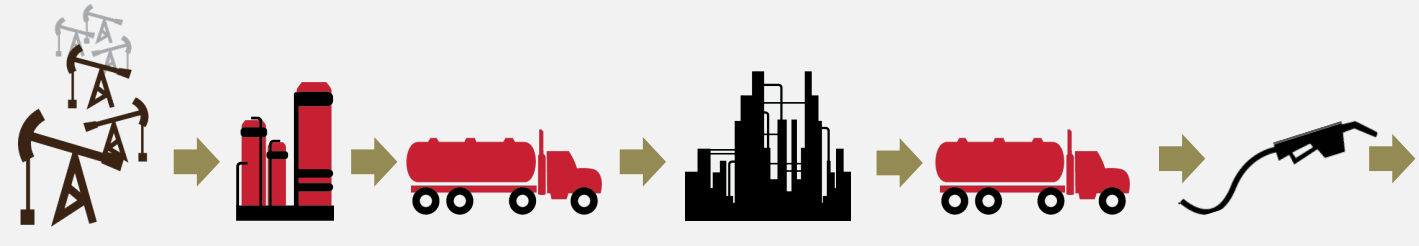
No. The lowest damage strategy differs regionally and by vehicle type: there is no one solution fits all.

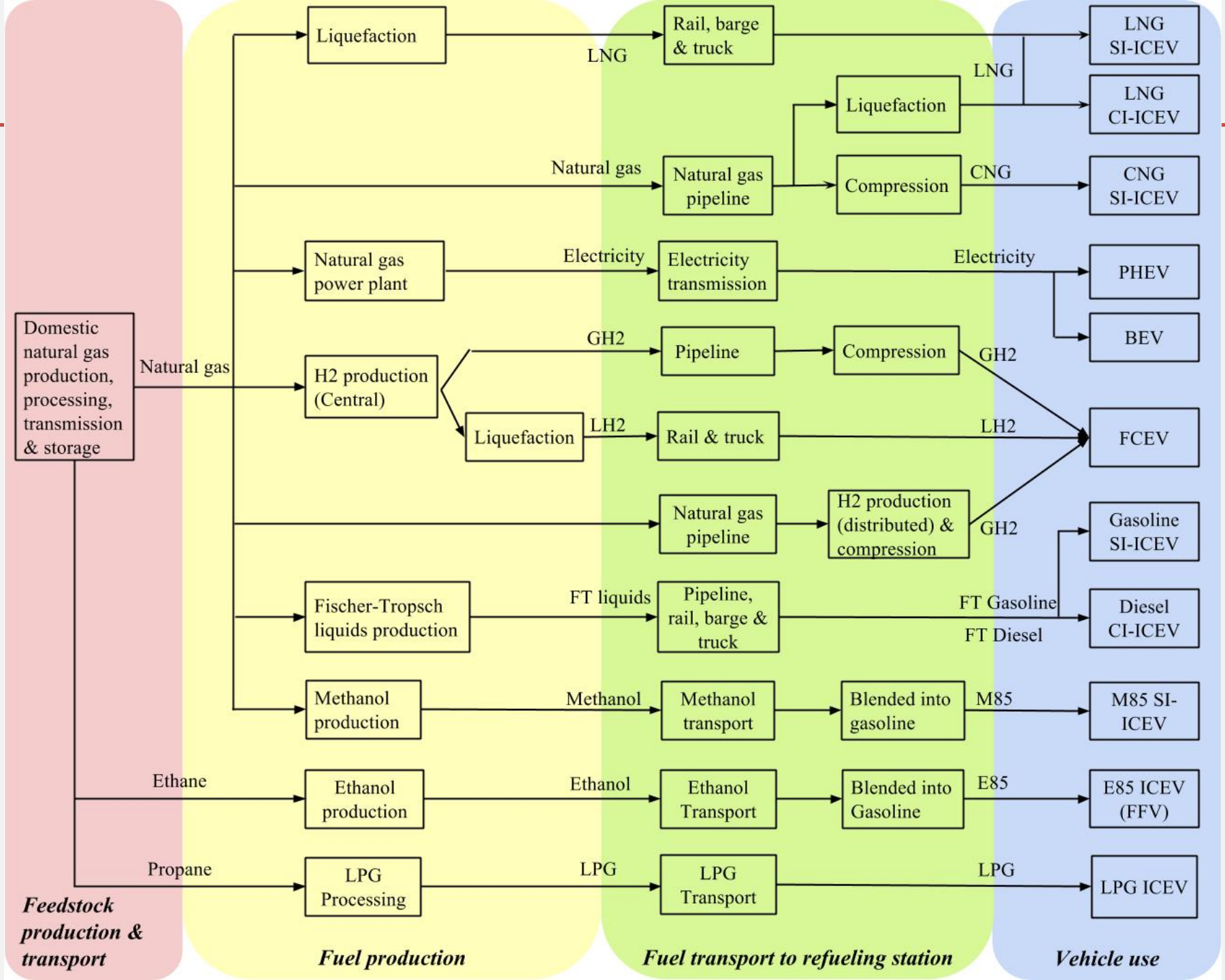
Should we pursue a transition to natural gas use for transportation as a de-carbonization strategy?

Shale gas revolution

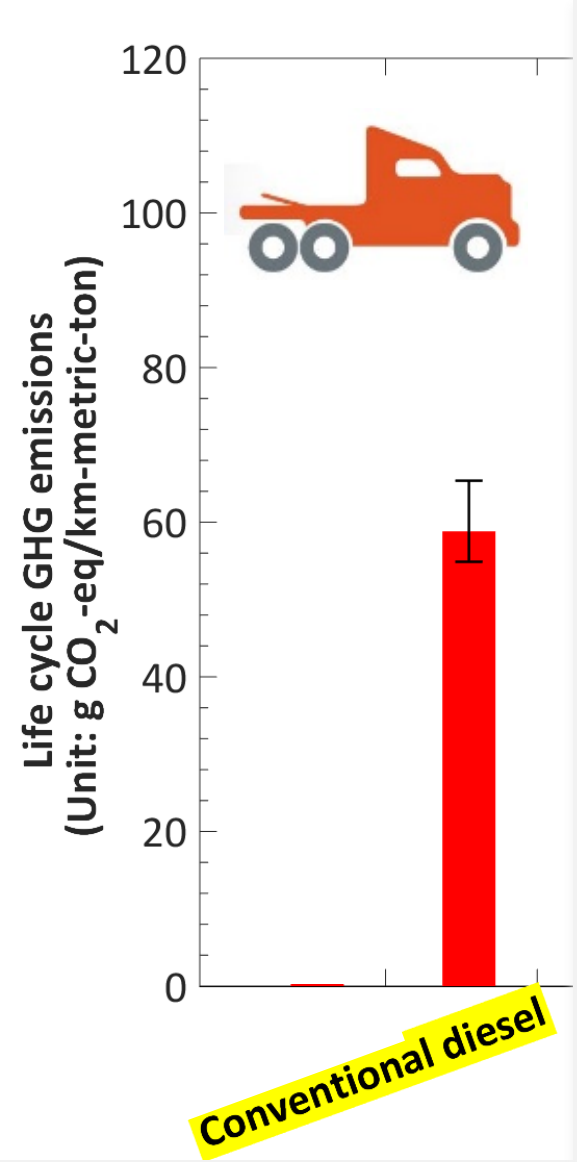
- The availability of shale gas in the United States leads to the question: should we also use natural gas for transportation?
- To understand if that's a good solution in what concerns climate mitigation, we need to look at the life-cycle emissions of natural gas use for transportation versus using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

