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Understanding the Costs and Benefits of Electrification: Electrification Cost-Benefit Case Studies

Introducing the Holistic Value Test with an Application to City Buses

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How EPRI has defined Efficient Electrification

"The application of electric-powered technology as a substitute for fossil-fueled or non-energized processes at the customer premises (residential, commercial, agricultural, industrial, and government/institutional) that results in net economic benefit to the customer and net environmental benefits to society."

Evaluating the Economics of Efficient Electrification

Analyzing the cost effectiveness of electrification-focused utility investments requires a different framework from the standard analyses which focus on traditional energy efficiency programs because electrification…

1. Increases electricity consumption
2. Increases need for electricity infrastructure
3. Involves substituting electricity for natural gas, propane, gasoline and diesel
4. Can provide environmental benefits
5. Can improve quality of life and business productivity
6. Can improve system load flexibility

How the project was done – I

A series of expert interviews with organizations active in the energy efficiency space

- We talked to a dozen experts about the economics of efficient electrification
- The experts provided us a snap shot of how energy efficiency organizations, state commissions, utility trade associations, and national laboratories think about efficient electrification
- The interviews were carried out by phone and email and helped us gain unique insights on the economics of efficient electrification

How the project was done – II

We also did a careful review of the academic and trade literature on cost-effectiveness

- The literature is surprisingly voluminous
- Our summary of the literature led to some brainstorming sessions within the EPRI-Brattle team
- Through this process, we identified a set of key factors for assessing the cost effectiveness of efficient electrification investments

Key factors in considering cost-effectiveness

1. The Standard Practice Manual (SPM) provides a great starting point for considering cost-effectiveness of electrification investments but some modifications are required
2. Non-energy benefits and costs should be better researched and quantified
3. Multiple test perspectives may be needed to reach a final answer
4. Uncertainty analysis should be included in the evaluation
5. The tests need to consider the flexibility value of electrification
6. Power simulation modeling will be important for valuing electrification investments
7. Electrification pilots may provide insights into feasibility and cost-effectiveness of electrification investments
8. A “free pass” should not be given to investments simply for satisfying certain policy objectives

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Comparing traditional energy efficiency investments and efficient electrification

Energy Efficiency Program Features	Efficient Electrification Program Features	Implications for cost-effectiveness assessment of efficient electrification
Reduces electricity consumption	Increases electricity consumption	Electrification programs do not present the same risks of cost under-recovery due to a reduced electricity sales base that is observed in energy efficiency programs. Alternatively, in the case of fuel switching, electrification increases risk of rate increase for alternative fuels. Consideration of non-electric rate impacts is important in this regard.
Impacts only one fuel type	Often involves fuel switching	Cost-effectiveness analysis cannot be limited to cost implications for a single utility or fuel type; must analyze costs and benefits across industries
Provides static (i.e., non-dispatchable) energy savings	Adds potentially flexible load	The value of load flexibility must be accounted for in an assessment of the potential benefits of electrification
Provides environmental benefit when power supply mix is dirty	Provides environmental benefit when power supply mix is clean	Must account for future decarbonization of the power supply mix when evaluating environmental benefits; static assumptions are not sufficient
Reduces future need for electricity infrastructure	Increases need for electricity infrastructure; may reduce future need for alternative fuel infrastructure	Analysis must account for net change in infrastructure costs across industries, including stranded assets in non-electricity industries

Proposed Framework for Analyzing the Economics of Efficient Electrification

TRC vs. Societal Tests:

- The *total resource cost test* does not easily allow for fuel switching (the three-pronged variant is too restrictive) or consideration of non-energy impacts
- The *societal cost test* allows for such considerations but is a bit too open-ended for regulatory filings and it also leaves the door open to using a much lower "societal" discount rate which means it can pass nearly anything.

