UCLA Institute of the Environment & Sustainability

Accelerating the Urban Transition to 100% Renewable Energy

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This Green Paper was prepared by undergraduate researchers **Madeleine Farrington** (B.S. '21) and **Mingyi Chen** (B.S./B.A. '20) as part of the UCLA Institute of the Environment and Sustainability's Corporate Partners Program (CPP).

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I. Commercial Urban Buildings Offer Enormous Potential

As of 2018, 55% of the world's population lived in urban environments, with that figure projected to grow to 68% by 2050.[1] Already, cities account for nearly two-thirds of the global energy consumption and 70% of the world's energy-related CO_2 emissions.[2] If we are to wean ourselves off fossil fuels, we must start in cities. It is not surprising then, that most major cities have specific targets for reducing emissions. For example, Los Angeles unveiled a "Green New Deal" in 2019, setting targets of 55% renewable energy by 2025, 80% by 2036, and 100% by 2045.[3] Ambitious goals of replacing fossil fuels with renewable energy - such as those in the LA Green New Deal - are a good first step, but real progress will require zero-ing in on specific sources of energy demand. In this report, we focus on opportunities for expanding renewable energy implementation in urban commercial buildings through examination of available technologies and the companies that are developing them.

Commercial buildings account for 36% of all US electricity consumption and are responsible for 18% of US carbon dioxide emissions.[4] Making a change in a single commercial building could be tantamount to changing energy sources in anywhere from 3 to 20+ residential homes.[5,6] Standard photovoltaic paneling has been reviewed by numerous analysts. Here, we focus on innovative or emerging technology types that are not widely used, but that have great potential for rapid growth. In particular, we examined solar windows, long-duration energy storage, and solar powered cooling systems. These technologies were selected because: 1) every building has windows, with some commercial buildings featuring window-to-wall ratios as high as 100%;[7] 2) renewable energy is intermittent, making long-term energy storage a necessity;[8] and 3) global warming is increasing the demand for air conditioning or other forms of cooling across all city types[9] (Figure 1).

I. Commercial Urban Buildings Offer Enormous Potential

> Making a change in a single commercial building could be tantamount to changing energy sources in 3 to 20+ residential homes.

As the energy transition comes into full swing, new technologies will hit the market at an increasing rate. What looks good in a lab, on a test bench, or when first at market, may falter as production demands increase. Some false starts are inevitable. However, if we are to minimize inefficient investment of capital, we need systematic assessments of new technologies. This report offers a "first draft" attempt at evaluating new technologies that may hold great promise for a very specific sector: urban commercial buildings.