life-cycle emissions



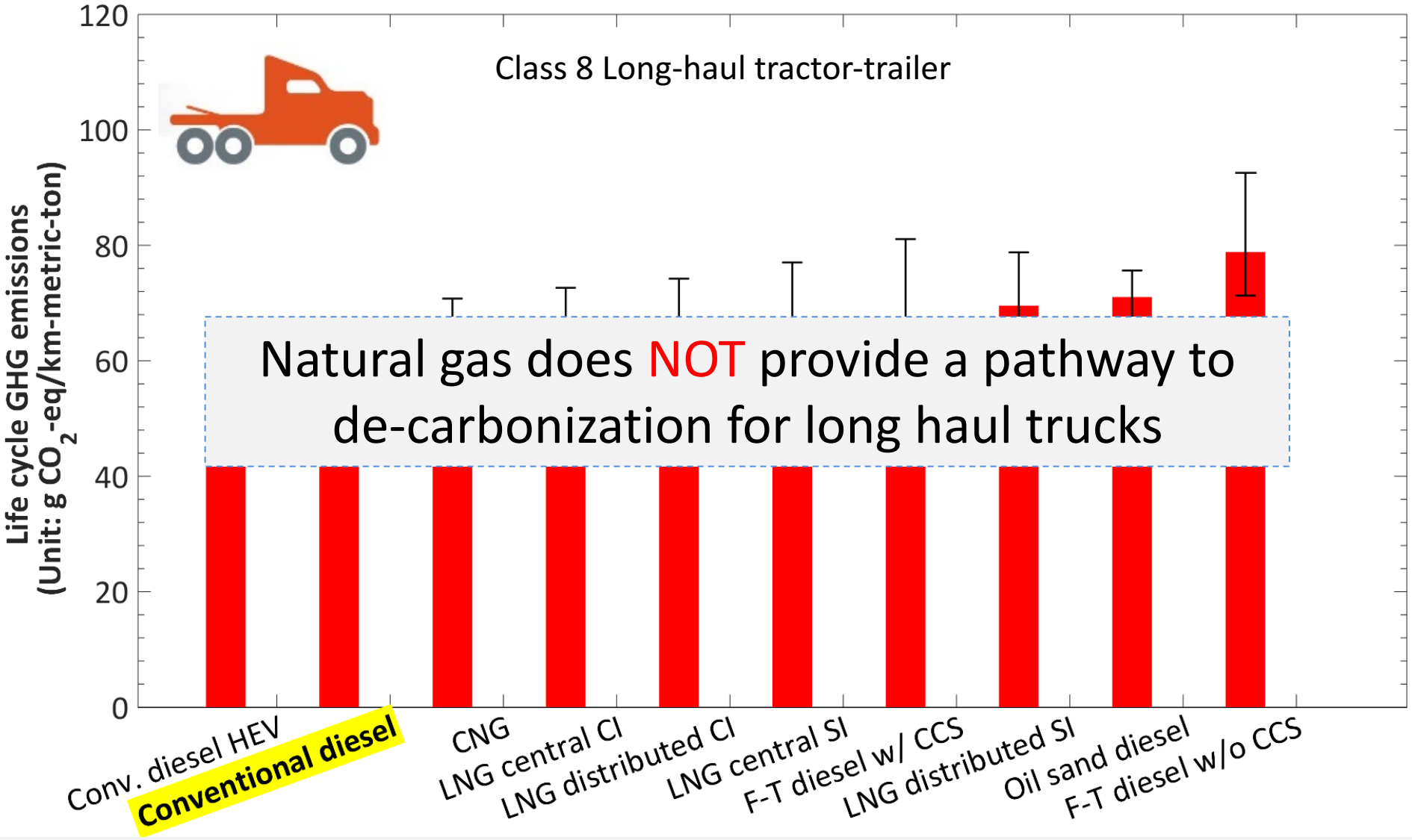

Domestic natural gas production, processing, transmission & storage
Natural gas
Ethane
Propane
Liquefaction
Natural gas pipeline
Natural gas power plant
H2 production (Central)
Liquefaction
Natural gas pipeline
Fischer-Tropsch liquids production
Methanol production
Ethanol production
LPG Processing
LNG
Natural gas
Electricity
GH2
LH2
GH2
FT liquids
Methanol
Ethanol
LPG
Rail, barge & truck
Liquefaction
Compression
Electricity transmission
Pipeline
Compression
Rail & truck
H2 production (distributed) & compression
Pipeline, rail, barge & truck
Methanol transport
Ethanol Transport
LPG Transport
LNG
CNG
Electricity
GH2
LH2
GH2
FT Gasoline
FT Diesel
Blended into gasoline
Blended into Gasoline
M85
E85
LNG SI-ICEV
LNG CI-ICEV
CNG SI-ICEV
PHEV
BEV
FCEV
Gasoline SI-ICEV
Diesel CI-ICEV
M85 SI-ICEV
E85 ICEV (FFV)
LPG ICEV
Feedstock production & transport
Fuel production
Fuel transport to refueling station
Vehicle use

Examples of key results: tractor-trailer trucks



100-year global warming potential

Examples of key results: tractor-trailer trucks



100-year global warming potential

Natural gas transportation pathways have very different consequences for different vehicle classes.

Emissions reduction potential	Natural gas pathways	Vehicle types	Insights
	Electricity + BEVs Gaseous H_2 + FECVs	Passenger vehicle, SUVs, and transit buses.	Efficient fuel production, zero tailpipe emissions, and efficient vehicle technologies.
	CNG	All vehicles.	Simple fuel production, and comparable vehicle technologies.
	LNG	Heavy-duty trucks.	
	Propane	Medium-duty trucks.	
	Methanol, Ethanol, and liquid hydrogen	Passenger vehicles	Complex fuel production (penalty), and comparable vehicle technologies.
	Fischer-Tropsch liquids	All vehicles	

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

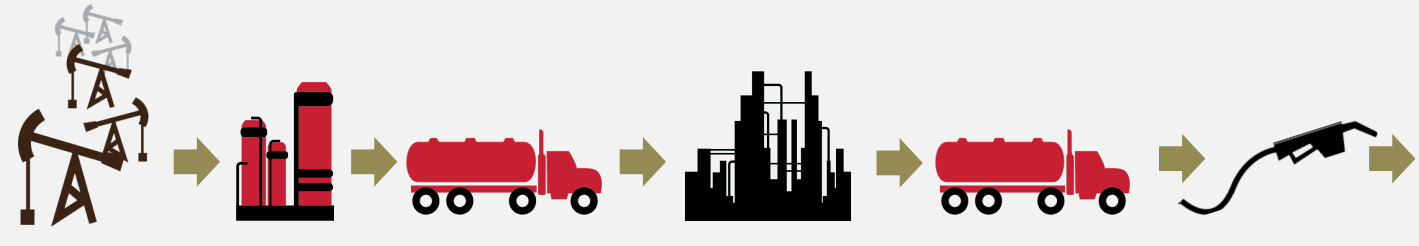
- The transportation sector…
  - Has recently become the largest contributor to CO_2 emissions in the United States (U.S.)
  - Is largest contributor to CO and NOx, and a substantial contributor to other criteria air pollutants (CAPs).
- NRC (2010) shows that on-road vehicles cause $110 billion air pollution and climate change damages.

