The Los Angeles 100% Renewable Energy Study

# Chapter 12. Synthesis

**FINAL REPORT: LA100—The Los Angeles 100% Renewable Energy Study**

March 2021

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Los Angeles Department of Water & Power
NREL Transforming ENERGY

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Los Angeles Department of Water & Power

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# Context

The Los Angeles 100% Renewable Energy Study (LA100) is presented as a collection of 12 chapters and an executive summary, each of which is available as an individual download.

- The **Executive Summary** describes the study and scenarios, explores the high-level findings that span the study, and summarizes key findings from each chapter.
- **Chapter 1: Introduction** introduces the study and acknowledges those who contributed to it.
- **Chapter 2: Study Approach** describes the study approach, including the modeling framework and scenarios.
- **Chapter 3: Electricity Demand Projections** explores how electricity is consumed by customers now, how that might change through 2045, and potential opportunities to better align electricity demand and supply.
- **Chapter 4: Customer-Adopted Rooftop Solar and Storage** explores the technical and economic potential for rooftop solar in LA, and how much solar and storage might be adopted by customers.
- **Chapter 5: Utility Options for Local Solar and Storage** identifies and ranks locations for utility-scale solar (ground-mount, parking canopy, and floating) and storage, and associated costs for integrating these assets into the distribution system.
- **Chapter 6: Renewable Energy Investments and Operations** explores pathways to 100% renewable electricity, describing the types of generation resources added, their costs, and how the systems maintain sufficient resources to serve customer demand, including resource adequacy and transmission reliability.
- **Chapter 7: Distribution System Analysis** summarizes the growth in distribution-connected energy resources and provides a detailed review of impacts to the distribution grid of growth in customer electricity demand, solar, and storage, as well as required distribution grid upgrades and associated costs.
- **Chapter 8: Greenhouse Gas Emissions** summarizes greenhouse gas emissions from power, buildings, and transportation sectors, along with the potential costs of those emissions.
- **Chapter 9: Air Quality and Public Health** summarizes changes to air quality (fine particulate matter and ozone) and public health (premature mortality, emergency room visits due to asthma, and hospital admissions due to cardiovascular diseases), and the potential economic value of public health benefits.
- **Chapter 10: Environmental Justice** explores implications for environmental justice, including procedural and distributional justice, with an in-depth review of how projections for customer rooftop solar and health benefits vary by census tract.
- **Chapter 11: Economic Impacts and Jobs** reviews economic impacts, including local net economic impacts and gross workforce impacts.
- **Chapter 12: Synthesis** (this chapter) reviews high-level findings, costs, benefits, and lessons learned from integrating this diverse suite of models and conducting a high-fidelity 100% renewable energy study.

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# 1 Learnings from a Holistic Approach to 100% Renewable Energy Planning: Costs, Benefits, and Other Tradeoffs

To understand the implications for costs, benefits, and other factors in achieving a 100% renewable energy supply, the LA100 study captures many changes—electricity demand, customer solar, renewable energy investments and operations, distribution grid upgrades, greenhouse gas (GHG) emissions, air quality and public health benefits, distributional justice of benefits, jobs, and economic impacts. Importantly, the study identifies key trends that are common to all paths to 100% renewable electricity and highlights where the scenarios differ.

On the road to achieving 100% renewables by 2045, all LA100 scenarios include significant deployment of renewable and zero-carbon energy by 2035, accounting for 84%–100% of energy[1] and a decline of 76%–100% GHG emissions from power plant operations in 2035 compared to 2020, depending on the scenario. Each of the scenarios builds new wind, solar, batteries, and transmission, coupled with operational practices that make more efficient use of these investments.

By 2045, electricity demand (both annual consumption and peak demand) is likely to grow. High levels of energy efficiency can offset this growth in the buildings sector due to hotter climate, population growth, and electrification. It is the electrification of the transportation sector that propels overall growth in electricity demand, due in large part to electric vehicle (EV) charging (Figure 1).

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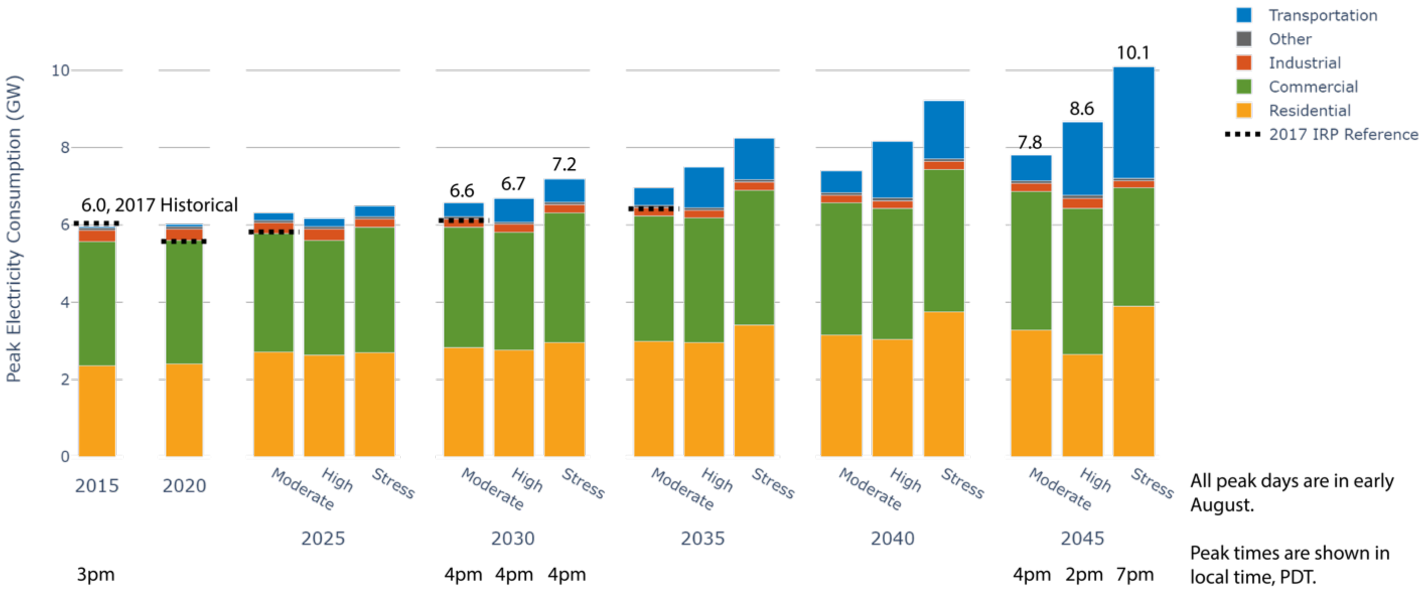
[1] In comparison, by 2035 the 2017 IRP generates 77% of electricity using renewable and zero-carbon resources.



All peak days are in early August.

Peak times are shown in local time, PDT.

**Figure 1. Peak electricity consumption by sector and customer demand projection**

Based on customer demand at the meter and not including losses. Totals are also prior to shifts in timing due to customer demand flexibility.

Also by 2045, with the incentives evaluated in the study, customers are likely to drive significant growth in rooftop solar: 3–4 GW, including up to a third of customers in existing single-family homes, based on favorable economics to the customer (Figure 2). LADWP might also deploy an additional 300–1,000 MW of non-rooftop, in-basin solar. The distribution grid can manage this growth in local solar—along with the projected growth in electricity demand. While almost all parts of the distribution grid will need some upgrades, the LA100 study estimates that, after correcting deferred maintenance on the existing system, a modest number of equipment upgrades would be sufficient to manage growth in demand and local solar. These distribution upgrade costs represent a small fraction of the total cost of the clean energy transition.

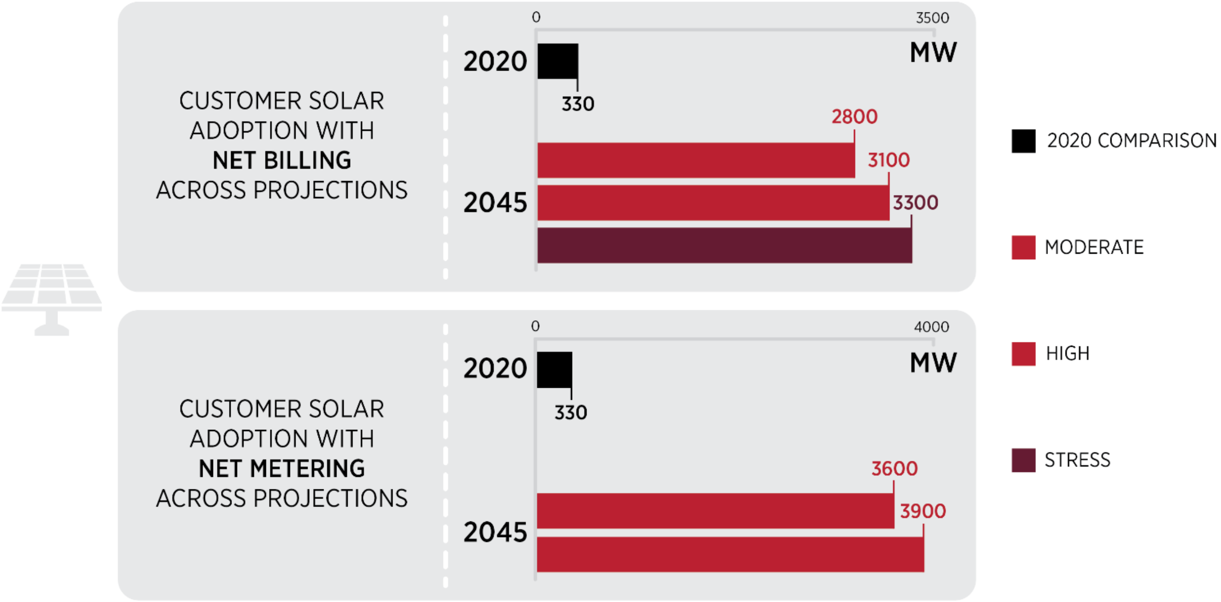
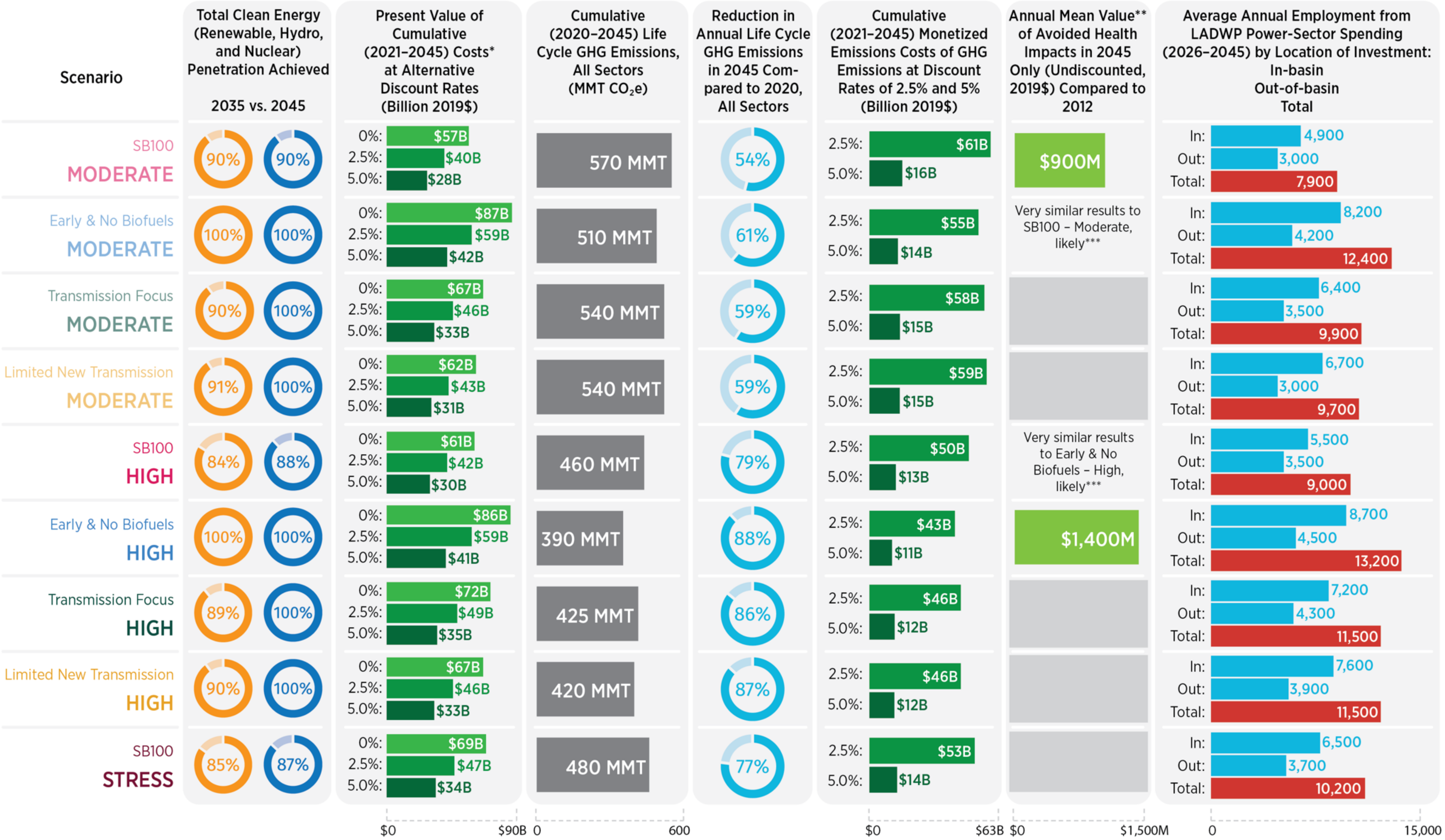


