The Total Value Test (TVT) for Assessing Electrification Programs

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THE Brattle GROUP

Electrification differs from traditional energy efficiency in many ways

Electrification …

1. Increases electricity consumption
2. Increases need for electricity infrastructure
3. Involves substitution of fossil fuels with electricity
4. Can provide environmental benefits
5. Can improve quality of life and business productivity
6. Can improve system load flexibility

By reworking two of the existing cost-benefit tests, we have created a test suited to the unique features of electrification

In theory, the Total Resource Cost (TRC) allows for fuel substitution but in practice it was rarely used for that purpose because the three-pronged test (now modified by the CPUC) got in the way; furthermore, the TRC test did not consider non-energy benefits and costs

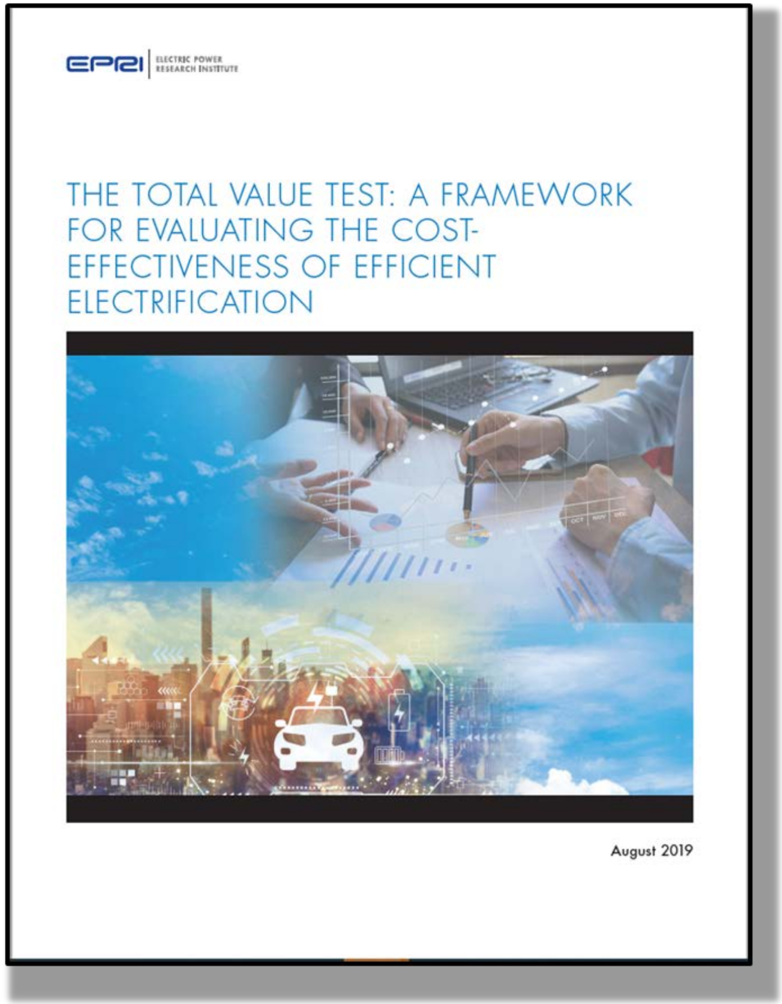
The Societal test considered non-energy benefits and costs but opened the door to using a really low discount rate which got in the way of its practical applications in regulatory hearings

Thus, EPRI and Brattle have created The Total Value Test (TVT) which allows for non-energy benefits and costs to be included without using a lower discount rate; the TVT also allows for fuel-substitution to be considered

The use of the TVT has been illustrated through three case studies

- Battery Electric City Buses
- Indoor Agriculture
- Electric Water Heating (Grid-integrated resistance heating and electric heat pump)

The details are provided in this EPRI report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THE TOTAL VALUE TEST: A FRAMEWORK FOR EVALUATING THE COST-EFFECTIVENESS OF EFFICIENT ELECTRIFICATION

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Available to download at www.epri.com

Appendix

Battery Electric City Buses

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

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 Economics of Efficient Electrification (EEE) 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)	Economics of Efficient Electrification (EEE) Test
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	

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

Indoor Agriculture Case Study

Indoor Agriculture Case Study Design

Using our proposed framework, we will analyze the costs and benefits of growing organic spinach in an indoor farm under LED lights rather than on a traditional outdoor farm.