What are the climate change and air quality consequences of different technology choices?

Climate change

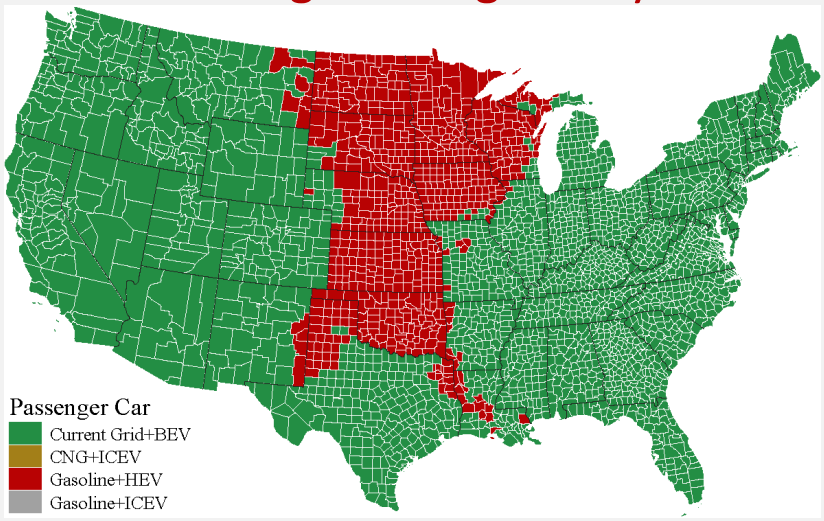
Air pollution consequences

life-cycle emissions

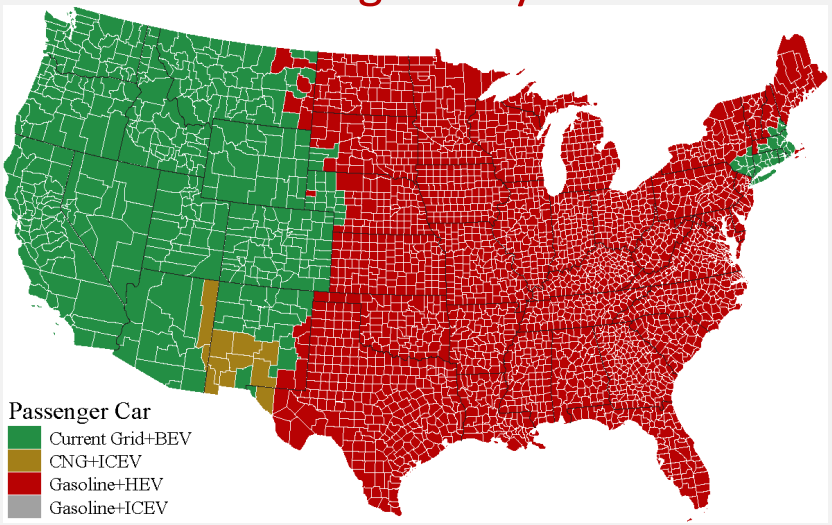


Here are the car technologies that are the best at reducing damages….

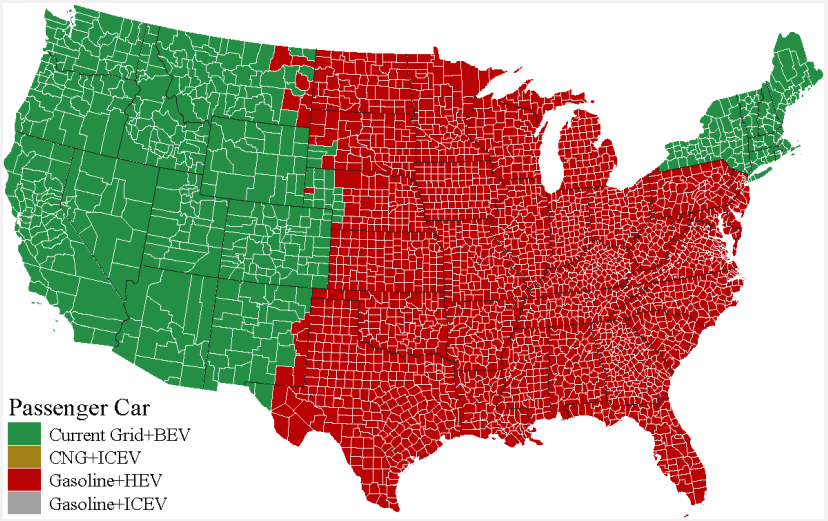
… if you account for climate change damages only



… if you account for air pollution damages only



Climate change + air pollution damages



Current Grid+BEV
CNG+ICEV
Gasoline+HEV
Gasoline+ICEV

Climate change, health, and environmental damages across counties

	Passenger car (¢$_{2010}$/mile)											
	Climate change + air pollution damages				Climate change damages				Air pollution damages			
	Gasoline	Gasoline hybrid	CNG	BEV	Gasoline	Gasoline hybrid	CNG	BEV	Gasoline	Gasoline hybrid	CNG	BEV
Median	1.66	**1.31**	1.64	1.68	1.25	0.92	1.18	**0.84**	0.41	**0.39**	0.46	0.83
Max	3.02	2.59	3.05	2.87	1.25	0.92	1.21	1.07	1.77	1.67	1.87	2.00
Min	1.54	1.19	1.42	0.91	1.25	0.92	1.14	0.47	0.28	0.27	0.26	0.26

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?

Carnegie Mellon
Vehicle Electrification Group

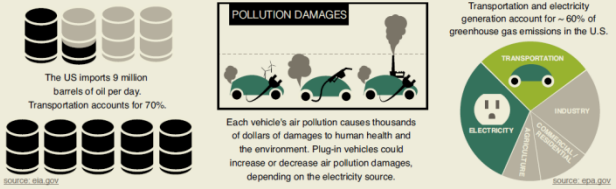
Jeremy Michalek
Professor
Engineering and Public Policy • Mechanical Engineering
Carnegie Mellon University

Two policy briefs

POLICY BRIEF

Electric Vehicle Benefits and Costs in the United States

Carnegie Mellon University Engineering & Public Policy



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...