**Figure 2. Comparison of customer solar capacity for net billing projections (left) and net metering projections (right) in 2045 by customer demand projection**

Electrification of vehicles and buildings leads to substantial improvements in air quality and associated benefits to health—widespread across both disadvantaged and non-disadvantaged communities. LA100's results indicate that realizing these health benefits is principally a matter of achieving high energy efficiency and electrification, independent of any particular renewable energy pathway for the power sector. Also regardless of the pathway, economic impacts to the city of the 100% renewable energy transition are projected to be small relative to the overall size of LA's economy—so while the transition could create thousands of clean energy jobs annually, the clean energy investments alone are not anticipated to notably impact LA's economy overall.

Figure 3 compares scenarios along metrics representing some of the costs and benefits analyzed in the study.



*Costs, as measured in the study, represent costs of expanding and operating of the power system from 2021. Present values calculated with a discount rate of 0% are equivalent to an undiscounted value.
**95% confidence interval of values of avoided health impacts in 2045 compared to 2012 is SB100 – M is (-$480M–$3,000M) and of Early & No Biofuels – H is (-$470M–$4,400 M).
***Because the contribution to emissions reductions from the power sector is small (ranging from 0.8%–1% for NOx among LA100-evaluated reductions), it is reasonable to qualitatively estimate the results stated.

**Figure 3. Comparison of scenarios across select metrics analyzed in LA100**

SB100 scenarios allow natural gas generation if offset by renewable electricity credits and to cover losses on the system. “Life cycle” GHG emissions consider all phases of both the generation facility and its fuel: plant construction; plant operation including fuel combustion (if applicable) and other O&M as well as emissions from the acquisition, treatment, and transport of fuels, when applicable; and finally plant decommissioning and disposal. Air quality modeling and associated health impacts were conducted for only four scenarios (SB100 – Moderate and High and Early & No Biofuels – Moderate and High). The global costs of GHG emissions are monetized ($2019) based on the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG, 2017). The IWG provides estimates at three discount rates, which represent the relationship between future impacts and present-day dollar values.

## 1.1 Major Trends Across all Pathways to 100%

### 1.1.1 Reliable, 100% renewable electricity is achievable—and, if coupled with electrification of other sectors, provides significant greenhouse gas, air quality, and public health benefits.

While achieving a reliable, 100% renewable electricity power system is a significant undertaking requiring substantial investments, the LA100 analysis identifies multiple pathways to get there. Wind and solar resources—enabled by storage—are fundamental to providing the majority of energy required to meet future load: 69%–87% depending on the scenario. New in-basin, renewable firm capacity—resources that use renewably produced and storable fuels, can come online within minutes, and can run for hours to days—will become a key element of maintaining reliability (represented in Figure 4 as hydrogen- and renewably [RE]-fueled combustion turbines and fuel cells).

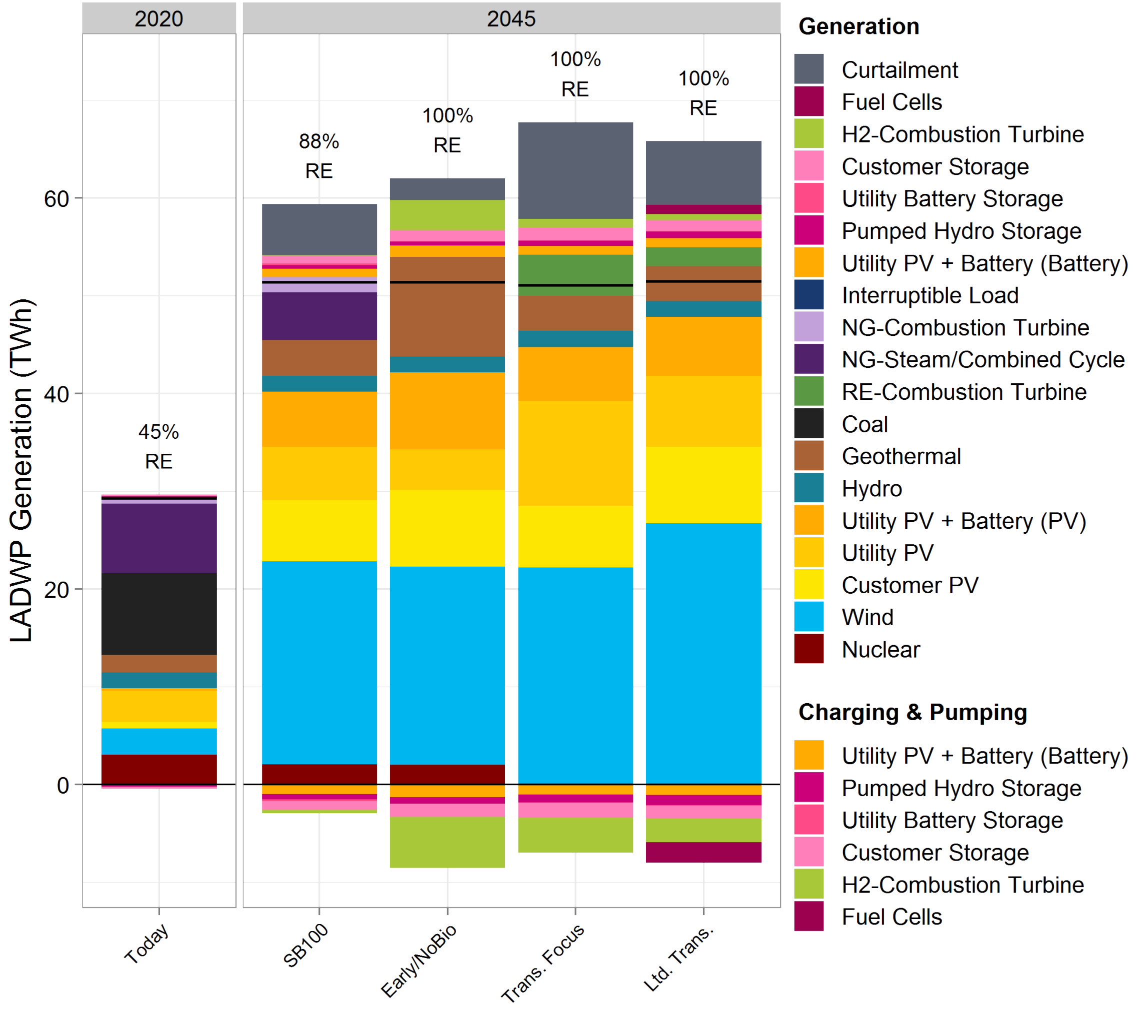


**Figure 4. Annual generation mix in 2045 for all High load scenarios compared to 2020**

The percent RE refers to percent of generation that is carbon neutral (renewable and nuclear). Negative values indicate the amount of electricity consumed by the plants (e.g., to charge a battery, pump hydro, or produce hydrogen fuel). Load (solid line) is customer electricity consumption exclusive of charging. Curtailment includes available energy that is curtailed to provide reserves.

Decarbonizing the power sector through renewable deployment helps create the enabling conditions for decarbonization of the buildings and transportation sectors through electrification. While the power sector itself contributes few non-GHG air pollutant emissions in a 100% renewable future, the electrification of combustion sources in other sectors enables more significant emissions reductions, and thus improved health for Los Angeles residents.

**Customer-oriented actions** that help complement a renewable energy transition include:

**Energy efficiency** → helps offset climate- and electrification-driven load growth and potentially higher electricity rates; lowers energy burden for low-income residents

**Greater electrification** → contributes to higher public health and GHG benefits; helps reduce per-unit electricity costs

**Customer demand flexibility** → helps contain costs of adding electrification and achieving 100% renewable energy; also supports reliability

### 1.1.2 All communities will share in the benefits of the clean energy transition—but improving equity in participation and outcomes will require intentionally designed policies and programs.

Disadvantaged communities (as defined by CalEnviroScreen scores) could expect to see many benefits in a clean energy transition, including reduced local and regional air pollution, improved indoor air quality from electrification, reduced vulnerability to climate change, and improved health outcomes.

Ensuring prioritization of these neighborhoods, however, is not an inevitable result of the power-system transition. A just, equitable clean energy future would require intentionally designed decision-making processes and policies/programs that prioritize these communities (see the text box on the next page).

### Examples of Actions to Support Prioritization of Environmental Justice

**Participation in decision-making**: Identifying barriers to procedural justice can inform improvements to who is included in decision-making, how decisions get made, and what resources are needed to enable parity of participation.

**Energy infrastructure**: LA100 shows strong potential for electrification, efficiency, demand response, and rooftop solar in disadvantaged communities—but the modeling does not capture real-world experiences and barriers to adoption. Actions to prioritize environmental justice include:

- Improved data collection and modeling on characteristics that could inform the design and evaluation of electrification, efficiency, demand response, and solar programs (e.g., differences in household size, appliance age, mobility options, access to smart energy devices)
- More comprehensive representation of benefits (e.g., indoor air quality, improved resilience to extreme weather events with energy efficiency upgrades)
- Policy designs that target barriers to these programs and related concerns (e.g., the potential for prioritization of benefits to lead to gentrification; impact of stranded costs on low-income customers who do not electrify or adopt rooftop solar; barriers specific to renters)
- Metrics for success and process for course-correction established in collaboration with stakeholders. One gap in environmental justice metrics is a method to align forward-looking modeling with retrospective-based tools such as CalEnviroScreen. While CalEnviroScreen scores are useful as benchmarks, there is a need to evaluate options for their potential future effects prior to implementation. Aligning forward-looking models with CalEnviroScreen metrics can enable flagging of potential deficiencies and the creation of optimal solutions toward improvement within the recognized CalEnviroScreen framework, as well as tracking of progress with granularity and frequency not now available through CalEnviroScreen.

**Jobs**: Identifying workforce needs for each energy technology identified in the study has important implications for potential future hiring and training needs. The City of LA could facilitate programs for in-demand occupations that may be hard to fill and for other high-quality jobs. The City of LA could also include in clean energy program design some of the workforce objectives sought by the community. For example, some have requested solar installations within disadvantaged communities as a way to support clean energy jobs that do not require long commutes.

**Maintaining support for electrification**: Electrification of transportation, building end uses, and the Ports of Los Angeles and Long Beach provide significant air quality and related public health benefits. Hence, a prioritization of disadvantaged communities as first immediate beneficiaries of localized air quality improvements would include a focus on electrification. But electrification can be hindered by increasing electricity rates. Toward the end of the 100% renewable energy transition, the cost of fully decarbonizing the power sector, if reflected in increased rates, could lead to public pressure to reduce the pace of electrification. Further analysis could consider options that maintain decarbonization and improved health as a goal, but with a better understanding of the interaction among the costs of power system decarbonization, pace of electrification, and rate design.

**Neighborhood-level health impacts**: Quantifying neighborhood-level impacts could be an important component of further analysis after LA100 with regard to achieving outcomes beneficial to disadvantaged communities. For example, the design and evaluation of any EV incentives could be coupled with analysis of local air quality benefits, especially in neighborhoods along roadways that suffer high local pollution. As another example, LA100 results suggest value to reliability in building new, state-of-the-art combustion turbines at current thermal generating station sites fueled by renewable-electricity-derived fuels (such as hydrogen) and operated less frequently compared to natural gas today. One step that LADWP and the City of LA can consider to prepare for this change is to establish expectations of anticipated neighborhood environmental impacts (based on local-scale air quality modeling), monitor these impacts, and revise operating protocols as needed.