- We estimate the total farm-to-store cost of 5,000 pounds of spinach per week for consumers in Denver, CO.
- Outdoor scenario – a 13 acre farm in the California central coast
- Indoor scenario – a 10,000 sq. ft. warehouse in the Denver metro area
- Indoor farming requires far more electricity in order to grow crops in a climate controlled, artificially lit environment
- The financial and environmental costs of this electricity are offset by reduced land use, reduced water consumption, and shorter transport distances

Categories of Cost/Benefit Considered

Following the proposed framework, analyzing the cost effectiveness of indoor agriculture requires considering the following types of costs and benefits:

Cost/Benefit Type	Subcategories
Costs of Production	• Electricity costs • Water costs • Land costs • Transportation costs (fuel, wages, maintenance) • Other fuel costs (farm equipment) • Labor costs • Other capital costs (equipment and warehouse) • Fertilizer use and application • Land maintenance costs (weeding, tilling, crop cycling)
Environmental and Human Health Externalities	• Greenhouse gas (GHG) emissions • Other air pollutant emissions • Public health impacts • Environmental/agricultural damages • Groundwater depletion and salt Intrusion • Fertilizer runoff effects • On-road accidents (shipping) • Noise pollution (shipping)
System Impacts of Increased Load	• Local distribution upgrades • Impacts on system peak load
Additional Considerations	• Reduced food waste/loss along supply chain • Fresher and more nutritious produce • Year-round availability of seasonal crops • Reduced susceptibility to disease and inclement weather

Indoor Agriculture Cost Effectiveness Results

In this case, under the assumption of a highly efficient indoor farm and relatively coal-intensive electricity generation, the indoor farm has higher external costs than the outdoor farm, but a lower Total Value Test Cost due to savings in land rent, water cost, and transportation costs.

5,000 lbs/week spinach farm	Annual Cost			Cost per Pound (Delivered)		
	Indoor Farm	Outdoor Farm	Difference	Indoor Farm	Outdoor Farm	Difference
Electricity Cost	$23,000	$0	$23,000	$0.16	$0.00	$0.16
Land Rent Cost	$18,600	$34,000	-$15,400	$0.13	$0.24	-$0.11
Water Cost	$2,000	$9,900	-$7,900	$0.01	$0.07	-$0.06
Transportation Cost	$500	$33,300	-$32,800	$0.00	$0.24	-$0.23
On-site Diesel Cost	$0	$8,700	-$8,700	$0.00	$0.06	-$0.06
CO2 Related Damages	$2,300	$1,000	$1,300	$0.02	$0.01	$0.01
Non-Carbon Externalities	$35,400	$22,600	$12,800	$0.25	$0.16	$0.09
Total	**$81,700**	**$109,400**	**-$27,700**	**$0.58**	**$0.77**	**-$0.20**

Note: Per-pound values are per pound of spinach that reaches the consumer, assuming 46% of harvested spinach is lost or wasted along the supply chain. Electricity rates reflect the average of 2018 commercial and industrial rates for the Mountain and Pacific regions, based on EIA projections. Diesel costs are reflective of the on-farm delivery of red dye (off-road) diesel in the central coast region. We assume the current generation mix for PG&E and Xcel Energy Colorado.

Additional Non-Quantified Benefits

- **Nutritional Value:** More locally grown produce will increase the nutritional value of leafy greens like spinach because nutritional value tends to decrease with increased time between harvesting and consumption.
- **Additional Benefits of Reduced Water Demand:** The reduction in water demand could have greater benefits in regions that are experiencing extreme drought conditions. The reduced water demand will also limit salt intrusion of existing water supplies.
- **Reduced Fertilizer Run-off:** The environmental impact of fertilizer run-off are well documented but are very specific to the conditions of the local terrain and waterways.
- **Food Security:** Indoor farming could also increase food security by reducing the potential for disease outbreak through the food supply and reducing food imports.