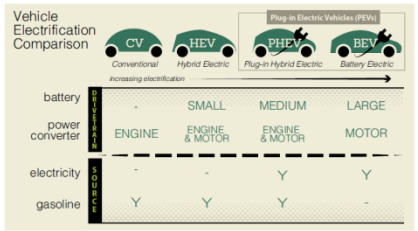
Vehicle Type

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 15-30%, depending on the electricity source.

A pure battery electric vehicle (BEV) could either cut these costs in half or double them, depending on the electricity source.

HEVs and PHEVs tend to offer more air emissions and oil displacement benefits per dollar spent than pure BEVs with comparable range.[1]

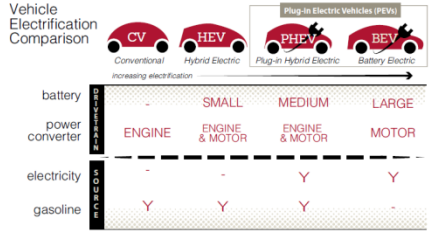


POLICY BRIEF

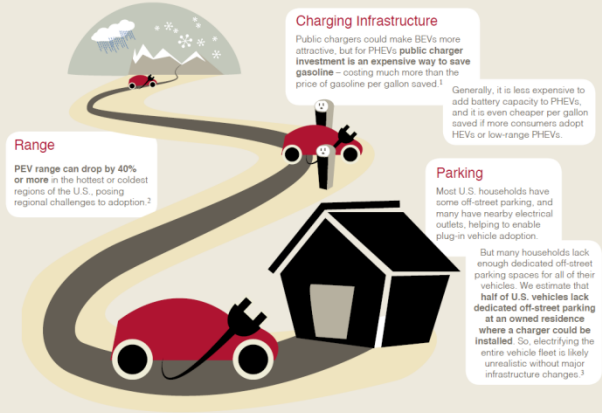
Electric Vehicle Adoption Potential in the United States

Carnegie Mellon University Engineering & Public Policy

Electric vehicles can only make impact to the extent that consumers adopt them.



Key Factors in PEV Adoption



Key message #1:

Electric vehicles are important:

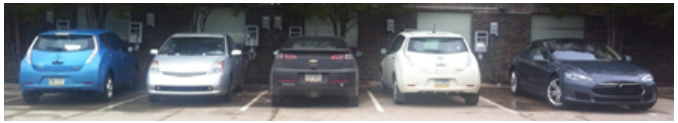
- One of the few technologies capable of near-zero emission transportation

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



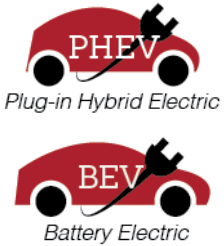
Electric vehicle benefits depend on…

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.

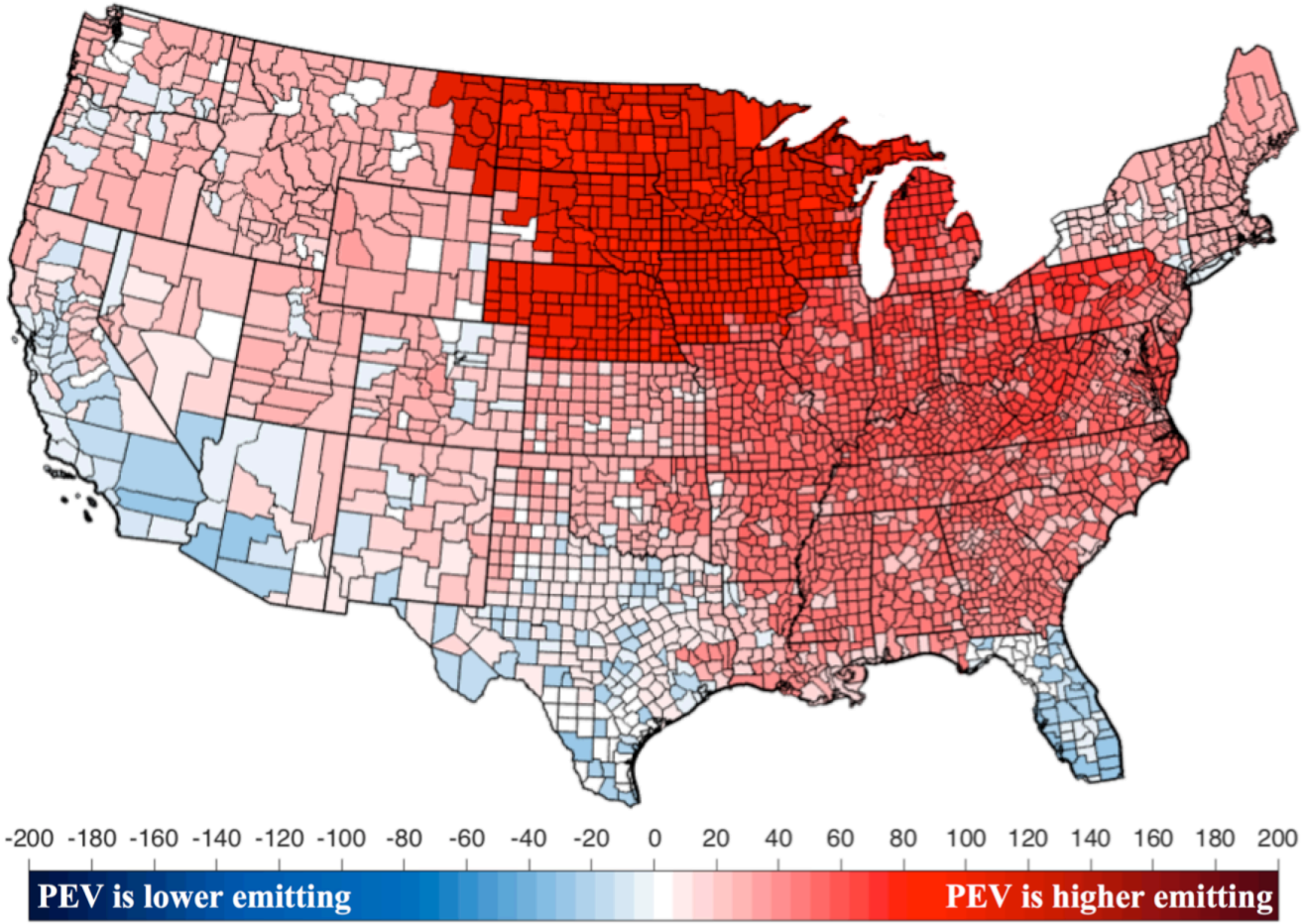
What time you charge:
In places like D.C., cheap coal plants are available at night. Charging at night creates more health costs than it saves in operation cost.