### 1.1.3 Net economic assessment shows that achieving the LA100 scenarios will not affect LA’s overall economy in any meaningful manner.

Using SB100 – Moderate as a reference scenario, the net impact to employment within the city (reflecting combined positive and negative impacts of economic activity measured in LA100, from 2026 to 2045) ranges from a low of 3,600 fewer jobs annually under the Early & No Biofuels – Moderate scenario to 4,700 additional jobs under the SB100 – Stress scenario. While there may be slight positive or negative impacts, these changes are small in relationship to the 3.9 million jobs and $200 billion in annual output of LA’s economy as a whole, so they have an almost negligible impact.

Specific to jobs associated with LADWP expenditures as measured in LA100, both in and outside of the LA Basin, higher expenditures on new infrastructure and operations of both existing and new infrastructure (exclusive of the distribution grid) correlate with higher numbers of jobs. The number of gross annual jobs (onsite and ripple effect) supported by these expenditures ranges from an average of 7,900 jobs per year in SB100 – Moderate to 13,200 jobs per year in Early & No Biofuels – High.

### 1.1.4 LA can get started now, with many no-regrets options that achieve significant emissions reduction (76%–99%) by 2030.

The LA100 study finds many no-regrets options. On the customer side, the study shows significant benefits from electrification in terms of improving GHG emissions, air quality, and health, and emphasizes the critical role of customer demand flexibility to reduce per-unit electricity costs and contribute to reliability.

When it comes to the LADWP power system, the no-regrets options include new wind, solar, batteries, and transmission—deployed in or out of the LA Basin and coupled with smart-grid operational practices that make more efficient use of these investments. Figure 5 illustrates these no-regrets options, including the minimum amount of new capacity for wind, solar, storage, and in-basin renewably or hydrogen-fueled combustion turbines added across all scenarios by 2045. LADWP can also address existing distribution maintenance needs to enable changes on the customer side, which were assumed to have already occurred as the starting point for LA100.

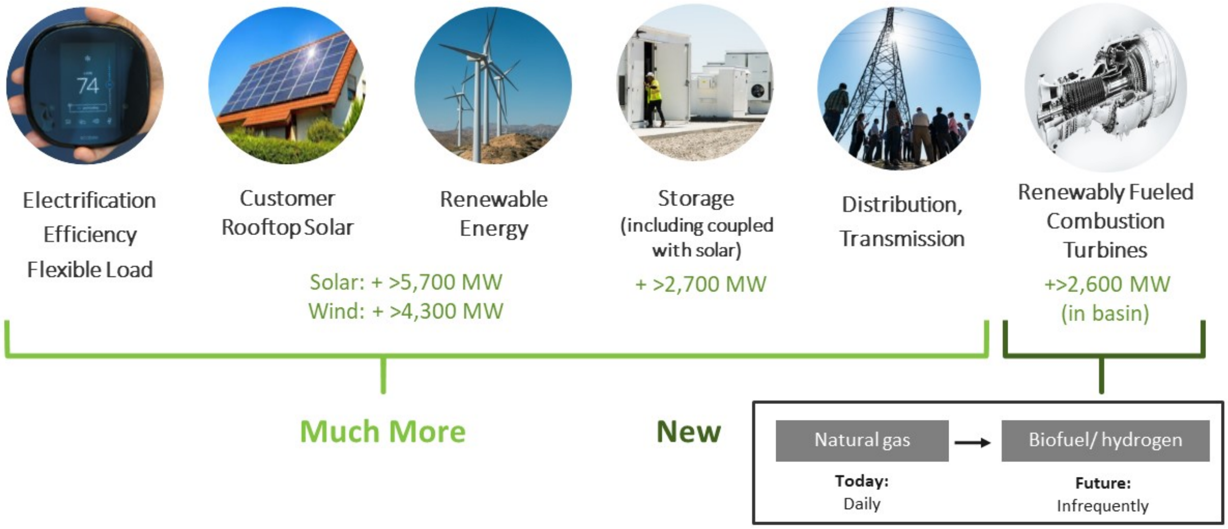


**Figure 5. No-regrets options on the path to 100% renewable energy**

## 1.2 Key Distinctions Between Pathways to 100%

### *1.2.1 The LA100 scenarios show similar cost increases until approximately 80%–90% renewable energy. The pathways diverge with differences in the technologies deployed to meet the last 10%–20% of energy demand that cannot be easily served by wind, solar, and conventional storage technologies—and to maintain reliability in the face of extreme events.*

In-basin renewable capacity that can come online within minutes and run for days serves a critical role: it provides energy during periods of lower wind and solar generation, extremely high demand, and unplanned events like transmission line outages.

Today, the lowest cost option for this type of peaking capacity is a storable renewable fuel used in a combustion turbine.

There are many potential options for storable renewable liquid or gas fuels. Biofuels are commercially available today and can serve as a transition fuel until commercially available, electricity-derived fuels become more widespread.

If the City of LA does not want to use currently commercially available fuels due to sustainability concerns, LADWP can produce its own clean fuel in the form of hydrogen (produced from renewable electricity). This option is not yet commercially available at scale, so building the necessary infrastructure could represent a significant portion of total costs associated with the clean energy transition. In the Early & No Biofuels scenario, investment in hydrogen technology leads to a 20+% increase in cumulative (2021–2045) costs compared to cases that allow biofuels.

The resources used to help meet this last 10% and maintain reliability can produce local air emissions, particularly when based on combustion generation. However, even accounting for future growth in energy demand, these new resources would be used much less often than current natural-gas plants, resulting in lower emissions—both in the power sector and economy-wide.

**This study is unique for a 100% renewable energy analysis in that it includes vulnerabilities to many types of events (heat waves, fires, earthquakes, among others).**

Keeping the lights on was a foundational part of this study, as the City of LA recognizes the critical role of a reliable and resilient power grid—especially in a future with more consumer products, like cars, electrified. A 100% renewable grid cannot compromise on reliability, particularly when electricity is playing a greater role in heating, cooking, and transportation.

Increasingly, studies of the evolving grid, regardless of the contribution of renewables, are examining the impact of climate change on demand for electricity, and the vulnerability of the grid to increased temperatures and climate-change driven natural disasters, whether they be wildfires or earthquakes.

Minimizing climate vulnerabilities requires careful planning and use of a mix of resources, including continued deployment of the cleanest resources that can maintain reliability (which today include combustion-based resources), while aggressively pursuing lower-emitting technologies, such as hydrogen fuel cells.

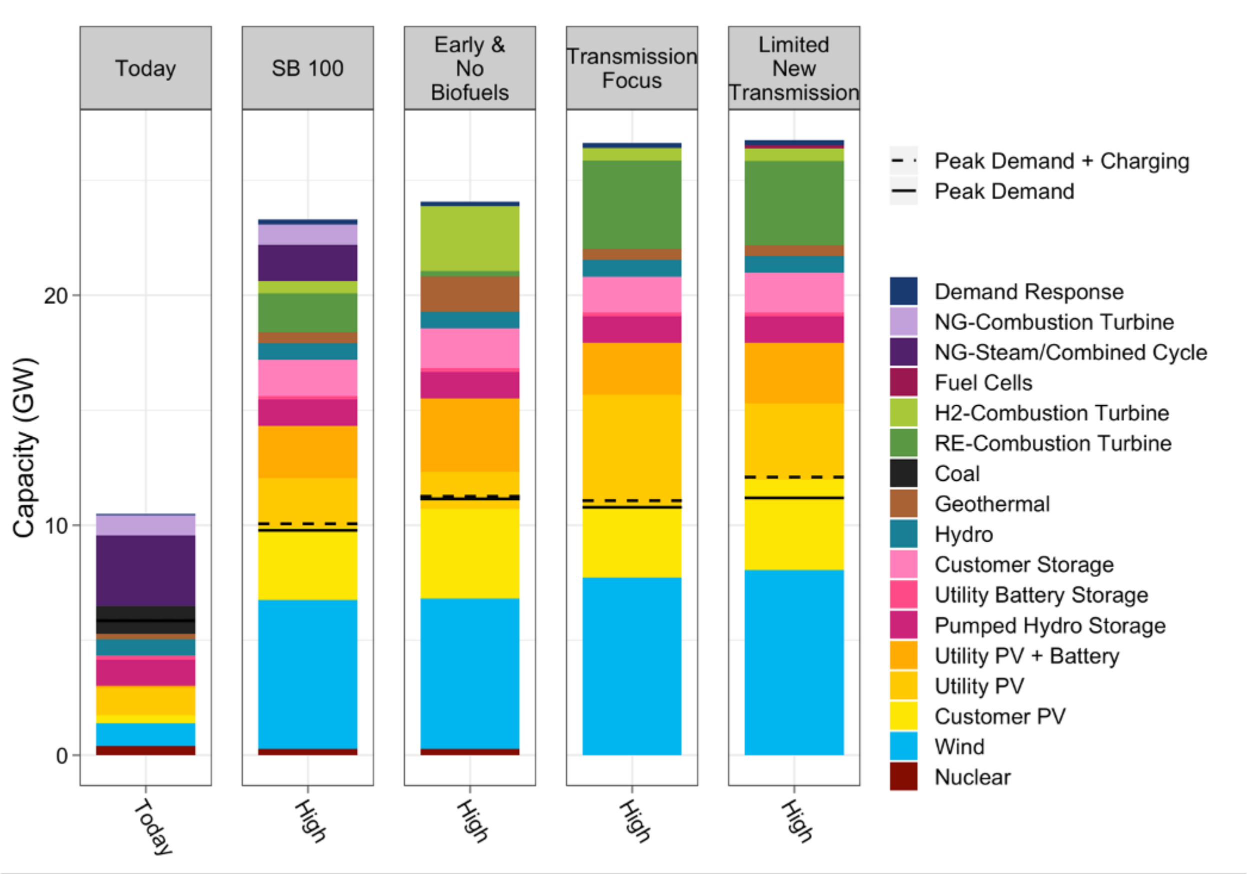
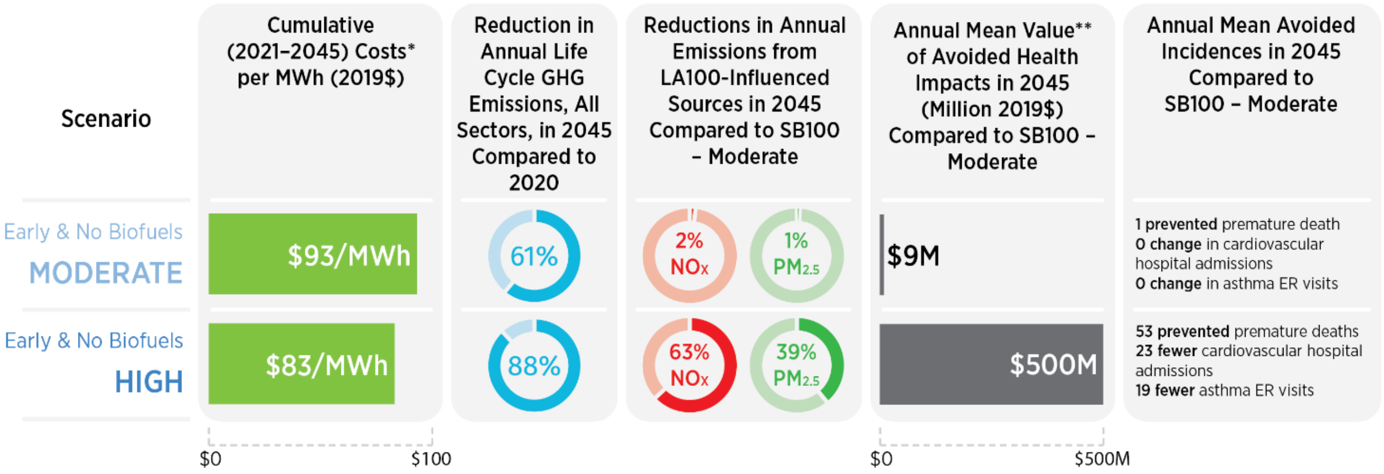


**Figure 6. Capacity mix in 2045 for High load scenarios compared to 2020**

Hydrogen-Combustion Turbine capacity produces fuel from renewable electricity and stores it on site; RE-Combustion Turbine capacity purchases a generic, renewable fuel from the market, which is assumed to be biofuel in the near term and hydrogen starting 2045.