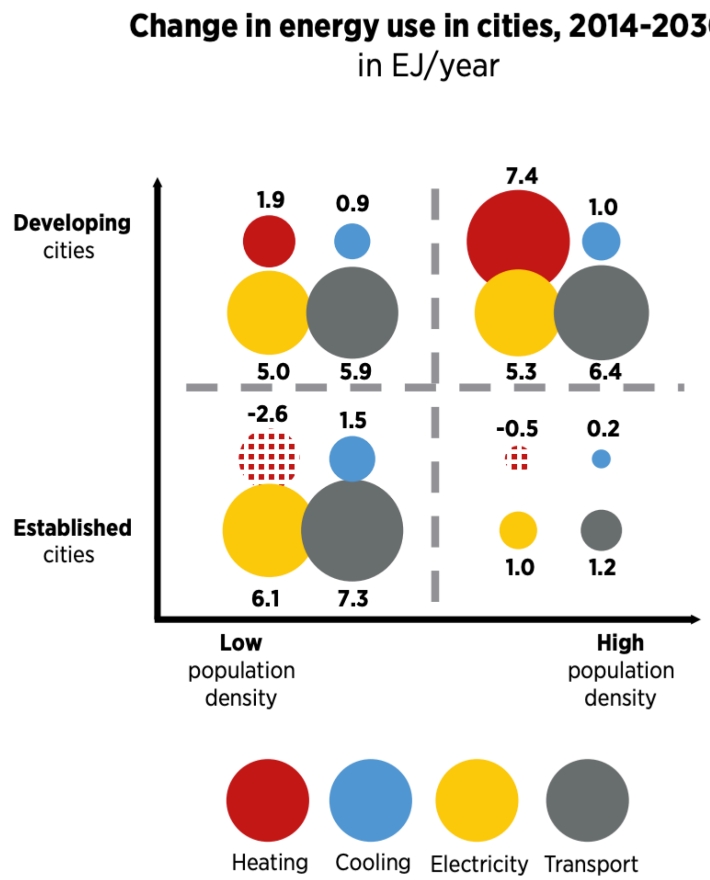

Figure 1: Changes in Energy Use in Cities, 2014-2030. This chart depicts how energy use for heating, cooling, electricity, and transportation will change across city types between 2014 and 2030, with the size of circles corresponding to the scale of change in EJ/year. Cross hatching indicates a projected decrease in energy use for the given sector, whereas a solid color indicates an increase. This figure was pulled from www.irena.org/publications/2016/Oct/Renewable-Energy-in-Cities.

II. Identifying Specific Companies and Conducting Interviews

In order to identify companies engaged with the above technologies (solar windows, solar chillers, and long-duration battery storage), we conducted internet searches and interviewed professionals and researchers in the renewable energy sphere. Initial searches turned up over 100 companies. We then inspected websites to determine if the businesses were active or capable of scaling up production to meet the demands of commercial buildings in a large metropolitan area like Los Angeles. We found only 22 companies poised to provide the desired technology for commercial scale products (Appendix 1). We then reached out to each of these 22 companies to request interviews. We conducted interviews with the following companies were sufficiently informative to include in this report: NEXT Energy Technologies, Solar Windows Technologies Inc, and Ubiquitous Energy for the solar windows category; Echogen Power Systems, ESS Inc, and NETenergy with NREL for the long-duration energy storage category; and Fahrenheit for the solar cooling category. A sample of interview questions is in Appendix 2.

At every stage of our research (initial informal interviews and discussions, initial internet searches, and in-depth interviews) solar cooling was poorly represented. For this reason, we analyzed solar cooling in a different way. We completed a market analysis to ascertain the demand for this new technology. Perhaps solar cooling was under-represented because it did not have as bright a future as solar windows and energy storage.

III. A Practical Framework for Assessing Emerging Energy Technologies

Whether comparing across technologies or between companies producing the same technology, one needs an assessment framework in order to make informed decisions. Key questions for any new renewable energy technology are:

1. How does the technology work, and how well-established is the product?
2. How much does the product reduce dependency on fossil fuel-based energy?
3. What does the product cost?
4. What are the product's environmental impacts?

There is no recipe for addressing these key questions. For the purposes of this report, we adopted a practical approach, for which information could be readily obtained. We recognize that a more in-depth analysis would be a valuable follow-up.

Considering the question of technology function and establishment, we investigated the degree to which the technology is being implemented, and what gap the technology fills. We also asked about each company's history and the status of product development. Direct statistics on the product's potential for reducing fossil fuel consumption were often unavailable. In lieu of this, reduced electricity or energy demand from the grid and energy efficiency improvements were considered. This information was often offered exclusively by the companies themselves. In-depth and individual examination of this topic for any of these technologies would be a valuable follow-up.

To assess the financial burden of switching to these new technologies, we considered both purchasing and installation costs. Most of these costs were provided by the companies themselves. Where available, we included payback ratios, which may help to justify the investment. Finally, to assess the environmental impact of new technologies, we examined the production process and waste streams — in other words, we considered the life cycle of the technology. Because we examined new products, we had to rely on the companies themselves for life cycle information.