Thus, we recommend using a test that uses the same discount rate as the total resource cost test but also includes other fuels and non-energy benefits

It is a cross between the total resource cost test and the societal tests

Our working name is the *Holistic Value Test (HVT)*

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Battery Electric Bus Case Study Design

Using our proposed framework, we will analyze the costs and benefits of purchasing battery electric buses instead of diesel buses in a medium sized city

- The bus fleet for medium sized cities is around **180 buses**
- Bus lifetime is about 12 years so agency would purchase **15 buses each year**
- Average bus has to drive about **135 miles per day (50,000 miles/year)**
- Newest electric buses with 400-450 kWh battery packs can cover about **90% of existing bus routes**; so assume **1-for-1 replacement of diesel buses**
- We assume the buses will **charge at the bus depot** using DC fast chargers (~120 kW/charger) and require spare chargers (assume 2 spares / 15 buses) due to reliability concerns

Due to several significant uncertainties and regional differences, our final report will include calculations for a range of costs and benefits to demonstrate the framework

Categories of Cost/Benefit Considered

Following the proposed framework, analyzing the cost effectiveness of city buses requires considering the following types of costs and benefits

Cost/Benefit Type	Subcategories
Total Cost of Ownership	• **Vehicle and battery costs, replacement ratios, and lifespan** • **Fuel costs** and cost volatility • **Maintenance costs** • **Charging infrastructure costs** • Revenue generated by grid (V2G) services
Environmental Externalities	• **Greenhouse gas emissions** • **Other air pollutant emissions** • Other public health impacts • Noise pollution
System Impacts of Increased Load	• **Local distribution upgrades** • **Impacts on system peak load** • Added grid flexibility • Impact on electricity rates (savings to ratepayers)
Additional Considerations	• Driver health/wellbeing • Customer benefits • Disaster relief • Energy security from reduced imports

Note: **Bold** items are quantified in this case study.

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Electric Bus Cost Effectiveness Results

Electric buses cost slightly more than diesel buses from the perspective of the transit agency, but they are cost-effective when viewed from the perspective of the Holistic Value Test. Below are the costs and benefits for the 12 year lifespan of 15 buses in a medium sized city.

NPV of Costs and Benefits (2018 $)	Participant Test (Transit Agency)	Holistic Value Test (HVT)
Costs		
Capital Costs	+ $5.4 million	+ $5.4 million
System Upgrade Costs	---	+ $0.5 million
Benefits		
Fuel Cost Savings	- $3.5 million	- $4.4 million
Maintenance Cost Savings	- $1.0 million	- $1.0 million
Avoided GHG Emissions Impacts	---	- $0.5 million
Avoided Air Pollutant Impacts	---	- $6.2 million
Total Quantified	**+ $0.9 million**	**- $6.2 million**
Non-Quantified	Potential flexibility value and revenues, improved customer experience, reduced noise pollution, mobile emergency electricity supply services	

Sources and Notes: We assume a 8% discount rate for calculating PV of annual costs over 12 year lifetime. Based on current costs for buses, battery packs, and fuel. Assume $50/ton cost of GHG emissions. Air pollutant costs based on estimates for diesel, coal and gas emissions in Shindell, The social cost of atmospheric release, Climatic Change, 130:313-326.

Additional Non-Quantified Benefits

- Electricity prices tend to be less volatile than diesel prices, so will decrease the **fuel cost volatility** for transit agencies
- Electric buses may provide some additional **flexibility value** to the system during the overnight hours (0-4 hours) in which it is not charging; but likely small due to limited need during low load hours
- Flexibility benefits of electrifying bus fleets is likely much higher for school buses that run in the morning and afternoon, but are available mid-day and evening hours
- Electric buses are much **quieter** and **cleaner** than diesel buses and have **smoother acceleration**, which will decrease urban noise pollution and improve the customer experience
- Electric buses can provide cities mobile **emergency electricity supply** during disaster events that can alleviate the impact on high-value demand, such as hospitals and nursing homes

Appendix on Electric Buses

Ownership Costs

Higher capital expenditures for purchasing electric buses (~$300k higher) are offset by lower fuel and maintenance costs

- Battery pack accounts for about $200k of the higher costs
- Each bus will require an 120 kW DC charger (plus a few spares)
- Maintenance costs are 20% lower due to simpler engine, lack of oil changes, and reduced break repairs

Component	Electric Bus	Diesel Bus	Difference
Vehicle Costs	$750,000/bus x 15 buses **= $11.25 million**	$450,000/bus x 15 buses **= $6.75 million**	**+$4.5 million** (+$550,000/year)
Charging Infrastructure	15 chargers (plus 2 spare) X $50k/charger **= $0.9 million**	No incremental costs	**+$0.9 million** (+$110,000/year)
Fuel Costs	750,000 miles/year x 2 kWh/mile x 15 c/kWh **= $225,000/year**	750,000 miles/year x 0.25 gal/mile x $3.50/gal **= $650,000/year**	**-$3.5 million** (-$425,000/year)
Operating & Maintenance Costs	$30,000/year/bus x 15 buses **= $450,000/year**	$38,000/year/bus x 15 buses **= $570,000/year**	**-$1.0 million** (-$120,000/year)

Notes: We assume a 8% discount rate for calculating PV of annual costs over 12 year lifetime.