### *1.2.2 The combination of higher energy efficiency, electrification, and demand flexibility, while associated with increased total costs, offers both greater benefits and reduced per-unit electricity costs compared to alternative scenarios.*

While LA100 does not represent a complete analysis of tradeoffs (e.g., it does not address costs of demand-side equipment, employment benefits from energy efficiency, and impact to overall energy expenditures, among others), the benefits as measured within the study are significant. For example, comparing a scenario with Moderate and High electrification levels (using either Early & No Biofuels (Figure 7) or SB100 (Figure 8) as examples) shows that while the High electrification version has higher total costs, it offers lower per-unit costs, higher GHG and air pollutant emissions reductions, and higher public health benefits.

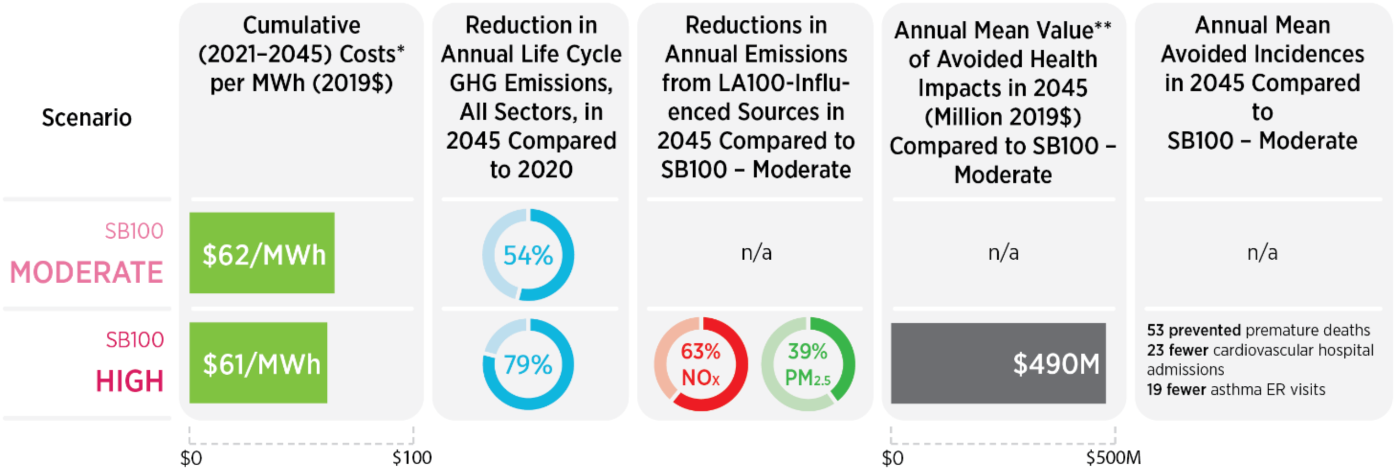


*Annual per-MWh costs do not equal rates—these costs represent the revenue requirement (per unit of generation) to cover the annualized costs associated with expenditures measured in LA100.

**95% confidence interval of values of avoided health impacts in 2045 compared to SB100 – M is: Early & No Biofuels – M ($1M–$24M) and Early & No Biofuels – H ($19M–$1,400 M).

**Figure 7. Comparison of costs and benefits between two different electrification levels for the Early & No Biofuels scenario**

The High electrification level offers higher benefits and lower per-unit electricity costs.



| Scenario | Cumulative (2021–2045) Costs* per MWh (2019$) | Reduction in Annual Life Cycle GHG Emissions, All Sectors, in 2045 Compared to 2020 | Reductions in Annual Emissions from LA100-Influenced Sources in 2045 Compared to SB100 – Moderate | Annual Mean Value** of Avoided Health Impacts in 2045 (Million 2019$) Compared to SB100 – Moderate | Annual Mean Avoided Incidences in 2045 Compared to SB100 – Moderate |
|---|---|---|---|---|---|
| SB100 MODERATE | $62/MWh | 54% | n/a | n/a | n/a |
| SB100 HIGH | $61/MWh | 79% | 63% $NO_x$<br>39% $PM_{2.5}$ | $490M | **53 prevented** premature deaths<br>**23 fewer** cardiovascular hospital admissions<br>**19 fewer** asthma ER visits |

*Annual per-MWh costs do not equal rates—these costs represent the revenue requirement (per unit of generation) to cover the annualized costs associated with expenditures measured in LA100.

**95% confidence interval of values of avoided health impacts in 2045 compared to SB100 – M for SB100 – H is ($18M–$1,400M).

**Figure 8. Comparison of costs and benefits between two different electrification levels for the SB100 scenario**

The High electrification level offers higher benefits and lower per-unit electricity costs.

In addition, comparing SB100 – Stress to SB100 – High shows the value of energy efficiency and demand flexibility (as the scenarios are otherwise the same). SB100 – Stress has an 8.5% higher annual electricity consumption and 17% higher peak demand compared to SB100 – High. The combination of efficiency and demand flexibility assumed in the High version reduce the cumulative (2021–2045) costs of that scenario by 13%.

### *1.2.3 Accelerating the target year to 2035 increases both costs and benefits.*

All else equal, an earlier target year means LADWP must make the necessary investments to achieve 100% renewable electricity more quickly. This results in earlier accumulation of debt, ultimately leading to greater costs over the timeframe of this study (2021–2045).

However, benefits also accrue more quickly, though not necessarily at the same rate as costs. The earlier LADWP achieves a zero-GHG-emission or 100% renewable system, the earlier the avoided emissions accumulate. Reducing emissions earlier has value in terms of reducing the magnitude of the effects of climate change. Similarly, new renewable energy jobs accrue more quickly.

The Early & No Biofuels scenario accumulates both the costs (from annualized payments for renewable technologies) and benefits (GHG emissions, renewable energy jobs) of this transition due to the 10-year head start (Figure 9; jobs not pictured).

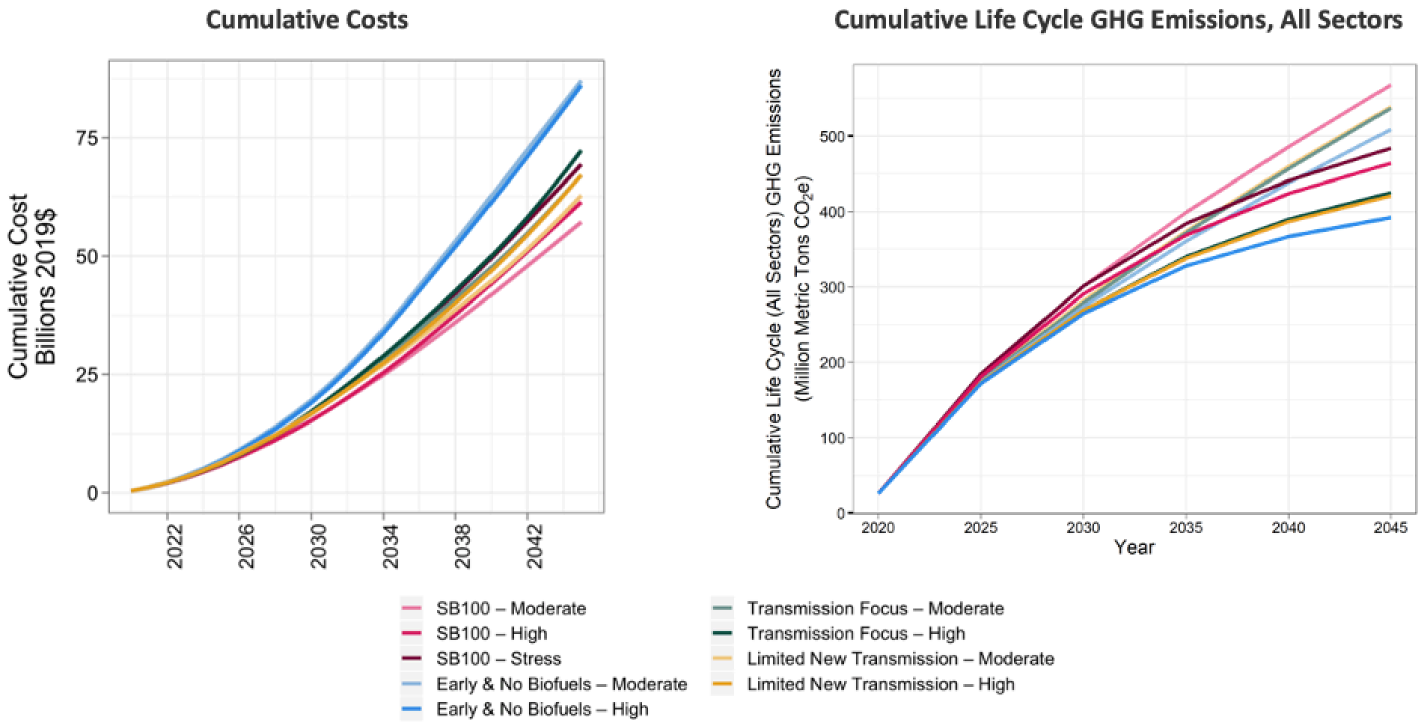
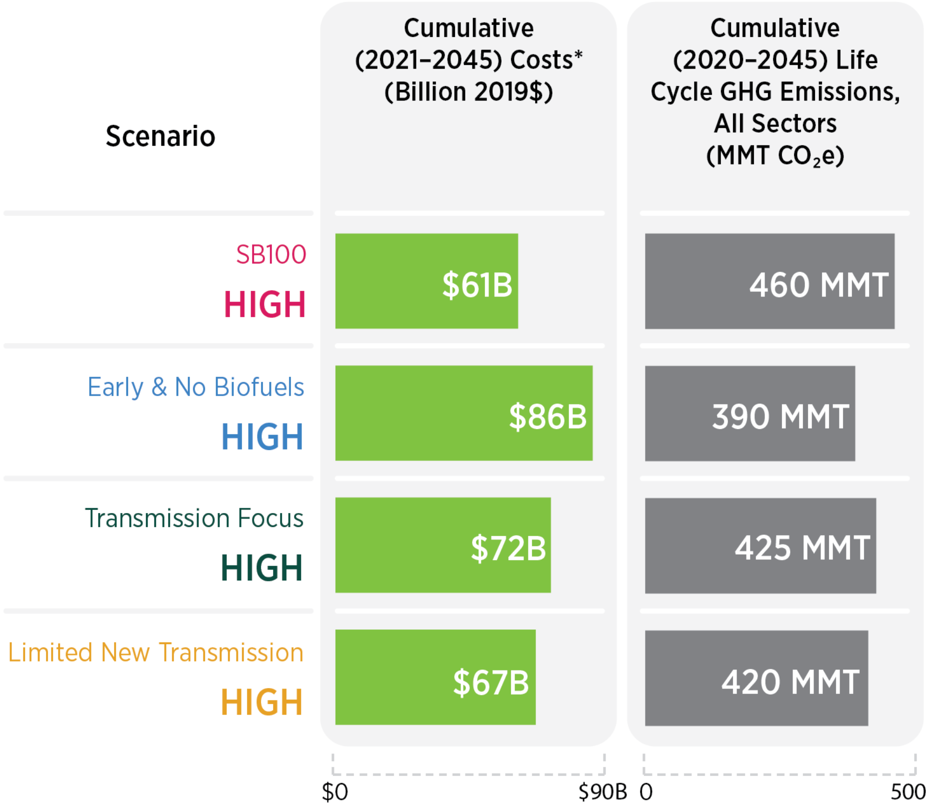


**Figure 9. Cumulative costs (left) and cumulative life cycle GHG emissions from all LA100-influenced sectors (right), by scenario**

Costs shown include bulk power system investment and operations costs, customer rooftop solar installation costs, and distribution upgrade costs to accommodate load growth and distributed energy resources, but do not include debt payments on assets installed prior to 2021, or future distribution costs related to operations.

Figure 10 compares these costs and GHG emissions for just the High load scenarios. It is difficult to use Early & No Biofuels as a proxy for costs of accelerating the target because the costs of this scenario reflect the restriction on biofuels—a restriction that has minimal impact on GHG emissions. However, accelerating the Transmission Focus and Limited New Transmission scenarios to 2035 adds 7%–8% to cumulative costs compared to the base scenarios (exclusive of distribution system costs), which is also approximately the percentage gain in cumulative GHG emissions that Early & No Biofuels accrues compared to those scenarios. Notably, even though the earlier target does not reflect a complete evaluation of benefits, the GHG emissions reductions are globally shared while the costs are borne by LADWP customers. Additional benefits also accrue from earlier compliance in terms of reduced air pollutant (non-GHG) emissions, particularly at the neighborhood level, as well as their health effects.