IV. Establishment, Reduced Energy Demand, Cost, and Environmental Impact

IV. 1 — Three Pioneering Companies in Solar Windows

Most commercial buildings have numerous windows – both to provide natural lighting and because research has shown they are key to employee performance and job satisfaction.[10] If these windows generated renewable solar energy, they would contribute substantially to reduced emissions and reduced operating costs for the business. Any technology that uses windows to generate electricity from the sun could be classified as a "solar panel window."[11] Energy-generating solar windows first appeared in the 1980s.[12] Since then, most commercial solar windows have been made from glass coated in amorphous silicon – similar to the black silicon solar panels found on rooftops.[13] While a few transparent photovoltaic (PV) materials were invented for coatings, they are all either too unstable, difficult to produce, or not efficient enough to be commercially viable.[14] Solar windows tend to be inefficient compared to traditional solar panels, but they offer the advantage of serving two purposes: being a window and a solar energy collector. The first major solar window installation was Physee's PowerWindows in the south of the Netherlands in June 2017.[15] In this report, we examine three solar windows companies in detail: NEXT Energy Technology, Solar Windows Technology Inc., and Ubiquitous Energy.

> If windows generated renewable solar energy, they would contribute substantially to reduced emissions and reduced operating costs for businesses.

Company Profile: NEXT Energy Technologies Inc.

Establishment of the Company and its Technology Offering

NEXT Energy Technologies was founded at the University of California, Santa Barbara in 2011.[16] They specialize in transparent photovoltaic cells for use in commercial windows that could produce 20% of a building's power needs.[17] The company received millions of dollars in grants from the U.S. Department of Energy and the National Science Foundation.[18] They are currently passing various reliability tests needed to go to market in the building and window space and are establishing demonstration sites based on prototypes in California.[19]

Potential for Energy Delivery and Energy Savings

- **Transparency and Efficiency** — under high-angle and low-light conditions, as well as under optimal conditions.[20]
- **30 Years of Stable Energy Production**[21]
- **Customizable Windows' Color and Transmission** — by clients' preferences.[22]

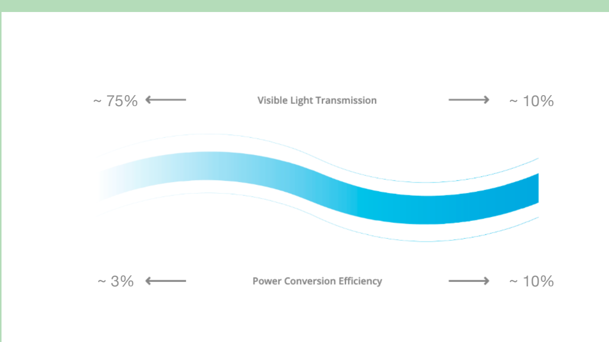

***Figure 2**: Customizable options of NEXT's Solar Windows Visible Light Transmission and Power Conversion Efficiency, from https://www.nextenergytech.com.*

Next Energy Technologies Inc.

Projected Cost

- **One-Year Payback** — the company promises a one-year payback if one includes tax credits, bonus depreciation, and reduced electricity bill.[23]
- **Cost Less Than Traditional Windows** — the effective price (accounting for tax credits and energy savings) of NEXT's windows is estimated to be less than traditional windows (~$95/ft2).[24] See Figure 3 for details.

Environmental Impact of Production and Usage

While no life cycle analysis of NEXT's windows is available, according to Jeff Horowitz, Director of Business Development & Partnerships at NEXT, the company's semiconducting materials are non-toxic, heavy metal free, and are printed using a low-energy process.[25] The non-proprietary portions of the cell employ materials that are common within the flat glass industry and generally regarded as safe under normal usage conditions.