Emissions and Local Health Benefits

We quantified the benefits of avoided GHG and other air pollutant emissions of adopting electric buses

- Benefits will depend on electricity generation mix in each locality; in the table below we assume 50% coal, 25% gas, and 25% clean based on Midwest generation mix
- The primary benefit is the reduction in local air pollutants and their local health impacts
- Reduced GHG emissions valued at $50/ton based on Social Cost of Carbon estimates; can be key piece of cities achieving GHG emission reduction goals

Component	Electric Bus	Diesel Bus	Difference
GHG Emissions	1,500 MWh/year x 0.6 tons/MWh = 900 tons/year x $50/ton **= $45,000/year**	190,000 gal/year x 0.011 tons/gal = 2,100 tons/year x $50/ton **= $105,000/year**	**-$0.5 million** (-$60,000/year, -1,200 tons/year)
Other Air Pollutant Emissions	1,500 MWh/year x $90/MWh **= $135,000/year**	190,000 gal/year x $4.75/gal **= $903,000/year**	**-$6.2 million** (-$768,000/year)

Notes: We assume a 8% discount rate for calculating PV of annual costs over 12 year lifetime.

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System Impacts

Adding 15 electric buses will increase load at the depot by 1.8 MW during overnight hours

- There are likely to be limited system-level upgrades necessary due to adding load during off-peak hours
- Some local, site-specific upgrades on the distribution feeders and at the depot may be necessary to meet the nightly spike in load

We include an estimate of these costs in the Holistic Value Test, but not the participant test (assuming they will be rate-based by the utility)

- For the *participant test*, we assume the agency will pay the whole retail rate but will not be charged for local system upgrades
- For the *HVT test*, we assume that generation costs account for 50% of the rate and that 25% will serve as a proxy for the costs of local system upgrades

Ratepayers are likely to benefit from decreased rates as cost recovery for fixed cost assets will be spread over more kWhs, slightly offset by any necessary upgrades

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Electricity Rate and System Upgrade Assumptions

- Participant Test Fuel Costs for Electric Bus = 100% of retail electricity rate
- Holistic Value (Efficient Electrification) Test Fuel Costs = 50% of retail electricity rate as a proxy for generation costs
- System Upgrade Costs = 25% of retail electricity rate as a proxy of additional costs incurred to service additional load at bus depot

Presenter Information

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Ahmad's consulting practice is focused on the efficient use of energy. His areas of expertise include rate design, demand response, energy efficiency, distributed energy resources, advanced metering infrastructure, plug-in electric vehicles, energy storage, inter-fuel substitution, combined heat and power, microgrids, and demand forecasting. He has worked for nearly 150 clients on 5 continents, including electric and gas utilities, state and federal commissions, independent system operators, government agencies, trade associations, research institutes, and manufacturing companies. Ahmad has testified or appeared before commissions in Alberta (Canada), Arizona, Arkansas, California, Colorado, Connecticut, Delaware, the District of Columbia, FERC, Illinois, Indiana, Kansas, Maryland, Minnesota, Nevada, Ohio, Oklahoma, Ontario (Canada), Pennsylvania, ECRA (Saudi Arabia), and Texas. He has presented to governments in Australia, Egypt, Ireland, the Philippines, Thailand and the United Kingdom and given seminars on all 6 continents. His research has been cited in *Business Week*, *The Economist*, *Forbes*, *National Geographic*, *The New York Times*, *San Francisco Chronicle*, *San Jose Mercury News*, *Wall Street Journal* and *USA Today*. Ahmad has appeared on Fox Business News, National Public Radio and Voice of America. He is the author, co-author, or editor of 4 books and more than 150 articles, papers, and reports on energy matters. He has published in peer-reviewed journals such as *Energy Economics*, *Energy Journal*, *Energy Efficiency*, *Energy Policy*, *Journal of Regulatory Economics* and *Utilities Policy* and trade journals such as *The Electricity Journal* and the *Public Utilities Fortnightly*. He is on the editorial board of *The Electricity Journal*. He holds B.A. and M.A. degrees from the University of Karachi, an M.A. in agricultural economics and Ph.D. in economics from the University of California at Davis.