*Costs, as measured in the study, represent expanding and operating the power system from 2021–2045. See Chapter 6 for more details.

**Figure 10. Cumulative costs and life cycle GHG emissions for the High load scenarios**

If the earlier target is pursued, success would also require an accelerated schedule for renewable energy procurement, permitting, siting, and workforce training, among other activities that are outside the scope of the study but are essential components of implementation.

### 1.2.4 Technology restrictions result in higher costs when it comes to meeting the last 10%–20% of energy demand—but almost no additional air quality or public health benefits.

The costs, GHG emissions, air quality, and public health trajectories across scenarios (within any given electrification level) are similar until each scenario reaches ~90% renewable and zero-carbon electricity. After 90%, the costs diverge for different scenarios, but the overall benefits plateau.

SB100 remains at approximately 90% renewable and zero-carbon electricity through 2045 due to how this scenario is defined. But all the other scenarios move from 90% to 100% renewable electricity by 2045—and they exhibit sharp increases in costs in the last 10%. Figure 11 (left) illustrates this—for Early & No Biofuels from 2025 to 2035, and for Transmission Focus and Limited New Transmission after 2040.[2]

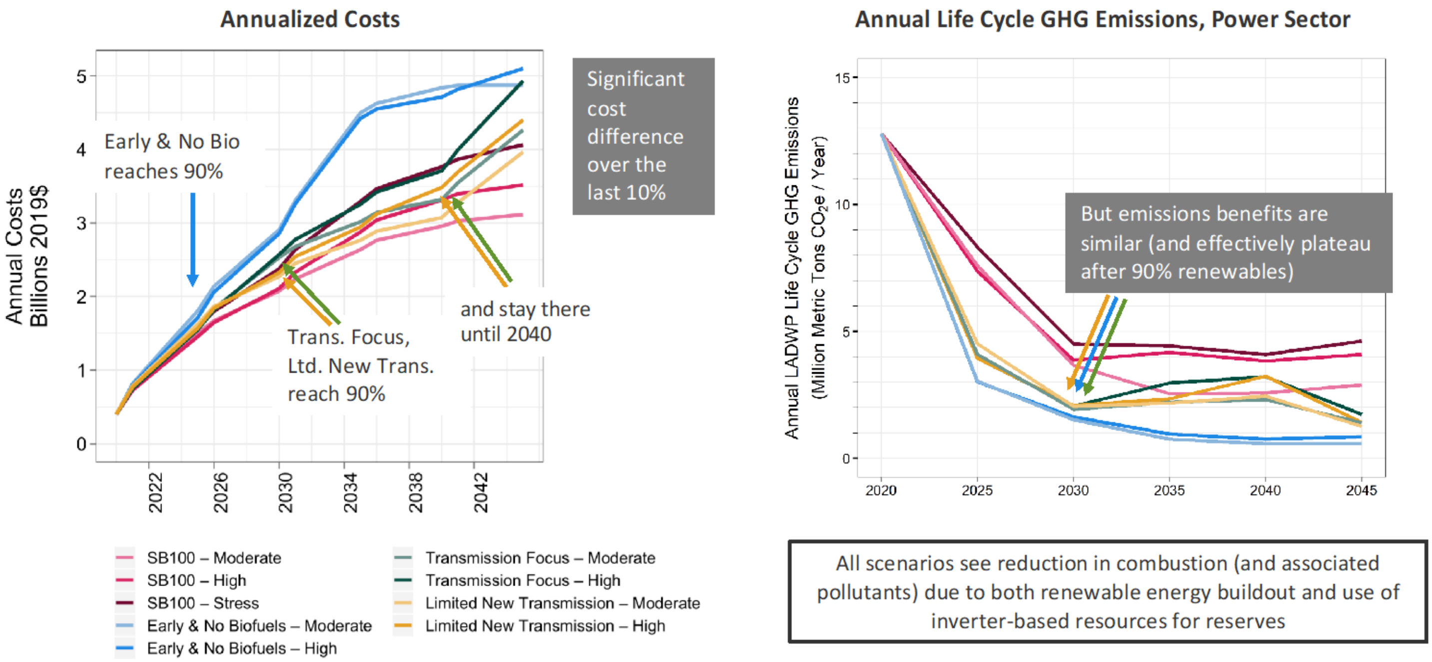


**Figure 11. Annualized costs (left) and annual life cycle GHG emissions in the power sector (right), by scenario, through 2045**

The higher costs associated with the Early & No Biofuels scenario are due in part to limited commercially available, near-term options to provide fuel for in-basin renewably fueled combustion turbines. While the other scenarios can draw on commercially available biofuels in the near term (and SB100 can still burn natural gas offset by renewable electricity credits [RECs]), Early & No Biofuels instead builds the infrastructure needed to produce and store hydrogen, a fuel that is not yet commercially available at scale, representing a 20+% increase in cumulative costs through 2045.

Figure 11 (right) illustrates the change in annual life cycle GHG emissions in the power sector for each scenario through 2045. All scenarios that retire natural gas approach zero MMT $CO_2$ life cycle emissions annually. All scenarios, including SB100, experience rapid reductions by 2025 as coal is retired; from there Early & No Biofuels proceeds towards zero MMT $CO_2$ annually;[3]

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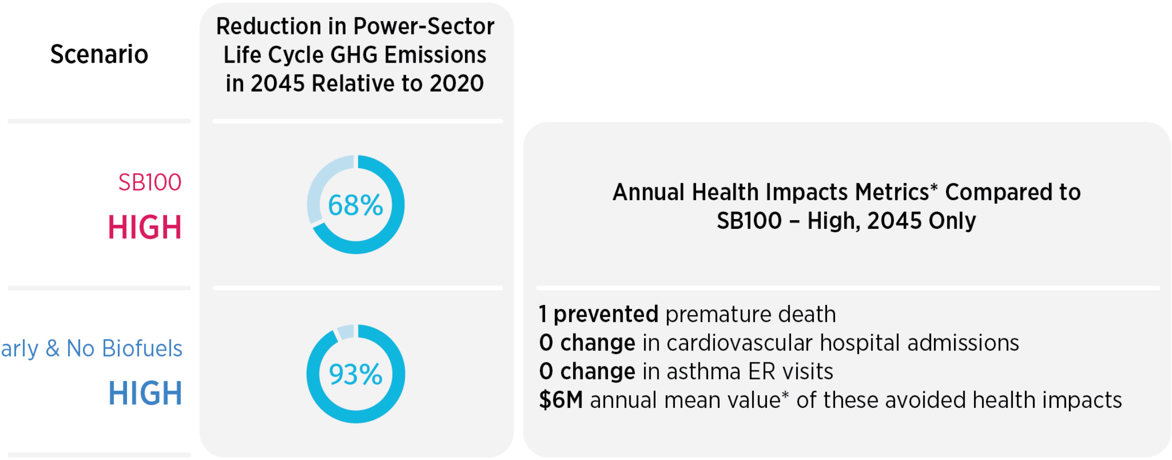
[2] Transmission Focus and Limited New Transmission reach 90% renewable and zero carbon electricity in 2030, stay at that level through 2040, and then rise through 2045 as nuclear is retired simultaneous with achieving the renewable target in 2045 (full financial lifetime costs of this new capacity extend through 2074).

[3] This scenario still has some emissions associated with manufacturing and disposal, which are included in the life cycle accounting approach used here. See Chapter 8 for more details.

Transmission Focus and Limited New Transmission stay fairly flat until 2040, after which they converge with Early & No Biofuels;[4] and SB100 remains elevated compared to the rest.

The additional benefits of restricting technology eligibility in terms of air quality and public health, as measured in the selected scenarios analyzed in the study, are minimal when electrification levels are constant because natural gas consumption across all scenarios is significantly reduced or eliminated compared to today (Figure 12). Because changes to the power sector only contribute 0.8%–1% of the NOx emissions reductions among LA100 scenarios compared to 2012, and 10%–18% of the particulate-matter emission reductions, it is clear that changes to energy efficiency and electrification levels (for vehicles, buildings, and the Ports of Los Angeles and Long Beach) are the predominant cause of health benefits.



*95% confidence interval of values of avoided health impacts in 2045 of Early & No Biofuels – H compared to SB100 – H is -$1M–$17M

**Figure 12. Comparison of GHG emissions and health impacts in 2045 between SB100 – High and Early & No Biofuels – High**

LA100 does not address all benefits related to this analysis of technology eligibility. Potential benefits of technology restrictions not captured include reducing neighborhood-level pollutants, achieving global leadership in attaining a 100% renewable target without RECs (i.e., without natural gas) and/or without biofuels, and addressing sustainability concerns about biofuels.

To better understand the cost impacts of technology restrictions, LA100 evaluated sensitivities to the scenarios by changing technology eligibility, which can provide insight into how LADWP could blend different aspects of the LA100 scenarios. Figure 13 shows estimated impacts to costs (exclusive of distribution system costs) from such changes to technology eligibility. For example, eliminating natural gas in SB100 – High to pursue similar GHG reductions to the other scenarios, would increase cumulative costs by ~2.5% through 2045 (~18% through all assets' financial lifetimes).

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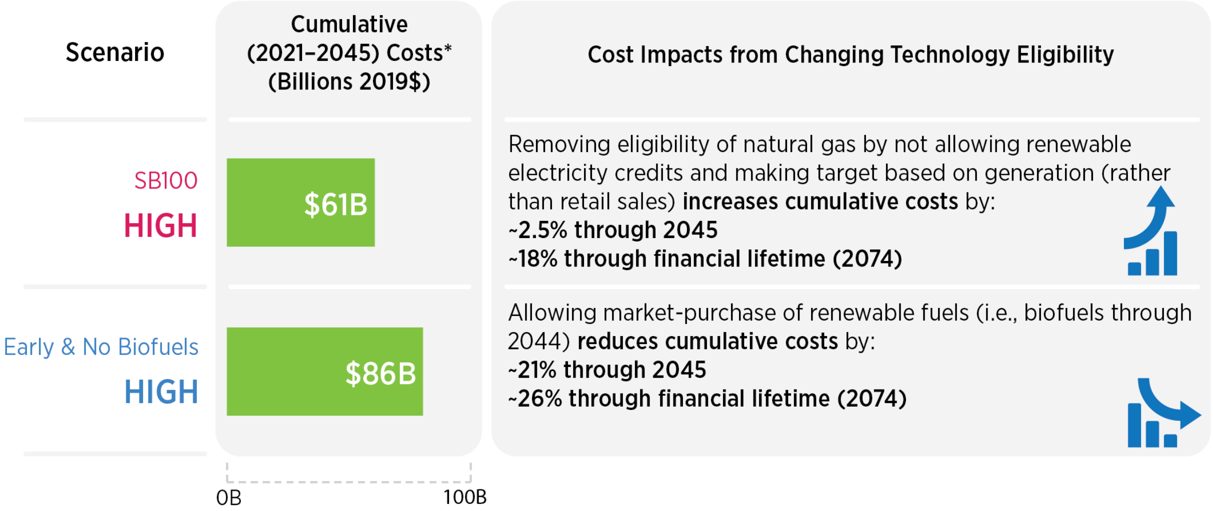
[4] While the renewable and zero carbon share of electricity stays constant at 90% between 2030 and 2040, overall load grows during this time, accounting for the bump in GHG emissions.



| Scenario | Cumulative (2021–2045) Costs* (Billions 2019$) | Cost Impacts from Changing Technology Eligibility |
|---|---|---|
| SB100<br>**HIGH** | $61B | Removing eligibility of natural gas by not allowing renewable electricity credits and making target based on generation (rather than retail sales) **increases cumulative costs** by:<br>**~2.5% through 2045**<br>**~18% through financial lifetime (2074)** |
| Early & No Biofuels<br>**HIGH** | $86B | Allowing market-purchase of renewable fuels (i.e., biofuels through 2044) **reduces cumulative costs** by:<br>**~21% through 2045**<br>**~26% through financial lifetime (2074)** |

*Costs, as measured in the study, represent expanding and operating the power system from 2021–2045. See Chapter 6 for more details.