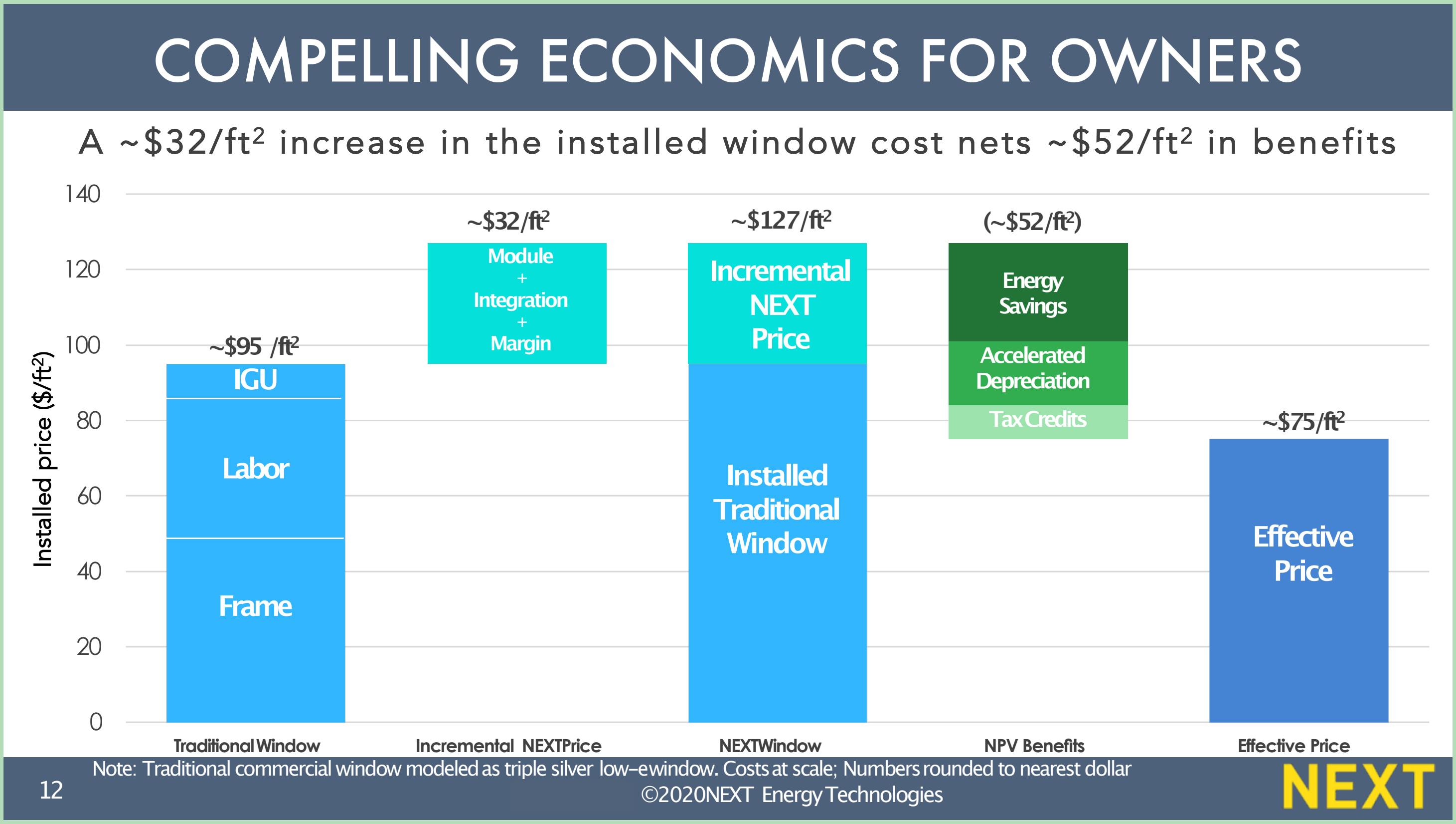

Figure 3: The incremental price of a NEXT Window and the NPV Benefit Streams to the Building Owner. NEXT's product not only adds just ~$32/ft^2 to the cost of windows but also offers energy savings, accelerated depreciation, and tax credits (~$52 in savings), which drops the effective cost of NEXT's windows to ~$75/ft^2. This figure is provided by Jeff Horowitz, Director of Business Development & Partnerships at NEXT Energy Technologies.

