Real-World Fuel Efficiency and Economics of Hybrid and Electric Vehicles in India and China

Anand R. Gopal

Sustainable Transportation Seminar
Stanford University
October 17, 2014
Lawrence Berkeley National Laboratory: Overview

Managed by the University of California for the United States Department of Energy

Environmental Energy Technologies Division

Vision

To be a global innovation hub for science, technology, and policy solutions to the world’s most critical energy and environment challenges

- China Energy Group
- Energy Efficiency Standards Group
- International Energy Studies Group
- Electricity Markets & Policy Group
- Indoor Environment Group
- Sustainable Energy Systems

13 — Nobel Prizes
13 — National Medal of Science recipients
4,200 — Employees
200 — Site acreage
International Energy Studies Group Overview

Established: 1978 (Co-founder Lee Schipper)
Number of Staff: 16 Term/Career + 1 graduate student + 6 Guests
Group Website: http://ies.lbl.gov/

The IES group
Makes an Impact through rigorous research relevant to transitioning to a clean, efficient, secure, reliable, and affordable energy system.
Provides Insights to developing country decision makers
Provides a Bridge between expertise held by colleagues at LBNL and beyond to developing country stakeholders.
Facilitates Exchange of ideas and builds capacity through training

Current focus areas

- Clean energy options and policy assessment in the Indian power sector
- Clean transportation technology assessment and policy
- Appliance efficiency techno-economic and policy/program assessment in several countries
- Buildings Sector Efficiency
- Evaluation Measurement & Verification
- Industrial sector energy efficiency
- Off-Grid and mini-grid techno-economic and policy assessment in India and Africa
Understanding the fuel savings potential from deploying hybrid cars in China

Samveg Saxena *, Amol Phadke, Anand Gopal

Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, United States

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Understanding fuel savings mechanisms from hybrid vehicles to guide optimal battery sizing for India

Samveg Saxena *, Amol Phadke, Anand Gopal and Venkat Srinivasan

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Electrical consumption of two-, three- and four-wheel light-duty electric vehicles in India

Samveg Saxena *, Anand Gopal, Amol Phadke

Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, United States
Emerging economies are the primary drivers of growth in demand for transportation energy.

China and India lead the way as rising incomes lead to greater desire for mobility.

China and India are eager to clean up transportation because of its major role in causing air pollution and oil import dependency.
Mitigating transportation GHGs in China and India is lower priority than other sectors like power or industry. Reasons given are:

1. Current emissions from transportation are small relative to others

2. It is too expensive to make deep reductions in transportation compared to other sectors, so let’s deal with it later
Emissions: Rapidly growing with income

Source: Dargay et al (2007)
Demand for Car ownership will explode soon in China and India

According to these projections, by 2030, Vehicle ownership per 1000 people will be:

China ~ 269 (42)
India ~ 110 (17)

Growth in transport emissions will be led by passenger LDV miles, followed closely by road freight miles

Source: Dargay et al (2007)
• Mitigating transportation GHGs in China and India is lower priority than other sectors like power or industry. Reasons given are:

1. Current emissions from transportation are small relative to others

2. It is too expensive to make deep reductions in transportation compared to other sectors, so let’s deal with it later

Improving fuel efficiency of conventional vehicles is cheap but does not offer deep reductions.

What about hybrid and electric vehicles? (H&EVs)
The light bulb moment for me
Research Questions

If we considered real world fuel efficiency what would be the energy and GHG benefits of hybrid and electric vehicles in China and India?

What do the findings imply for the economics of hybrid and electric vehicles as climate mitigation options in those countries? (Work in Progress)
Method: Powertrain Simulation Modeling

Very difficult and expensive to measure in-use FE data from cars in China and India
Driving Cycle Data

- 11 Chinese Cities and 3 Indian cities
Construct Cars in Autonomie

• Top selling car model in China and India (2011)
• Built 3 versions of the top model in Autonomie
  – Conventional vehicle as sold
  – Power-split hybrid of the same vehicle (no other changes)
  – Parallel (mild) hybrid of the same vehicle
  – Full EV version (only for Indian models)
• Since the publication of the papers we have now constructed 8 car models and 1 bus for India
Run Simulations

• We simulated each car model on each drive cycle
• Recorded instantaneous fuel efficiency, CO2 emissions per km and numerous other powertrain performance metrics
• We took a VKT-weighted average of fuel efficiency and emissions for both the conventional car and hybrid versions
• We also simulated US drive cycles and vehicles for comparison
India v US Real- World Fuel Efficiency