**Figure 13. Estimated cost impacts from changing technology eligibility: SB100 from retiring natural gas in 2045 and Early & No Biofuels from allowing biofuels**

## 1.3 Looking Ahead: Addressing Uncertainty, Prioritizing Future Decisions

### *1.3.1 Identifying alternative options for firm, in-basin capacity likely represents the largest opportunity to reduce the costs of the transition and points to the highest priorities for R&D: hydrogen and extended demand response.*

All LA100 scenarios build new sources of in-basin dispatchable capacity. The timing of building these new resources can be cost-effectively delayed somewhat with a combination of energy efficiency, local solar and storage, new transmission, and technologies and techniques to increase the capacity of existing, in-basin transmission. But delays in deploying these *other* options could accelerate the need for new in-basin resources. And even with these measures, new capacity that can run for extended periods is eventually needed at specific locations in the LA Basin to maintain reliable service.

LA100 scenarios rely on infrequently used combustion-based resources to help meet the last 10%–20% of electricity demand that is not easily met by low-cost wind, solar, and batteries. How these resources can be fueled varies by scenario. Several scenarios use biofuels, which are commercially available today. The primary role of biofuels is to serve as a net-zero-carbon transition fuel while technologies such as hydrogen-based fuels mature. However, this option presents risks associated with competition from the transportation sector, and some in the LA community are interested in eliminating biofuels due to sustainability concerns (as reflected in the LA100 Advisory Group-driven scenario design).

Alternatives to biofuels include renewable electricity-derived hydrogen fuel, or hydrogen derivatives, such as synthetic methane or ammonia. There is considerable uncertainty regarding hydrogen's long-term cost and commercial availability, as well as generator modifications needed to use these fuels. There is also uncertainty as to how long it will take to develop infrastructure for transportation and storage. To reduce hydrogen costs, the City could partner with industry as part of economy-wide decarbonization where hydrogen-derived fuels are used to power industry, non-electrified transportation, and serve as feedstocks for chemicals and materials that currently rely on fossil fuels.

Across the scenarios, allowing fuel flexibility (biofuels inclusive) allows LADWP to start now without committing to hydrogen infrastructure. Allowing RECs (to continue limited use of natural gas) could mitigate risk; limiting use of RECs to a few percent could provide the needed reliability benefits and still provide nearly all the GHG, air quality, and public health benefits associated with the transition to 100% renewable electricity.

In addition to fuel flexibility and RECs to mitigate uncertainty in the use of hydrogen and biofuels, one alternative yet to be deployed and tested at scale is multiday demand response. Such a program could be initiated now to enable more rapid roll-out should the City proceed with biofuel or hydrogen options and find those paths infeasible or cost-prohibitive.

The primary role of a multiday demand response program as an alternative to combustion turbines is to provide reliability during a multiday event, such as a heat wave or transmission outage. Much of the in-basin capacity added for reliability purposes has a very high cost of energy given its very low utilization, meaning LADWP is paying for capacity that sits idle for much of the year. These costs could be compared to paying some customers to reduce demand during periods when these plants would otherwise be run. Such a program would require a detailed analysis of the customer base to identify customers with flexible loads, and the necessary compensation needed to reduce these loads for extended periods. Automation of buildings and vehicle charging, as well as new IT and other low-cost communication technologies, may make it possible to incentivize demand reductions for lower cost than building new renewable generation capacity that has very low utilization. Exploring this option would likely require pilot programs and new rate designs that compensate customers for reduced energy consumption, as these types of programs do not exist at scale in the United States outside of very large industrial customers.

### 1.3.2 What if LA wants to pursue an earlier target?

The LA100 study did not evaluate achieving 100% renewable energy prior to 2035. However, in 2030 the scenarios achieve a decline of 76%–99% GHG emissions from power plant operations compared to 2020, and an overall renewable and zero-carbon energy contribution of 77%–99% of energy, depending on the scenario—so significant progress can be made in the next decade if LA starts now.

A faster transition to 100% renewables would likely require deployment of technologies at a higher cost, reflecting both technology maturity and commercial availability. The costs could be particularly high for firm capacity resources needed to fully replace natural gas, given the current role of natural gas in responding to extreme events. We assume this complete transition is feasible by 2035, but we have not evaluated the supply chain and other aspects of feasibility that would be required to effect this change in less than 10 years.

Availability of this type of firm capacity resource (e.g., hydrogen production, renewably fueled combustion turbines, fuel cells) would benefit greatly from a robust RD&D program at the financial scale of national and international initiatives rather than a single city's budget.

Expediting regional transmission development would likely require state- and federal-level support.

### 1.3.3 This study marks an important but not final analysis in LA's pivot toward a clean and equitable energy future.

LA100 establishes a methodology that could serve as a foundation for additional and updated analyses that could help reassess costs, benefits, and tradeoffs over time. Continued analyses are needed to understand how to improve implementation, monitor results, and adjust decisions. In particular, using current-generation, forward-looking models to anticipate implications for environmental justice does not capture real-world experiences and barriers to adoption. Therefore, effectively prioritizing environmental justice in implementation, per the City Council motion, would require ongoing monitoring and adjustments.

In addition, aspects related to customer demand (efficiency, electrification, demand response, and customer solar and storage) also represent high-priority areas for ongoing analyses. The changes on the demand side occur, to a large degree, outside of LADWP's immediate control and planning, but can be substantially impacted by rate structures, incentives, or local policies, and have significant potential to affect the costs and benefits of the 100% renewable transition.

# 2 Next Steps for LADWP and the City of LA

As noted above, LA100 represents an early but not final set of analyses on transitioning to 100% renewable energy. This section outlines specific activities, such as further analyses and trainings, that LADWP and the City of LA can consider when implementing next steps.

## 2.1 The Customer

The first set of next steps focuses on the customer, including further analyses to design, monitor, and evaluate programs to prioritize investments, such as energy efficiency upgrades, in environmental justice neighborhoods; realize targets for energy efficiency, electrification, and demand response; improve access to clean mobility options; and facilitate customer adoption of rooftop solar and storage.

### *2.1.1 Prioritizing Environmental Justice in Participation and Outcomes*

Effectively prioritizing environmental justice neighborhoods as the first immediate beneficiaries of localized air quality improvements, as described in the LA City Council motion (#16-243), will depend in large part on how LADWP achieves 100% renewable electricity—both in its process for decision-making as well as how it implements the chosen pathway.

Next steps for LADWP, the City of LA, and other researchers could include improving environmental-justice-related user data represented in modeling and analyses, which will inform design and evaluation of programs to prioritize disadvantaged communities as first beneficiaries. In addition, there is value in better aligning retrospective tools like CalEnviroScreen with prospective modeling tools like those used in LA100.

Examples of needed data improvements include:

- Better representation of environmental-justice-related characteristics in electricity demand projections, such as capturing differences in average size of household, income, and renter vs. owner. For example, projections of electricity demand in single-family households may underrepresent demand in locations where multiple families live in single-family households, which has implications for power system analyses.
- Building, appliance, and vehicle types, age, and usage specific to household characteristics. For example, better data could help characterize cultural differences in equipment usage (e.g., cooking), motivation for electrification, and how equipment lifetime and fuel choice vary with household characteristics. Knowing how these data vary with environmental-justice-related characteristics could enable the design of incentive programs that would better support household energy efficiency and electrification upgrades in disadvantaged communities.
- Localized benefits, such as indoor air quality improvements from electrification. Calculating benefits of electrification would also be improved with data on degradation of existing equipment (e.g., older equipment might leak more gas), which likely varies across communities. Other localized benefits include for those who live in close proximity to LADWP generation stations, to major roadways and the Ports, all of which experience emission reductions in LA100 scenarios but whose benefits were underestimated since near-source pollutants and health effects were not modeled.
- Access to employment in energy efficiency and clean energy sectors.

- Analyses of energy poverty, percentage of discretionary household income spent on electricity and mobility, and potential financial barriers to upgrade energy efficiency and electrify both buildings and transportation.
- Impact of prioritization of benefits (e.g., electrification, efficiency, rooftop solar) in environmental justice neighborhoods on their potential for gentrification; and how gentrification pressures could be reduced by complementary city-level policies.
- Impact of stranded costs on low-income customers who do not electrify or adopt rooftop solar (e.g., fixed costs of a gas distribution system).

### *2.1.2 Achieving Energy Efficiency, Electrification, and Demand Response Targets*

This study projected different levels of energy efficiency, electrification, and demand response—but did not analyze *how* to realize those projections. Historical programs (e.g., rebates and incentives) would likely not be sufficient to yield the participation required to achieve the High customer demand projection, which includes, for example, that all consumers choose to purchase the most efficient electric technologies when replacing appliances or upgrading building materials. Nevertheless, a broad set of regulatory and policy tools are available, including the California Governor's 2020 announcement to ban sales of internal-combustion engines starting in 2035, and zero- or low-interest loans dedicated to upgrades. Without more information on different implementation pathways to realize these outcomes, costs cannot accurately be captured in modeling, and incentives could be limited to designs associated with historical approaches. Follow-on analyses could include, for example:

- Total and per-household costs of upgrades and change in total energy expenditures.
- Impact of alternative retail rate designs, both in choices for technology adoption (electrification, rooftop solar, efficiency) as well as timing of electricity demand. Rate design will have a potentially profound impact on demand flexibility, with corresponding impacts on system reliability and costs. A better understanding of how various groups respond to price signals or are able to adopt technologies that support price response and demand flexibility also has implications for improving environmental justice.
- Better representation of the benefits of resilience to ride through outages and extreme events from efficiency improvements or storage deployment strategies. For example, how does efficiency mitigate increases in indoor temperatures that could occur under extreme heat waves, and how do extreme heat waves drive technology adoption?
- Access to financing; for example, from changes in home value from efficiency upgrades, or availability of alternatives to commercial lending, such as best practices associated with on-bill financing.
- Addressing renter-owner barriers to technology adoption (energy efficiency upgrades, electrification of building end uses, EV chargers, and rooftop solar).

### *2.1.3 Decarbonizing Industry*

Decarbonization goals typically include significant changes in industrial energy use, including electrification. The changes include switching from fossil fuels in a variety of industrial applications and at the Port of Los Angeles and Los Angeles International Airport. The potential growth in electricity demand at these locations and other industrial sites would benefit from further evaluation.

Large industrial customers can be an important source of flexible demand, and it will be important to further analyze the ability of existing and new sources of industrial load to contribute to a 100% renewable grid. Another important potential source of system flexibility is further coordination of the water and power system. An important aspect of both electrification and flexible load is the use of alternative fuels for industrial applications. The LA100 scenarios envision deploying hydrogen-based fuels for in-basin electricity generation during periods of higher demand and/or lower solar and wind production. The fuels could be used in many applications currently dependent on petroleum products or natural gas. Development of hydrogen-based resources in coordination with LADWP's needs could substantially reduce the cost burden on any single entity. It may also be important to evaluate how declining demand for gasoline could introduce new opportunities for alternative fuel production at existing refineries. Note that there would be additional air pollution-related benefits to the residents of LA from industry fuel switching, electrification, and energy efficiency improvements.

### 2.1.4 Clean Transportation

Various solutions are being developed and deployed to decarbonize transportation across all modes, ranging from scooters and cars to public transit and airplanes. Transportation is a critical element of any decarbonization strategy and a key lever to reduce air pollution, not by reducing overall mobility but by increasing affordable clean mobility options.

Electrification of on-road vehicles is only one aspect; additional technologies including electrolytic hydrogen and sustainable biofuels can also contribute, especially for off-road modes. Assessing the options most appropriate for LA, and that reflect planning across sectors (including industry and power), remains an area for future analysis. For example, LA100 focused on just personal light-duty vehicles and buses, but analysis could consider additional loads from other vehicle types as well as hydrogen production for transportation (and other uses).

In looking forward, planners could consider vehicles and mobility beyond what exists today. While passenger vehicles today are predominantly personally owned, in the future they may be shared, or operated in a Mobility-as-a-Service model (fleets or ride-hailing vehicles). Already we have seen the shift in freight movement from long-haul to shorter regional-haul trips, and this will continue to evolve with e-commerce. Thus, as part of electrification analysis, LA could consider the changing vehicle requirements and electrification opportunities (and associated charging requirements) to facilitate more effective investments.

Along with customers' evolving relationships to vehicles and mobility, LA must consider customers' evolving interactions with the grid. The LA100 study demonstrated benefits in encouraging customer flexibility (including both EV charging and other uses) to better align electricity demand with renewable generation. Electric vehicles are projected to be largest new source of load, and managed charging can greatly help to support grid planning and operations in numerous ways. This outcome requires charging infrastructure (e.g., providing convenient charging to all, workplace charging, charging integrated with other distributed energy resources like solar photovoltaics and batteries) as well as solutions to enable customer control of charging to align with economic incentives or other ways of compensating consumers' flexibility. Much research remains on how to design and plan for a cost-effective and convenient charging infrastructure that offers mobility solutions to all while also integrating effectively with the grid.