Takeaways

NEXT's windows can be customized for any building and light situation. They also have a projected cost that is less than conventional windows. It is important to see whether this prediction is accurate once the products are commercialized. While no life cycle analysis is available, ideally photovoltaic-coated glass would be recycled just as easily as regular commercial window glass. However, the window industry, in general, performs poorly in recycling products at their end of life, partly because it is costly and there is little incentive for companies to do so.

Company Profile: Solar Winidows Technologies Inc.

Establishment of the Company

Solar Windows Technologies Inc. was founded in 1998, and is currently developing transparent electricity-generating coatings for glass and flexible materials, with a focus on commercial and architectural glass, retrofit and laminate veneers, and flexible glass and plastics.[27] The company states many potential applications for electricity-generating SolarWindow™ coatings.[28] Its initial target market is glass windows in commercial buildings. Other applications include residential windows, automotive sunroofs, commercial and military aircraft, and more.[29] The company also develops products for application on existing windows.[30]

SolarWindow™ coatings are currently in the research and development stage. The company is seeking commercial manufacturing partners that will integrate SolarWindow™ coatings and processes into existing glass fabrication processes.[31] In this way, SolarWindow™ does not need to develop its own customers and market - rather it provides added value to established window producers.[32] Solar Windows Technologies Inc. has not released a timeframe for when its products may be ready for market. The company is raising more capital in order to formalize strategic relationships with glass, energy, and building industries.[33] One of the company's primary objectives is to develop high speed and large area roll-to-roll (R2R) and sheet-to-sheet (S2S) coating methods required for commercial-scale window products.[34]

Potential for Energy Delivery and Energy Savings

The company claims that its SolarWindow™ can outperform today's solar by as much as 50-fold when installed on a 50-story building, according to independently validated power production calculations.[35] The two main advantages of SolarWindow™ compared to conventional solar systems are:

- **Applicable to All Sides of Buildings** — SolarWindow™ can be applied to all four sides of tall buildings, while conventional solar is limited to rooftops.
- **Utilizing Natural, Shaded and Artificial Light** — SolarWindow™ can potentially generate electricity using natural, shaded, and even artificial light, while today's solar systems do not perform well indoors or under artificial light.[36]

City, State	Cadmium Telluride (CdTe)	kWh Equivalency Estimates (Annually)
Manhattan, NY	45,110	1,112,400
Savannah GA	50,020	1,233,310
Lansing, MI	41,190	1,015,670
Chicago, IL	43,150	1,064,030
San Francisco, CA	52,960	1,305,860
Amarillo, TX	56,880	1,402,590
Miami, FL	52,960	1,305,860
Baltimore, MD	57,750	1,112,400
Denver, CO	55,900	1,378,410
Phoenix, AZ	63,750	1,571,870
Nashville, TN	48,060	1,184,950

Figure 4*: Energy Generation Comparison of CdTe and SolarWindow™. For some major cities in America, Solar Windows Technologies Inc. compares its energy generation to the most common solar technology CdTe based on the company's estimates of its power production model on a 50-story building. This figure is made from data on https://www.solarwindow.com/powermodel*

Projected Cost

One Year Payback — the company states that SolarWindow™ can achieve payback within one year, according to independently validated financial modeling results from 2015.[37] They also claim that producing an equivalent amount of energy with conventional solar systems would require at least 10-12 acres of valuable urban land and take 5-11 years to pay back the installation investment.[38]

Environmental Impacts

Production — The company refers to its SolarWindow™ as 'organic photovoltaic solar arrays' (OPV) due to the family of materials used in production.[39] SolarWindow™ modules are created by applying ultra-thin layers of liquid coatings on glass and flexible plastics.[40] Their liquid coatings are made primarily of hydrogen and carbon.[41] Unlike conventional solar, their method of applying the coating does not require high-temperature or high-vacuum production techniques that may draw on fossil fuels.