USA Driving
(0.55City+0.45Hwy)

Conventional vehicle vs. Prius hybrid of comparable mass

Indian driving
Maruti Alto conventional vehicle vs. hypothetical hybrid Maruti Alto

% Improvement in Fuel Consumption

0.55xUDDS + 0.45xHWFET

Pune
Delhi
India Urban
Modified Indian Drive Cycle

39.98%
47.41%
44.06%
41.44%
29.44%
20%
25%
30%
35%
40%
45%
50%
55%

Urban
Modified Indian Drive Cycle
China vs US Real-World Fuel Efficiency

% Improvement in Fuel Consumption of Hybrids over Conventional Vehicle

- Parallel ISG
- Power-split

Summary with weighted averages

USA vs China

Berkeley Lab
A deeper look at the India HEV results

**Contribution of % Imp FC for Hybrid over ICE-only vehicle from each fuel savings mechanism**

- Engine shutdown
- Regen. braking
- Optimized Eff.

<table>
<thead>
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<tbody>
<tr>
<td>UDDS</td>
<td>53.7%</td>
<td>23.3%</td>
<td>47.4%</td>
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<tr>
<td>HWFET</td>
<td></td>
<td></td>
<td>44.1%</td>
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<tr>
<td>Pune</td>
<td>47.4%</td>
<td>23.3%</td>
<td>44.1%</td>
</tr>
<tr>
<td>Delhi</td>
<td>44.1%</td>
<td>23.3%</td>
<td>44.1%</td>
</tr>
<tr>
<td>IDC Urban</td>
<td>41.4%</td>
<td>29.4%</td>
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<tr>
<td>MIDC</td>
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</tbody>
</table>

Total % Imp FC of Hybrid:
- UDDS: 53.7%
- HWFET: 23.3%
- Pune: 47.4%
- Delhi: 44.1%
- IDC Urban: 41.4%
- MIDC: 29.4%
Explaining “Optimized Efficiency”

Fuel consumption map for an engine in a small vehicle, driving in Pune, India
Lot’s of power produced far from engine optimal efficiency zone

Same engine, same drive cycle, but in a power-split hybrid
Most power produced near optimal efficiency zone for engine
BEV Simulations and Results for India

• Added more vehicle models
  – 2 wheeler
  – 3 wheeler
  – Low range BEV car (70 km range)
  – Higher range BEV car (130 km range)

• Estimated real-world fuel efficiency in terms of Wh/km

• Simulated the same vehicles on US test cycles for comparison
BEVs are much more fuel efficient in India. They yield significant GHG benefits even in the current coal intensive grid.
Research Questions

If we considered real world fuel efficiency what would be the energy and GHG benefits of hybrid and electric vehicles in China and India?

What do the findings imply for the economics of hybrid and electric vehicles as climate mitigation options in those countries? (Work in Progress)
Marginal Carbon Abatement Cost of H&EVs

• Manufacturing cost estimation of conventional vehicles, HEVs and EVs for India and China
  – Less powerful cars -> smaller battery -> lower cost
  – Lower labor costs (not likely to be a very significant effect)

• Annual VKT is expected to increase faster than the US (shortens payback time for H&EVs)

• Total abatement potential will depend on new vehicle sales growth rate (very high)

• China and India value oil demand reduction immensely

• For BEVs: Grid Marginal Carbon intensity (using PleXoS Dispatch Modeling)
### Methodology: Costs of Passenger Car BEVs (100-km./Charge Range)

Difference in manufacturing cost between 100-km. range BEVs and conventional cars (USD/vehicle).*

<table>
<thead>
<tr>
<th>Year</th>
<th>Ultracompact Hatch</th>
<th>Subcompact Hatch</th>
<th>Compact Sedan</th>
<th>Multi-Use Vehicle/Van</th>
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<tr>
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<td>$2,841</td>
<td>$2,919</td>
<td>$2,725</td>
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<td>$1,552</td>
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Thank You

Funding for this research is provided by DOE’s Office of International Affairs under the Electric Vehicle Initiative of the Clean Energy Ministerial

News

EVI Research Highlights the Potential for Electric Vehicles in India

EVs could save 4.8 billion barrels of oil, 270 million tons carbon dioxide (CO2)

Tuesday, May 20, 2014