Electric Water Heating Case Study

Electric Water Heating Case Study Design

Three types of residential water heaters considered:

- Natural Gas Water Heater
- Heat Pump Water Heater
- Grid Interactive Electric Resistance Water Heater

Three main costs considered:

- Cost of electricity relative to natural gas
- Value of load flexibility (frequency regulation)
- CO_2 emissions

Electric Water Heating Cost Effectiveness Results

Based on regional and case-specific differences in fuel costs, CO_2 content of marginal electricity generation, and flexibility value, there is no clear winner across all scenarios.

		CO2 content of marginal electricity generation (tons/MWh)											
	Off-Peak	1.0	1.0	0.8	0.8	0.6	0.6	0.4	0.4	0.2	0.2	0.0	0.0
	Peak	1.2	1.0	1.2	0.8	1.0	0.6	0.8	0.4	0.6	0.2	0.4	0.0
Electricity Cost ($/kWh)	**Flexibility Value** ($/kW-yr)												
High Cost Peak = $0.07 Off-Peak = $0.05	20	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	40	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	60	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	80	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
	100	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Moderate Cost Peak = $0.05 Off-Peak = $0.03	20	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	40	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	60	NG	NG	NG	NG	NG	NG	NG	HP	HP	HP	HP	HP
	80	NG	NG	NG	NG	NG	NG	GI	GI	GI	GI	GI	GI
	100	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
Low Cost Peak = $0.03 Off-Peak = $0.01	20	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
	40	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP
	60	HP	HP	HP	HP	HP	HP	GI	HP	GI	GI	GI	GI
	80	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI
	100	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI	GI

NG	= Natural Gas Water Heater
HP	= Heat Pump Water Heater
GI	= Grid Interactive Electric Resistance Water Heater

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.

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 EEE 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 *EEE 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

Electricity Rate and System Upgrade Assumptions

- Participant Test Fuel Costs for Electric Bus = 100% of retail electricity rate
- 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

Appendix on Indoor Agriculture

Water and Energy Costs

Indoor Scenario

- Electricity for lighting and HVAC – 365 MWh per year
  - Assume electricity rate of 8.4 cents/kWh
  - Assume that 75% of that rate reflects costs (the remaining 25% are a transfer payment to utility and other ratepayers).
  - Costs $23,000 per year
- Diesel for shipping – 50 gallons per year (costs included in marginal shipping cost)
- Water for irrigation – 18 acre-inches (480,000 gallons) per year
  - Costs $2,000 per year at a price of $111 per acre-inch for Denver municipal water

Outdoor Scenario

- Diesel for farm equipment - 3,000 gallons per year at $2.86 per gallon costs $9,000 per year
- Diesel for shipping – 3,000 gallons per year (costs included in marginal shipping cost)
- Water for irrigation – 350 acre-inches (10 million gallons) per year
  - 8 MWh per year to pump from a depth of 120 feet with pump efficiency of 48%
  - Costs $10,000 per year at a price of $27 per acre inch

Land and Transportation Costs

Indoor Scenario

- Land use - 10,000 sq. ft. warehouse on a 25,000 sq. ft. lot in the Denver metro area
- Land rent cost - $19,000 per year based on an assumed rental rate of $27,000 per acre per year
- Shipping costs - $500 per year based on a marginal shipping rate of $1.59 per truck-mile and a shipping distance of 20 miles

Outdoor Scenario

- Land use - 13 acre farm in the California central coast region
- Land rent cost - $34,000 per year based on an assumed rental rate of $2,400 per acre per year
- Shipping costs - $33,000 per year based on a marginal shipping rate of $1.59 per truck-mile and a shipping distance of 1,300 miles

Externalities

Indoor Scenario

- Release of criteria air pollutants
  - $50,000/year from electricity used for lighting and HVAC
  - $130/year from shipping
- Carbon emissions - $3,000/year (230 tons/year at $14/ton)

Outdoor Scenario

- Release of criteria air pollutants
  - $14,000/year from diesel consumed on-farm
  - $50/year from electricity used to pump groundwater
  - $8,000/year from shipping
- Carbon emissions - $1,000/year (70 tons/year at a cost of $14/ton)