Usage — The company claims that SolarWindow™ can achieve 12-times the environmental benefits of conventional solar.[42] According to test modules installed on a single 50-story tower, a single installation of SolarWindow™ modules are predicted to avoid carbon emissions equivalent to vehicles driving over 2.2 million miles each year, compared to today's rooftop (PV) systems, whose installation avoids emissions equivalent to a lesser 180,000 miles.[43]

Takeaways

The company needs more capital and partnerships to become commercialized. SolarWindow™ vastly outperforms traditional solar technology (CdTe) as demonstrated by the modeled emissions reductions if installed on a 50-story building.

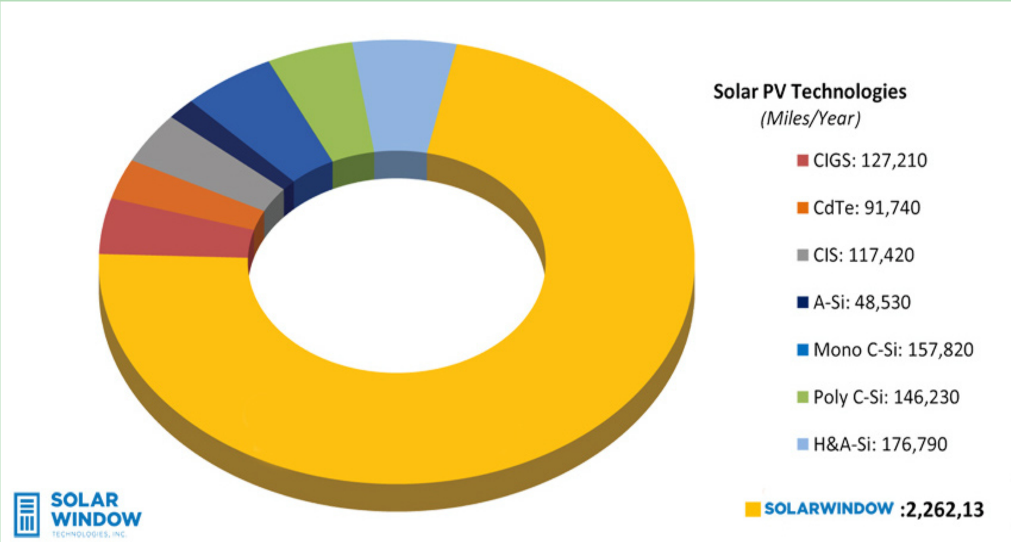

***Figure 5**: Carbon emission reduction measured in miles/year of various solar technologies, compared to SolarWindow™, based on the company's estimates of its power production model on a 50-story building in Amarillo, TX. SolarWindow™ is estimated to be able to reduce 134,473 more miles/year compared to the most common CdTe technology. From solarwindow.com*

Company Profile: Ubiquitous Energy

Establishment of the Company and its Technology Offering

Ubiquitous Energy was founded at Massachusetts Institute of Technology in 2012.[44] Their breakthrough technology is a specialized glass coating applied directly onto glass during manufacturing, which absorbs only ultraviolet and infrared light to produce electricity.[45] The transparency of this coating varies between 40% and 70%.[46] These solar windows differentiate themselves from others on the market by producing electricity while simultaneously letting visible light through.