In addition, hydrogen production (e.g., for long-haul trucks) could also support seasonal energy storage and fuel that LADWP could tap during periods of low wind and solar generation.

In summary, research on clean transportation includes evaluation of *future* mobility, not past; electrification of a broader class of vehicles in conjunction with enabling flexibility in charging; and charging and hydrogen production infrastructure that reflects opportunities to reduce costs of both the transportation and power sectors while also ensuring reliability of the distribution system.

### 2.1.5 Customer Solar and Storage

The LA100 scenarios rely on customer-sited storage to help maintain a reliable grid and assume appropriate (but unspecified) compensation mechanisms to incentivize this operation. Deployment and operation of distributed energy resources, both customer-adopted and otherwise, will depend in part on how LADWP implements its chosen pathway to 100% renewable energy. Next steps for LADWP, the City of Los Angeles, and other stakeholders could include the following:

- Increased clarity on the design and implementation of the LADWP feed-in tariff, which could be particularly effective in incentivizing deployment of distributed energy resources on large commercial and multifamily buildings.
- Improved focus on the value of local reliability and resilience in the 100% transition. For example, to what extent do LADWP ratepayers value this as a service, and/or should it be reflected in local generation and storage valuation?
- Additional focus on the role of customer-adopted distributed storage. For example, do current retail tariffs appropriately communicate the value of distributed storage and its dispatch? Determine improvements to adoption forecasting methods as the technology evolves and gains market share.
- Increased focus on planning for new construction, urban in-fill, and co-location of solar and storage with vehicle charging stations—all of which could provide higher value than deployment on existing distribution networks.

## 2.2 The Power System

A 100% renewable power system represents a dramatic shift in how LADWP plans, builds, and operates the power system. Changes will occur at all levels—transmission, generation, and distribution systems.

### 2.2.1 System Planning and Operation

As shown in the scenarios considered, a 100% renewable energy power grid will likely make increased use of remote resources throughout the western United States, bringing in power from at least five or six states. While LADWP has a long history of building and using long-distance transmission, increased reliance on out-of-basin resources will require even greater use of existing and new transmission assets. This includes the potential opportunities and challenges of shared development of new generation resources and transmission with other utilities throughout California and the West. Planning and operation of the transmission network will benefit from innovative approaches that maximize utilization to avoid the need for in-basin spinning generation to provide transmission reliability and operating reserves. Innovative approaches include new physical hardware, such as flexible AC and DC transmission, improved monitoring and controls, and new software to ensure that unplanned outages will not critically overload transmission components.

All LA100 scenarios deploy thousands of MW of new wind, solar, and storage capacity, and therefore planning for this large-scale deployment is part of a no regrets pathway, regardless of the eventual mix of resources or actual renewable target. As a result, the LADWP resource, transmission, and distribution planning teams will want to employ new techniques to address seasonal, diurnal, and sub-hour variable generation, and to plan for dispatchable resources in times of extreme renewable variability and during long transmission outages that are both planned and forced.

Increased reliance on wind, solar, and storage will show value in improving how LADWP forecasts resource supply, demand, and the overall state of the system. This forecasting includes monitoring either directly (or indirectly) distributed resources and creating the proper signals and incentives to optimally use customer-sited storage, controlled EV charging, and demand response. New software, controls, communication, and monitoring across the entire system can enable better coordination of the operation of generation, transmission, and distribution resources across multiple timescales. This coordination will be particularly important to maximize the use of wind and solar delivered from outside the LA Basin and to decrease the use of expensive in-basin dispatchable generation assets traditionally used to provide reliability services. New tools and models will be valuable, such as state-of-the-art simulation tools that seamlessly blend production cost modeling and transmission planning (power flow and dynamic stability), particularly as inverter-based resources replace conventional synchronous generators and are used to provide reliability services including frequency support.

### 2.2.2 Hydrogen

The greatest uncertainty around achieving 100% renewable energy is addressing the hours of demand that are not easily served with wind, solar, storage, and other renewable resources. All LA100 scenarios depend on in-basin generation fueled by storable fuels, many derived from hydrogen and stored in various forms, including in the form of ammonia. This hydrogen technology has not been deployed at scale, and LADWP may be among the first to utilize hydrogen-fueled generators. Hydrogen would require substantial investments in new infrastructure and regular monitoring of technology development to ensure LADWP remains flexible in deploying cost-optimal resources.

### 2.2.3 Addressing the Three R's: Reliability, Resource Adequacy, and Resiliency in the Face of Climate Change

The LA100 scenarios are designed to address traditional resource adequacy and reliability performance (including multiyear weather variability), but with the understanding that planning and operational practices will need to evolve given the increased reliance on out-of-basin, variable resources. In addition, the study considers two elements of the increasing risks of climate change: increased demand due to more air conditioning and increased risk of wildfires leading to extended transmission outages. However, the uncertainty of extreme weather events will almost certainly require continued analysis of changing load patterns, availability of demand flexibility (e.g., during a prolonged heat wave), plant efficiencies, renewable resource availability (precipitation, cloud coverage, wind patterns), and the impact of temperature on system components including transformers and overhead transmission lines. This increased uncertainty leads to the need for additional analysis of system restoration and the resilience of the system to local and regional outages.

### 2.2.4 LADWP Workforce Development

Any pathway to a 100% renewable future would require substantial wind, solar, and storage deployment, representing an important change for LADWP's workforce. While traditional thermal generation resources will operate less frequently, all LA100 scenarios continue to use this type of resource (but with renewable fuel instead of natural gas) and will continue to require skilled labor for O&M of these plants. Design, construction, and operation of these plants may actually be more complex than natural gas plants, particularly when using fuel supplies such as hydrogen and ammonia that require additional chemical processing.

LADWP will also likely need to expand its system planning and operation capabilities. A host of new models and techniques support the operation of a 100% renewable electricity power system. This area of workforce development includes building expertise within LADWP to control a system that is more reliant on inverter-based control systems.

### 2.2.5 Distribution Grid Evolution

The increased deployment of distributed energy resources and large load impacts of electrification highlight the need to further enhance the planning and operation of the distribution system. The LA100 study developed the first distribution-system-wide electrical models for LADWP. But there remains considerable work for LADWP to adapt, develop, and maintain a detailed power flow model of the distribution system to support the specific designs needed as the actual paths toward 100% renewable energy unfold. This work includes identifying constraints and opportunities for both electrification (especially transportation) and local solar and storage.

In some portions of the distribution system, the load and distributed energy changes on the pathways to 100% renewable energy (particularly in combination with existing upgrade needs from deferred maintenance) could introduce a need for feeder/circuit redesign and substation transformer upgrades. While these upgrades could be managed with careful engineering using the existing 4.8kV local distribution system, these changes could also represent an opportunity to transition at least some of the system to higher voltage classes (e.g., 12.47kV) as has become common across much of the United States. Additional study—and then, if appropriate, pilots and demonstrations—using these higher voltage classes would help LADWP identify if, when, and how such a transition might take place.

Another opportunity for further evaluation by LADWP is the opportunity to optimize the placement of distributed energy resources to help offset some of the distribution system upgrade needs. The increased use of distributed resources also makes it important to analyze the interaction between the distribution and transmission systems. While LA100 shows how upgrading the distribution system to simultaneously manage load and distributed generation can offer incidental synergies, considerable additional benefit could be achieved through optimized placement and use. In most cases, it is expected that the same quantity of distributed energy resources (or more) could be deployed, but in alternate locations that help offset upgrade needs. Such "non-wires alternatives" analysis represents an additional future direction for LADWP and its partners.

### 2.2.6 Opportunities for Advanced Coordination and Control

Similar to non-wires alternatives in planning, there are important opportunities to coordinate distributed energy resources, demand response, and other resources to support distribution and transmission system *operations*. For instance, adapting the dispatch for specific storage devices or small curtailments of local solar could help support localized distribution system needs while still providing the same systemwide energy and services. Basic versions of such coordination can be achieved with distributed energy resource management systems and demand response management systems, potentially in combination with various aggregator structures and/or an advanced distribution management system. There are also ongoing real-world demonstrations of more advanced coordination technologies such as autonomous energy systems and other distributed-hierarchical control architectures.[5] Next steps for LADWP in this area include assessing available options for advanced coordination, potentially including evaluating various approaches first in full-scale (but offline) laboratory test environments and later in field pilot studies.

### 2.2.7 Cybersecurity

Cybersecurity represents an emerging threat to grid operations. The future systems envisioned in the LA100 scenarios introduce new considerations due to increased consumer-owned generation, controllable loads, the potential for third-party control of renewable energy generation, and expanded communication requirements for system operations, among other new vulnerabilities. Further actions to analyze and prepare for potential attacks include identifying vulnerabilities, simulating attacks (e.g., attack LADWP's renewable energy, spoof distributed energy data, gain control of distributed energy resources), redesigning operations and/or equipment to mitigate risks, preparing response protocols, and training LADWP's and the broader renewable energy workforce.

## 2.3 The Community

This section focuses on four specific areas that will be important components of the clean energy transition: quantifying neighborhood benefits and costs of changes, managing end-of-life waste streams for technologies, workforce training for jobs within the industry, and community engagement.

### 2.3.1 Neighborhood Benefits and Costs of Changes Envisioned in the Study

LA's clean energy future can include many types of benefits and costs; estimating the neighborhood-level impacts could be an important component of environmental justice. For example, the design and evaluation of any electric vehicle incentives could be coupled with

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[5] Benjamin Kroposki, Andrey Bernstein, Jennifer King, and Fei Ding, "Tomorrow's Power Grid Will Be Autonomous: IEEE Spectrum," *IEEE Spectrum: Technology, Engineering, and Science News* (IEEE, November 23, 2020), https://spectrum.ieee.org/energy/the-smarter-grid/tomorrows-power-grid-will-be-autonomous.
Benjamin Kroposki, Andrey Bernstein, Jennifer King, and Fei Ding. 2020, "Good Grids Make Good Neighbors," *IEEE Spectrum* 57 (12): 38–43 (November 25, 2020), https://doi.org/10.1109/MSPEC.2020.9271807.
Benjamin Kroposki, Emiliano Dall'Anese, Andrey Bernstein, Yingchen Zhang, and Bri-Mathias Hodge. 2017. *Autonomous Energy Grids: Preprint* (NREL 2017), NREL/CP-5D00-68712, https://www.nrel.gov/docs/fy18osti/68712.pdf.

analysis of local air quality benefits, especially along the roadways that suffer high local pollution.

As another example, LA100 results suggest value in building new, state-of-the-art combustion turbines at current thermal generating stations sites (or retrofitting existing turbines where possible) fueled by renewable-electricity-derived fuels (such as hydrogen) and operated at much lower output compared to natural gas today. One step that LADWP and the City of LA can consider to prepare for this change is to establish expectations of neighborhood environmental impacts, monitor these impacts, and revise operating protocols as needed.

The LA100 study evaluated the closure of natural gas plants, including LADWP's once-through cooling units, on regional ozone and particulate matter, but these plants are a relatively small source of the air emissions that lead to formation of these two pollutants in the LA Basin, so regional effects are small. To build from this analysis, the City and LADWP could quantify the expected local benefits and costs of retiring these plants and replacing them with renewably fueled peaking capacity. The benefits, with a focus on adjacent neighborhoods, include reduced toxic and hazardous air pollutants from the retirement of the once-through cooling plants; the costs include new limited operations of combustion turbines. The future fuels to be burned are newer and not as well characterized in terms of their emissions. LADWP could help fill this knowledge gap and inform the local community of potential hazards. This type of analysis can provide crucial information on impact of holding peaking capacity at these sites, which can lead to improved outcomes in terms of community participation in shaping LA's clean energy transition.

We also note there may be additional impacts to the local community associated with the broader goals of a clean energy system, including potentially reduced operations at local refineries, and changes in vehicle fuel infrastructure and distribution. While not studied here, these changes could be significant, particularly for certain neighborhoods.

### 2.3.2 End-of-Life Waste Stream Management

Accelerated adoption of renewable energy technologies such as solar photovoltaics and batteries requires planning how to manage these technologies when they reach the end of their useful lifetimes. Circular economy strategies such as repair and resale to secondary markets can prolong life and reduce environmental impacts. But eventually all of these technologies reach their end of life, where recycling to recover valuable, scarce, and potentially hazardous materials is preferable to locking the materials away in landfills. The final owner is responsible for managing these technologies, and California state government agencies are developing regulations. Currently, management of these technologies at end of life is not straightforward or simple, and thus it is recommended to consider viable and preferable pathways upfront for economic and environmental stewardship reasons.