Appendix on Electric Water Heating

Assumptions

- Purchase of a water heater for a new, single-family home
- Electricity costs
  - Marginal electricity costs have an average peak-to-off-peak price differential of \$20/MWh and range from \$30/MWh (peak) and \$10/MWh (off-peak) at the lower end to \$70/MWh (peak) and \$50/MWh (off-peak) at the upper end
  - Non-fuel portion of electricity price is assumed \$.07/kWh
- Natural gas prices
  - In all cases, the natural gas price is held constant at \$0.40 per therm
  - Non-fuel portion of natural gas price is assumed \$.60 per therm
- Value of load flexibility - The value of load flexibility ranges from \$20/kW-yr to \$100/kW-yr consistent with observed frequency regulation prices
- CO_2 emissions rate
  - Electricity – ranges from 0 to 1.2 tons/MWh (typical coal plant)
  - Natural gas – 0.0053 tons/therm

Assumptions

- Water heater cost
  - Natural gas - $1,300
  - Heat pump - $1,800
  - Grid interactive - $1,900
- Peak period is defined as 10 AM to 10 PM
- Assumed typical use
  - Natural gas
    - 250 therms of natural gas/year
  - Grid interactive resistance
    - 4,000 kWh/year, all in off-peak period
    - Max load of 4.5 kW
  - Heat pump
    - 2,000 kWh/year, split evenly between peak and off-peak period

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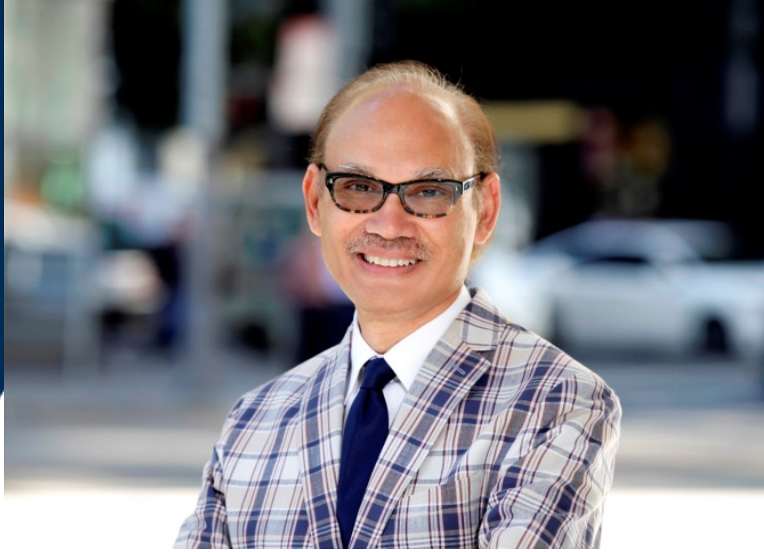

Ahmad's consulting practice is focused on the efficient use of energy. His areas of expertise include electrification, rate design, demand response, energy efficiency, distributed energy resources, advanced metering infrastructure, energy storage, inter-fuel substitution, combined heat and power, microgrids, 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.

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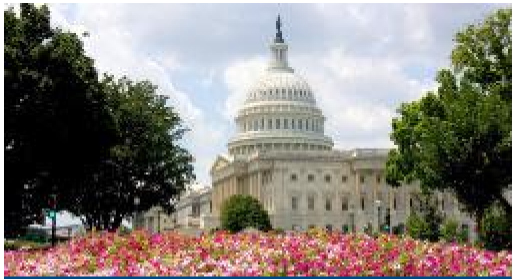

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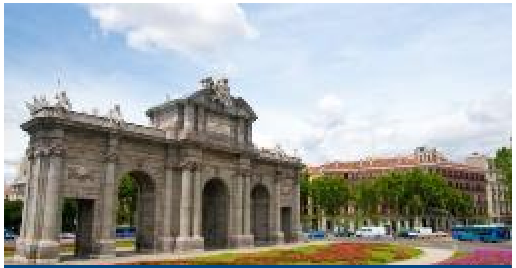

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