Ubiquitous relocated to the Bay Area in 2015.[47] Since then, they have scaled up and improved the performance of their technology. The company launched a pilot production facility in the Bay Area to produce 14 x 20 inch Ubiquitous Energy transparent window panes.[48] They are now seeking opportunities to provide proof-of-concept pilot installations as a way of demonstrating the technology, at locations such as universities.[49]

At the company headquarters in Redwood City, California, approximately 100 square feet of transparent solar windows were installed to produce electricity, powering LED lighting in the conference rooms while maintaining the performance of standard commercial window glass.[50] By 2022, Ubiquitous plans to build a high-volume manufacturing line capable of producing windows as large as 1.5 x 3 meters (59 x 118 inches).[51]

Energy Potential for Energy Delivery and Energy Savings

- **Absorbing only the Ultraviolet and Infrared Light** — Ubiquitous designs its solar cells to selectively transmit light visible to the human eye while absorbing only ultraviolet and infrared light to convert into electricity.[52]

- **Over 10% Energy Efficiency, Up to 90% Visible Light Transmission** — Ubiquitous technology is unique in that it allows up to 90% visible light transmission. In contrast, others allow only a portion of visible light to pass through, either by thinning down the photoactive material or by segmenting cells across the module area, sacrificing efficiency and transparency of the windows.

Projected cost

- **Difficult to Estimate —** projected cost in urban settings is highly dependent on variables such as location and labor.[53]

- **Projected to Cost Slightly More —** Veeral Hardev, Director of Business Development, claims that Ubiquitous windows will cost only 10-30% more than traditional windows once their high-volume production line is in place.[54] The cost for the company headquartes' 100 square foot project is unavailable. However, according to Hardev, it is estimated that the total cost of Ubiquitous windows per square meter in downtown San Francisco is approximately $1050, compared to $900 for traditional windows.[55]

Environmental Impact of Production and Usage

While no lifecycle analysis of Ubiquitous windows is available, the solar windows are internally tested and externally validated at accredited national labs for durability and offer the industry-standard 10-year warranty.[56] Materials used for production are abundant, non-toxic commodities.[57] The application of the special coating is achieved by modifying materials' properties in a non-energy intensive process, using vacuum chambers and physical vapor.[58] Clients receive Ubiquitous windows 4-6 weeks after ordering.[59] The time it takes to wire on location is determined by the scope of the project. For example, it took a month to wire solar windows for a 100 square foot conference room located at the Ubiquitous headquarter.[60]

Takeaways

One distinct feature of Ubiquitous solar windows is that they absorb only ultraviolet and infrared light for energy generation, allowing full transmission of visible light. However, their projected cost and cost efficiency remains ambiguous until more applications are installed.

IV. 2 — Three Pioneering Companies in Long-Duration Energy Storage

Wind and solar energy are intermittent resources. If these renewable sources of energy are to truly replace fossil fuels, long-duration energy storage will be necessary.[61] Until recently, most public policy regarding renewable energy (rebates and tax incentives) focused on energy generation. With the American Energy Innovation Act of 2020, energy storage is receiving more attention.[62] Section 1301 specifically establishes a research, development, and deployment program; creates a grant program for trial projects of emerging technology; and institutes a competition to encourage recycling materials critical to energy storage systems.[63] Additionally, the Act instructs the Federal Energy Regulatory Commission (FERC) to enact regulation supporting cost recovery for investment in energy storage projects.[64] This initiative should accelerate the development and implementation of new storage technologies. In this report, we examined three long-duration storage companies in detail: Echogen Power Systems, ESS Inc.,

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With the American Energy Innovation Act of 2020, energy storage is receiving more attention.

ECHOGEN power systems

ESS INC

NETenergy

Company Profile: Echogen Power Systems

Establishment of the Company and its Technology Offering

Echogen was founded in 2007 and produces waste heat-to-power systems that use CO_2 as a working fluid.[65] They also have an ongoing energy storage project called "The Echogen Electro-thermal Energy Storage (ETES) system," which uses a thermodynamic cycle to convert energy between electricity and heat based on development of commercial supercritical CO_2 power cycles.[66]

ETES is charged by a cycle of using electrical power to move heat from a cold reservoir to a hot reservoir and creating stored energy as both "cold" and "heat" (heat pump refrigeration cycle).[67] The electrical power is discharged by using heat stored in the hot reservoir (heat engine power cycle), while the cold reservoir improves performance of the heat engine.[68]