### 2.3.3 Broader Community Workforce Development

The LA100 study identifies workforce growth associated with investments in construction, operation, and maintenance of LADWP's generating capacity. A next step for the City of LA could be to work with local renewable industries to identify specific gaps in skills sets that make recruiting and expanding difficult. The City could then work with local education institutions, unions, and other community groups to establish a mechanism for Angelenos to effectively compete for these positions and to inform workforce development or training priorities. In addition to renewable energy, the same set of actions would help position LA residents to participate in and help build energy efficiency and electrification industries.

### 2.3.4 Community Engagement

The LA100 study has identified technical and economic opportunities for 100% renewable pathways, situated within a broader context of GHG emissions, air quality, public health, environmental justice, jobs, and the economy. These transitions, however, are less likely to be successful if not grounded in the community, which represents the drivers for change, concerned ratepayers, and residents who can help implement the vision. Next steps for the community, the City of LA, and LADWP to consider could include instituting metrics for the transition as a way to guide implementation, measure progress, and establish off-ramps in case expected thresholds are not met (e.g., costs, pollution, distribution of rate impacts). Education campaigns (from the community and from LADWP) will be key to providing Angelenos information to support their participation and foster support for the decisions that emerge from this engagement. The City of LA could also consider establishing a cross-disciplinary organization (including scientists, social scientists, community activists, and economists, among others) with experience developing customer-focused program design, coordinated infrastructure siting and expansion, and related activities.

# 3 Implications for Other Locations

Most deep-decarbonization and high-renewable-energy studies identify a significant role for solar, wind, and batteries to decarbonize significant shares of electricity, with resources sited on both the transmission and distribution grids.[6] The LA100 study's findings are consistent with these studies.

Given that carbon-free generation represents 37% of electricity generated nationally in 2019,[7] to achieve deep decarbonization in the power sector, most jurisdictions would need to add significant amounts of renewable energy and deploy nearly all readily available options—wind, solar (local and remote), storage, transmission, energy efficiency, and demand response. Jurisdictions can get started on this while considering the more context-specific options for the final 10%–20% of the target. For LA, the in-depth analysis of reliability of this study, combined with LADWP's governance, geography, resources, and load profile, shows value in storable renewable fuel and multiday demand response for meeting the final 10% of the target. For other jurisdictions, the final pathway to 100% will vary and depend on interconnectivity, local options, and objectives (e.g., resiliency, job creation, affordability, economic growth), among other differences.

To help explain how LA100 is applicable to other jurisdictions, Table 1–Table 3 summarize distinctions about LADWP, the city of LA, and the LA100 study.

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[6] National Academies of Sciences, Engineering, and Medicine, *Accelerating Decarbonization in the United States: Technology, Policy, and Societal Dimensions* (National Academies of Sciences, Engineering, and Medicine, 2020), https://www.nationalacademies.org/our-work/accelerating-decarbonization-in-the-united-states-technology-policy-and-societal-dimensions.
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## 3.1 Governance

**Table 1. Characteristics of LADWP in Terms of Governance, and Implications of LA100 Results for Other Cities/Regions**

| Characteristics of LADWP | Characteristics in other areas | Implications |
|---|---|---|
| LADWP is its own balancing area authority and therefore responsible for reliability | Utilities (municipal, investor-owned, co-ops) that are part of larger public power group, with shared governance on decision-making<br>Cities that are part of a larger investor-owned utility | LA100 includes a strong focus on reliability, which most cities do not need to consider; this has affected results, which include more peaking capacity to manage contingencies than a city might otherwise plan for in a 100% renewable electricity target. In other areas, the reliability concerns might be managed separately by system operators.<br>LADWP as its own balancing area authority also has more freedom to define how to meet regional reliability requirements, which is also reflected in **LA100 results** (e.g., through use of battery storage and demand response for grid services). |
| LADWP is a vertically integrated utility and therefore has complete control over entire process of planning to operations | Cities might be served by separate distribution and transmission utilities with power systems not centrally planned | LADWP is able to integrate into planning all aspects of the power system (transmission, generation, distribution, tariffs). The city is not subject to decisions from multiple jurisdictions.<br>LADWP can monetize and gain value from services like storage that can be more difficult in other jurisdictions.<br>**LA100 results:**<br>LADWP is able to build less total capacity due to optimized planning (e.g., it can site distributed generation locally as part of optimized bulk-distribution planning). |
| LADWP is not currently part of a power market (Will join the western Energy Imbalance Market in 2021) | Cities and vertically integrated utilities in wholesale market regions | Wholesale power markets could reduce operating costs by allowing access to a broader set of generating resources, typically across a larger geographic area.<br>**LA100 results:**<br>While LADWP builds to meet resource adequacy without relying on a market, not relying on a market for operations restricts access to exchanges that can lower costs, improve revenue, and provide additional insurance to managing contingencies. |
| Rate design not subject to public utilities commission (PUC) | Utilities that serve cities are often subject to a state PUC for approving retail tariffs | **LA100 assumptions**:<br>While the study does not evaluate different retail tariffs beyond a moderate and high customer solar projection, the study does make a number of assumptions that essentially imply a change in retail rate structure. Two changes in particular affect results:<br>• Customer storage is centrally dispatched<br>• Load flexibility is greater (e.g., for EV charging, fast frequency response)<br>Given the potential impacts of retail tariffs on costs of achieving 100% renewables, LADWP is well positioned to holistically plan retail rates as part of power system planning. |

| Characteristics of LADWP | Characteristics in other areas | Implications |
|---|---|---|
| Municipal utility that is governed by the City of LA | Corporate decisions subject to state-level approval (e.g., regulations, policies)<br>Cooperative decisions subject to support of members | **LA100 input assumptions** show tight linkages with city political leadership.<br>• Once-through cooling plants retired due to health and GHG considerations<br>• New in-basin natural gas not considered as transition fuel<br>• Coordination between power system and transportation planning<br>Multi-stakeholder governance elsewhere can create additional challenges in aligning around goals. |

## 3.2 Grid, Resource, and Load Characteristics

**Table 2. Characteristics of LA's Grid, Resources, and Customer Electricity Demand, and Implications of LA100 Results for Other Cities/Regions**

| Characteristics of LA's Grid, Resources, and Customer Electricity Demand | Implications |
|---|---|
| Power system—relatively clean compared to nationally<br>Air quality—relatively polluted compared to other cities | The benefits of LA100 scenarios to GHG emissions and air quality are specific to LA.<br>The average carbon footprint of electricity in 2020 for LADWP is lower compared to the national average. Therefore, the benefits of power sector decarbonization are smaller in LA100 than what other cities might experience. Analysis could reveal additional benefits of vehicle electrification, particularly for medium- and heavy-duty vehicles. Other cities could have different proportions of emissions from sectors, and thus could lead to different results.<br>The impacts to air quality of the different metrics analyzed in the city were mixed—fine particulate matter concentrations reduce, but ozone actually increases due to the nonlinear response of ozone to changes in precursor emissions (a counterintuitive yet expected result). Other cities might see ozone decrease instead. |
| The existing power system has significant storage in the form of pumped hydro | The existing large storage capacity makes better use of new solar and wind, reducing the costs of those investments. Also, other jurisdictions might need to identify other storage capacity or alternatives such as flexible load. |
| The existing power system has large, long-distance transmission from regions with excellent renewable resources, providing access to world-class utility-scale solar, wind, and geothermal | LA has many options to scale up clean generation, which has allowed greater flexibility in evaluating different pathways to 100% and which mitigates potential concerns about feasibility of rapid growth.<br>LA100 results indicate a more solar-dominated system compared to cities with more direct wind access and lower solar resources such as in the Midwest.<br>Geothermal provides firm capacity, which was especially valuable for the scenarios that do not allow biofuels. |
| Wildfire and other natural disaster risks | LA100 results include capacity that uses storable fuel to withstand potentially frequent and multiday transmission outages due to wildfires, earthquakes and other natural disasters. There could also |

| Characteristics of LA's Grid, Resources, and Customer Electricity Demand | Implications |
|---|---|
| | be a potential impact of wildfire smoke and other air quality impacts on solar generation.<br>Other regions might manage different risks (e.g., transmission outages due to icing and other extreme types of weather, such as hurricanes), which in turn affect options for achieving reliability in a 100% renewable electricity system. |
| Unique in-basin transmission constraints | Cities typically have transmission congestion, and planning will be city specific. |
| High-quality in-basin solar | Production of solar will be higher in LA compared to most other cities in the United States, presenting improved economics for the customer and LADWP to adopt solar. |
| Limited offshore wind | There are limited nearby offshore wind options due to lack of shallow continental shelf. Other coastal cities, such as on the east coast, may more readily be able to access nearby offshore wind as an alternative to remote renewable resources. |
| Large 34.5kV grid, more constrained 4.8kV grid | The presence of a 34.5kV grid throughout the LA Basin allows larger-scale local solar and storage deployment at low integration costs, providing options for community solar, utility-scale solar, and virtual net metering. It can also more readily support high-power electric vehicle charging stations.<br>For solar, storage, and EV charging at homes and mid-sized commercial locations, the lower power capacity of the 4.8kV grid does require upgrades that might be reduced for systems operating at higher voltage levels. Still, for LA100, all anticipated upgrades appear feasible. |
| Low heating demand; high cooling demand, especially with climate change | Solar generation is strong during periods of peak demand, which align with summer temperature extremes, and low during the winter. Therefore, LA100 meets more of its peak demand with solar plus storage compared to a city that must manage winter peaking.<br>In addition, LA may be susceptible to extreme heat waves due to climate change, which will likely further drive summer peaking capacity due to increased adoption of cooling. Other areas may not see as much increase in peaking capacity due to climate change. |
| LA has a lower share of industrial load compared to national averages | Cities with more industry would have more options for demand response programs. |
| State and local community goals and priorities | Based on the city and communities' objectives, the LA100 study's framing is premised on 100% renewable energy as the critical pathway to decarbonization. The study did not evaluate cross-sectoral interactions (e.g., impact of going from 95% to 100% renewables on rates, which could affect electrification in other sectors, or on optimized infrastructure (e.g., through hydrogen production). Different framings would lead to different understandings of trade-offs.<br>Also due to stakeholder guidance, the study did not consider new nuclear or carbon capture and storage technologies that could be options in other locations. |

## 3.3 Study Scope

**Table 3. Characteristics of LA100 in Relationship to Other Decarbonization and Renewable Energy Studies, and Implications of LA100 Results for Other Cities/Regions**

| LA100 | Other Types of Studies | Implications |
|---|---|---|
| 100% renewable energy | <100% renewable energy studies | **Getting to ~90% renewable energy:**<br>LA100 has consistent findings with other studies, but the associated costs and feasibility will vary region to region.<br>**Getting to 100% renewable energy:**<br>Everything gets more difficult the closer to 100%, and all the issues described in Table 1 and Table 2 become more significant to feasibility of solutions. |
| 100% renewable energy at all times, including contingencies and extreme events | 100% renewable energy in normal year | A significant share of costs is due to reliability, thus results (capacity, costs) observed in this study could be higher than in a study that allows alternate resources for meeting reliability requirements or planning for extreme events.<br>For example, this study would build more solar, wind, and batteries—and less capacity in renewably fueled combustion turbines—if extreme events were not considered. |
| 100% renewable energy for a city | 100% renewable energy studies for a region, nation | Conducting a study at a regional or national level is both harder and easier: harder in that constraints become more difficult to represent, requiring simplification (e.g., transmission and multi-area operations may have to be approximated); and easier in that the same simplifications make it appear easier to find pathways to 100%, and because regional and national studies have a broader set of available resources and interconnectivity options to choose from.<br>The LA100 study reflects the specific constraints of a city planning for 100% renewable energy. |

Regardless of location, undertaking a power system transition of this scale benefits from complex systems analysis to provide deep insights for electrification, clean transportation, and power-sector decarbonization, coupled with implications for environmental justice, air quality, and economics.

The approach taken by LA100 allows consideration of multiple priorities, grounded in a techno-economic understanding of options, addressing not only the practical system-operator concerns but also the issues that motivate broader community participation.

This study charts a methodology that employs an unprecedented scale of data and interwoven modeling tools that can be used to replicate, build upon, and scale up this type of analysis for other questions and jurisdictions.

The Los Angeles 100% Renewable Energy Study

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