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

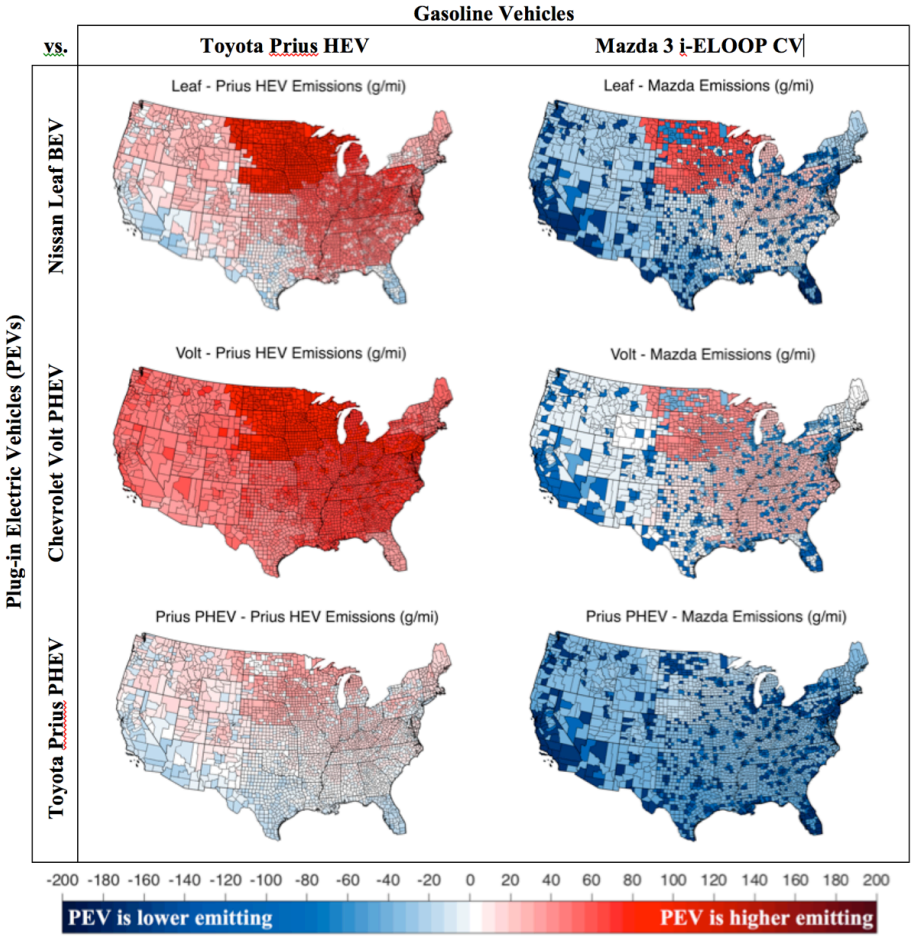
- Leaf produces lower greenhouse gas emissions than Prius in urban counties of the southwest, TX, & FL
- Prius better in midwest, south, and most rural counties



Lowest GHGs: elec. or gas? Depends on vehicle

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.)

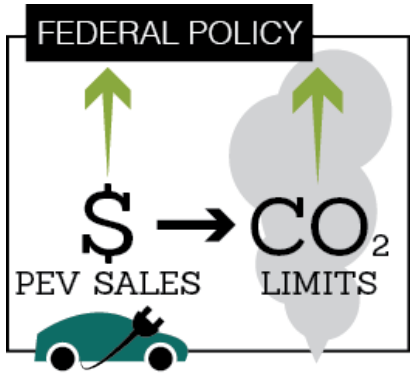
Key message #2:

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

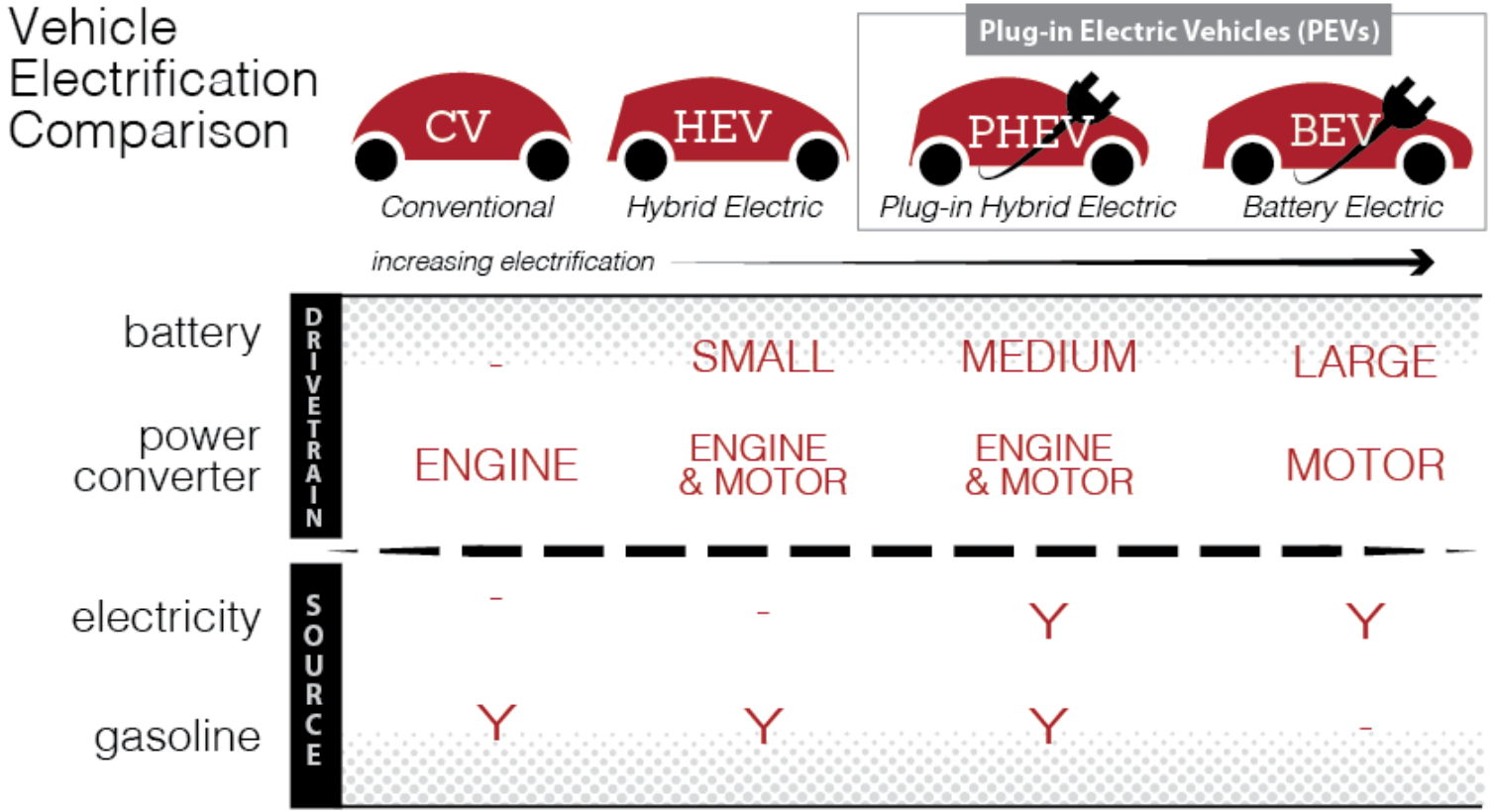
Jeremy Michalek	Vehicle Electrification Group
jmichalek@cmu.edu	www.cmu.edu/cit/veg
	Carnegie Mellon Vehicle Electrification Group

Publications:

- Jenn, A., I.L. Azevedo and J.J. Michalek (2016) "Alternative fuel vehicle adoption increases fleet gasoline consumption and greenhouse gas emissions under United States corporate average fuel economy policy and greenhouse gas emissions standards," *Environmental Science & Technology*, v50 n5 p.2165-2174.
- Michalek, J. *Electric Vehicle Benefits and Costs in the United States*, Policy Brief, updated April 2017. [video]
- Michalek, J. *Electric Vehicle Adoption Potential in the United States*, Policy Brief, updated April 2017. [video]
- Yuksel, T., M. Tamayao, C. Hendrickson, I. Azevedo and J.J. Michalek (2016) "Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of electric and gasoline vehicles," *Environmental Research Letters*, v11 n4 044007.

Backup

Terminology



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

Fan Tong, Ph.D.
Postdoctoral Research Associate, Engineering and Public Policy

Carnegie Mellon University
Scott Institute for Energy Innovation

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

traffic21 | Carnegie Mellon University Scott Institute for Energy Innovation

Carnegie Mellon University

A policymaker guide and a policy brief

POLICYMAKER GUIDE

Which Alternative Fuel Technology Is Best for Transit Buses?

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POLICY BRIEF

Which alternative fuel technology is best for transit buses?

Carnegie Mellon University Scott Institute for Energy Innovation

traffic21

Transit agencies are continually planning for their future bus purchases. Today, most transit buses run on conventional diesel fuel. However, many transit agencies are considering other options, such as biodiesel, electricity and natural gas. So, how do the different options compare?

	Conventional		Alternatives					
	Diesel		Biodiesel		Electricity		Natural Gas	
	Produced from crude oil. Conventional diesel buses comprise 60% of the existing fleet. Diesel hybrid electric buses have better fuel economy.		Biodiesel is typically made from vegetable oils, animal fats or recycled restaurant grease. Currently, producing biodiesel is expensive and the supply might be limited.		Battery electric buses have electric motors and batteries that charge en route (rapid, medium battery) or overnight (slow, large battery).		Requires dedicated refueling infrastructure, modifications to garages and special onboard tanks.	
	CV	HEB	B20	B100	BEB	BEB	CNG	LNG
	Conventional Diesel	Diesel Hybrid Electric Bus	20% Biodiesel + 80% Diesel	100% Biodiesel	Battery Electric Bus (Rapid-Charge)	Battery Electric Bus (Slow-Charge)	Compressed Natural Gas	Liquefied Natural Gas
Battery		- +			- +	- +		
Range	›››	››››	›››	›››	›	›	›››	›››
Social Cost*[1]	$5.00	$4.30	$4.60	$3.00	$4.70	$5.80	$6.30	$7.70
Agency Cost*[1]	$59.40	$56.50	$60.20	$64.90	$44.90	$47.80	$59.60	$68.00

Finding

Battery electric buses have the lowest overall life cycle cost, particularly when support from federal funding is available.[1] However, they also have the shortest driving range, which will need to improve before they are widely adopted.

*Costs are in units of $1,000/bus/year in 2015 dollars.
Results assume: a 40-foot bus with federal funding; 12-year lifetime for the bus; 1% discount rate; Port Authority of Allegheny County data.

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

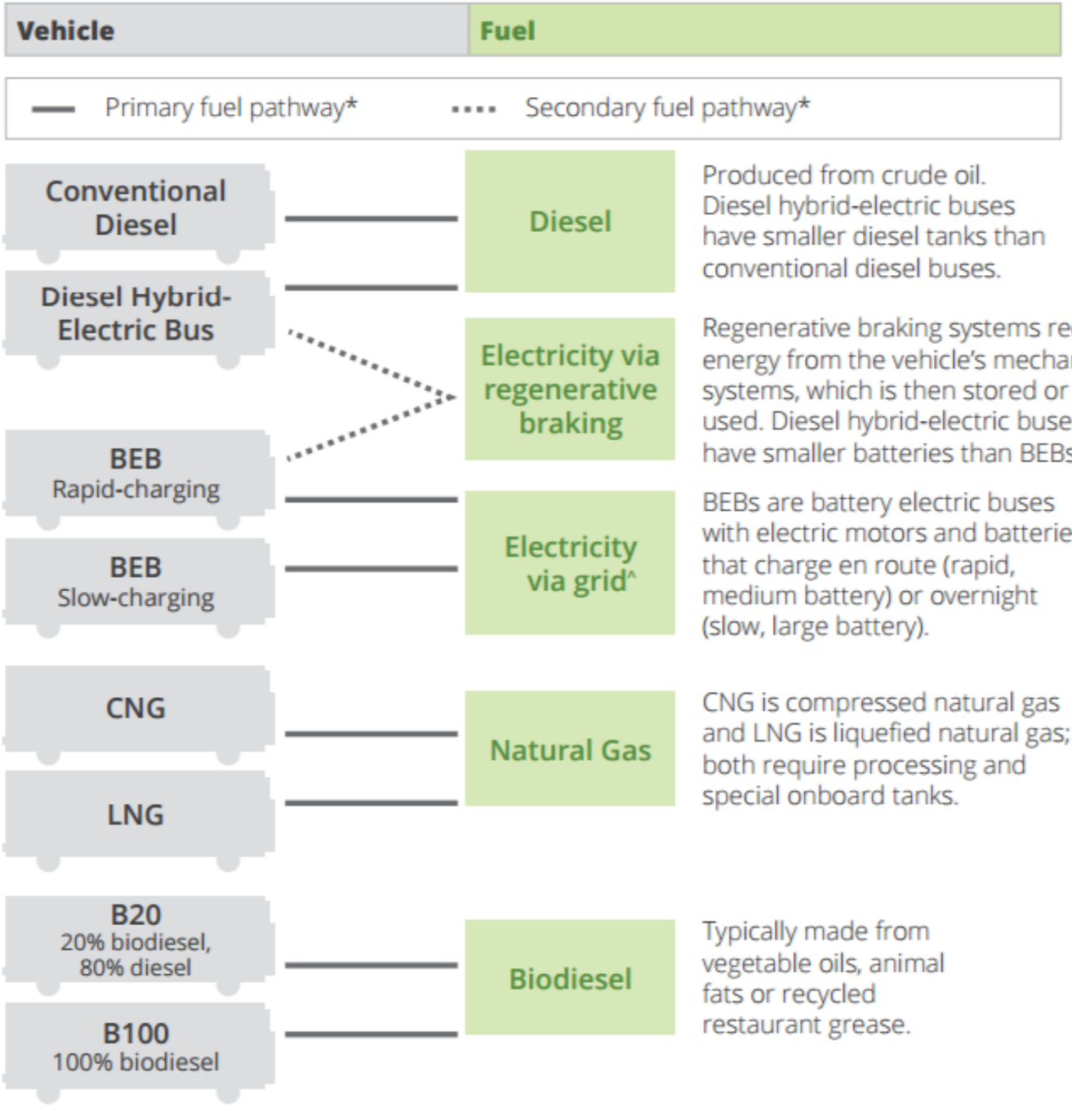
INVEST IN BATTERY ELECTRIC BUSES.

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



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.

http://www.bus-history.org/blog/?p=84

Gladstein Neandross & Associates (2012)

Gladstein Neandross & Associates (2012)

Social costs caused by air emissions

- Greenhouse gas emissions – climate change impacts
- Criteria air pollutants – health impacts

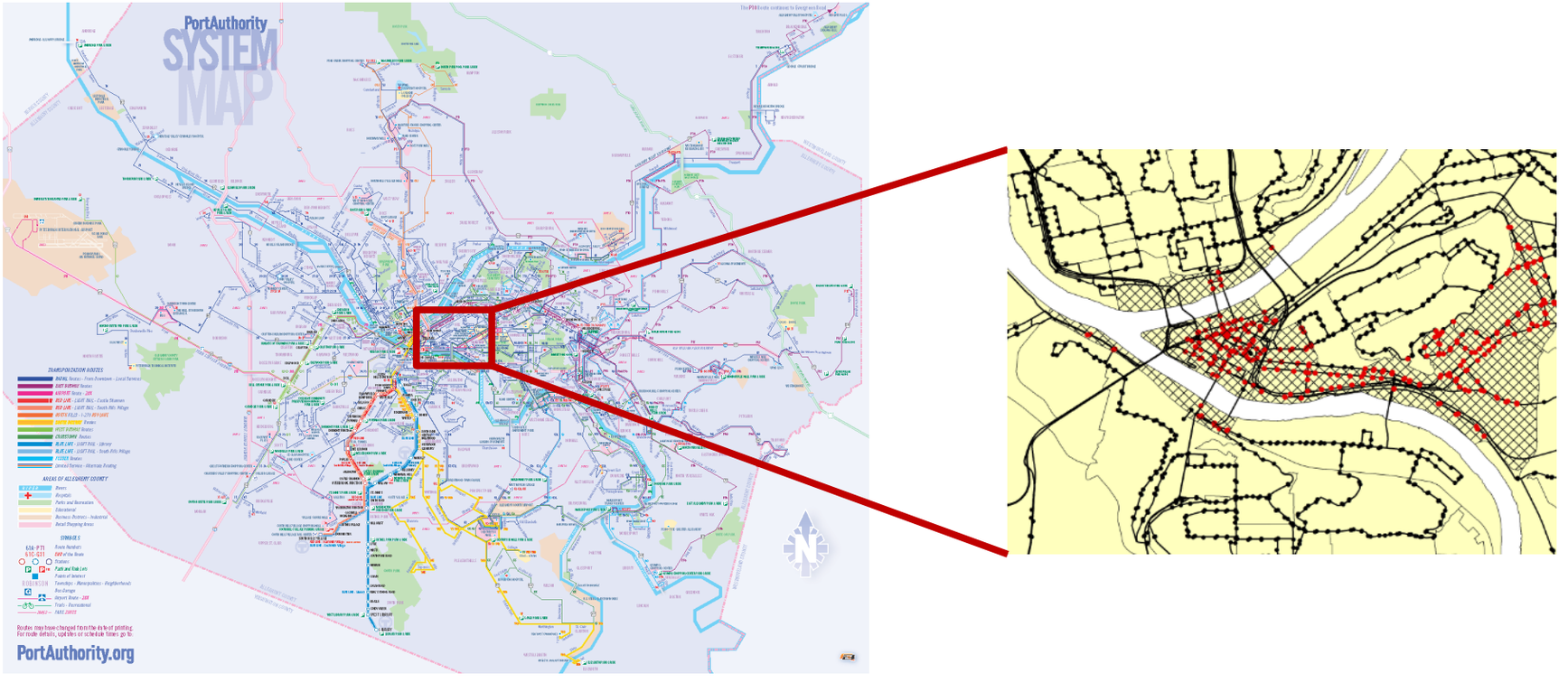
Modified from a GREET model presentation (Argonne National Lab)

Battery Electric Buses Have Zero Tailpipe Emissions

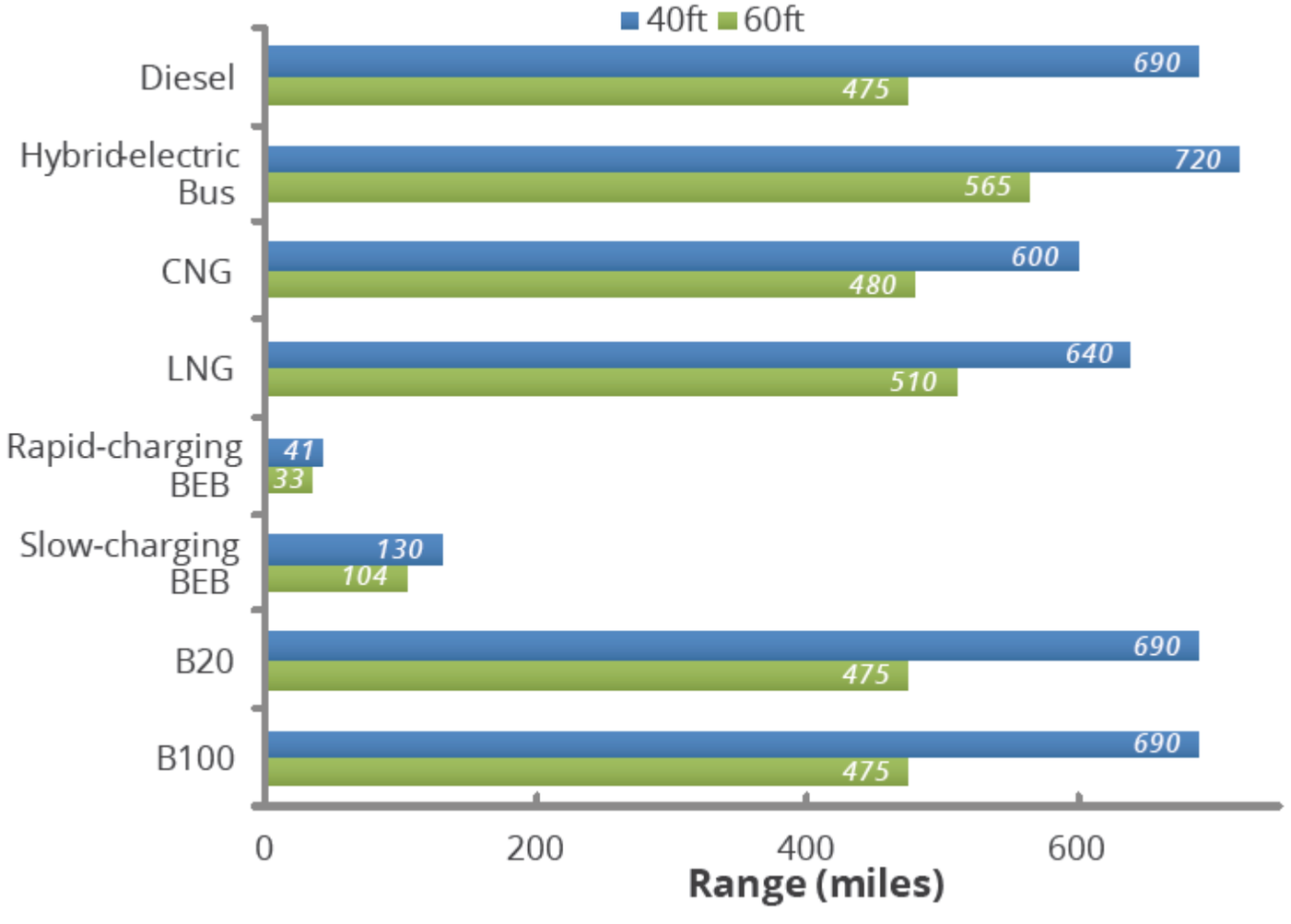
Transit buses contribute to 1% of direct $PM_{2.5}$ emissions from mobile sources in Allegheny County.

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



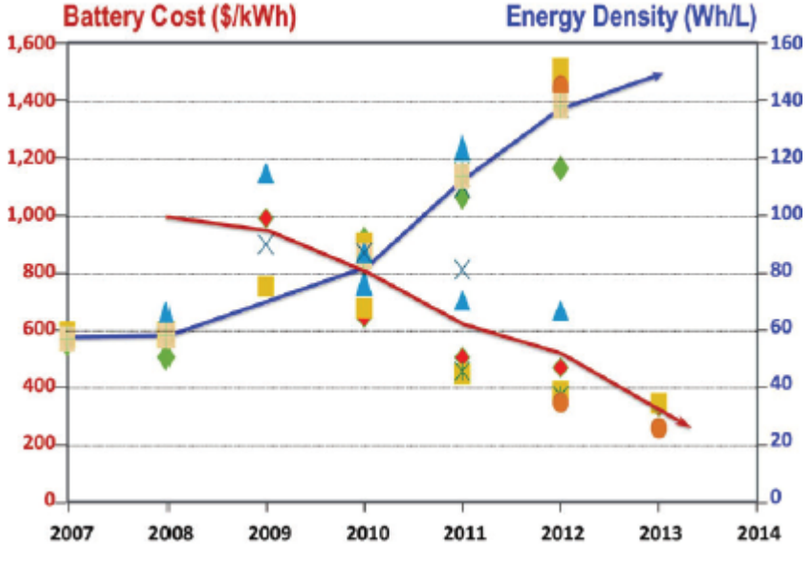
Transit buses run on average 100 miles per day according to Port Authority in Pittsburgh and several transit agencies in California.

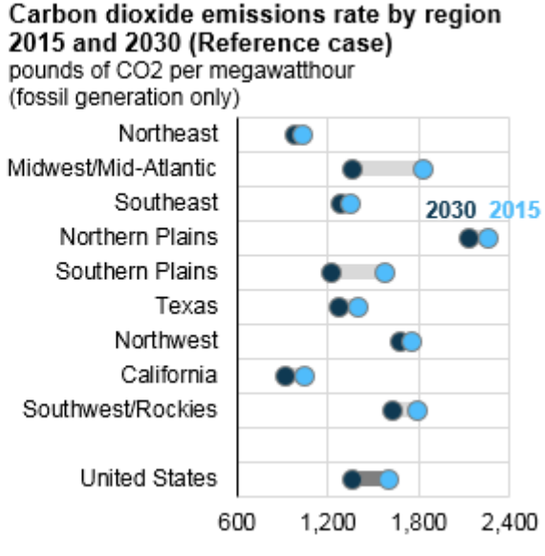
Battery Electric Buses are Improving in Cost and Performance

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/.

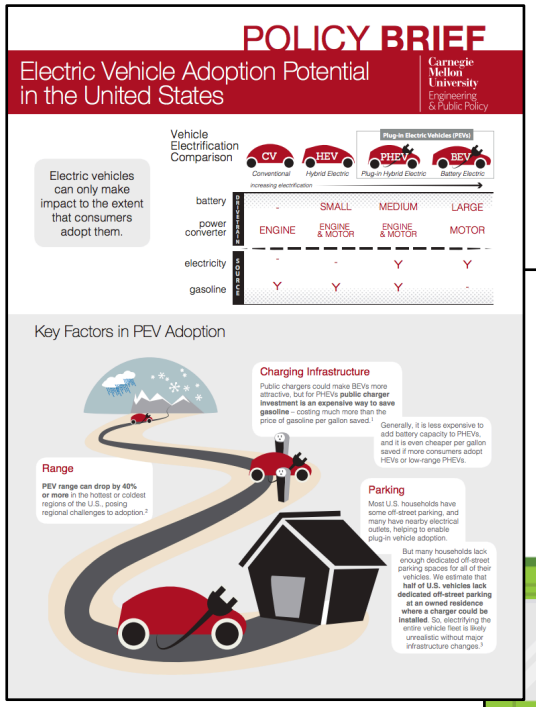
    Its goal is to design, test, deploy and evaluate information and communications technology based solutions to address the problems facing the transportation system of the Pittsburgh region and the nation.
  - Scott Institute for Energy Innovation.

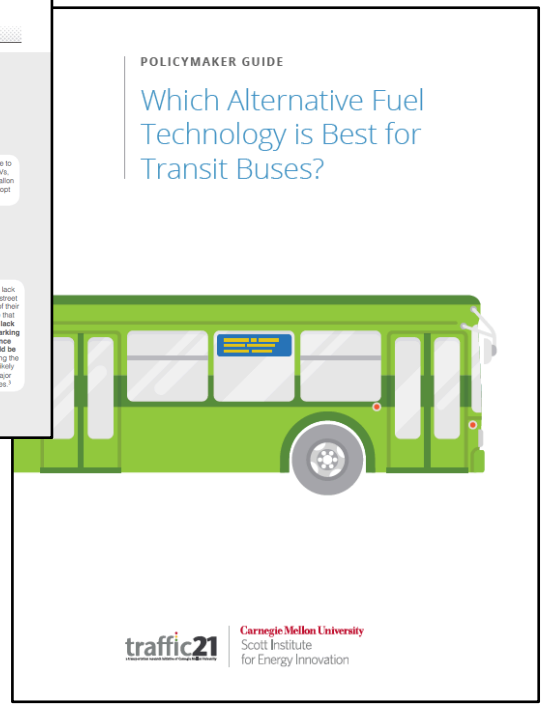
- Publication
  - The policymaker guide and policy brief are available at http://www.cmu.edu/energy/public-policy/guides.html.
  - Tong, F.; Hendrickson, C; Biehler, A.; Jaramillo, P.; & Seki, S. (2016). Life Cycle Ownership and Social Costs of Alternative Fuel Options for Transit Buses. Invited to revise and resubmit to Transportation Research Part D: Transport and Environment.

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
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