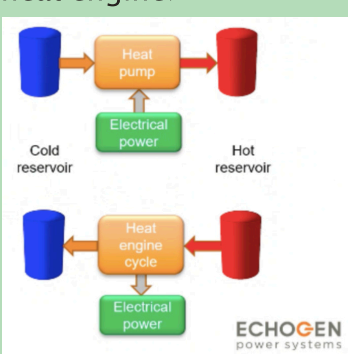

***Figure 6**: Simple Visualization of Echogen ETES Charging Cycle and Generating Cycle. Figure fromTimothy Held, CTO at Echogen.*

This product stores electrical energy as thermal energy, then recovers back to electricity. This product is suited for larger scale projects than urban buildings due to its 10MW efficiency threshold.[69] This energy storage project has received funding from ARPA-E and other ongoing U.S. federal energy funding initiatives.[70] The company is currently designing a 10MWe, 8 hours demonstration plant, actively seeking industry partnerships and federal funding, and targeting late 2021/early 2022 for commissioning and operations.[71] They predict that a successful demonstration will lead to 3-5X scale-ups.[72]

The company has identified three new power grid markets that could be opened by longer duration storage:[73]

- Green residential/commercial microgrids - driven by the supply of local renewable generation and the need for resilient back-up from major grid threats, such as weather and terrorism.
- Industrial microgrids - driven by similar reasons above with heating/cooling opportunities using thermal storage systems.
- Data centers - replace fossil-fueled power with contracted renewables.

Energy Potential for Energy Delivery

- **4- 6 Hours of Energy Storage** — scales up to several days worth of storage (up to approximately 100 hours).[74]
- **Maximized Storage Efficiency** — by omitting the DC-AC power converter.
- **Optimism on the Market** — "the development of non-battery storage solutions currently underway offers much lower incremental storage costs than batteries, opening the market for durations from 6 hours up to 12 hours and even longer."[75] Long-duration storage is also predicted to play an important role in renewable-driven conventional grids via three applications:[76]
    - Pairing with wind and solar - for high capacity factor power plants.
    - Stand-alone storage - to defer investment in new transmission (larger scale) and new distribution (smaller scale) due to changes in power supply and demand locations.
    - Islanded power grids - to lower power costs and provide back-up power and eliminate high cost diesel and LNG fuels.

Projected Cost

- **LCOS Advantage for > 6 hours Storage Time** — comparing ETES capital cost and levelized cost of storage (LCOS) to the capital cost of fixed electrolyte battery solutions such as lithium-ion, ETES gains advantage for storage times greater than 6 hours and retains a 40-50% LCOS advantage into 2030.[77] See figure 7 and 8 for details.
- **Fraction of Total Cost** — according to Timothy Held, CTO at Echogan, the cost of battery itself accounts for a small fraction of total cost, but labor and installation cost do not scale down with time and expansion.[78]

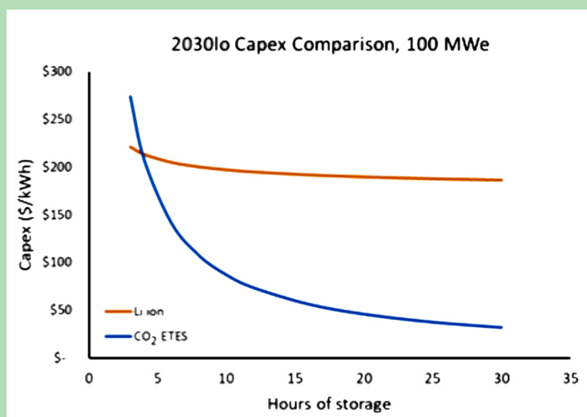

***Figure 7**: Echogen ETES 2030lo Capex Comparison, 100 MWe. ETES cost per kWh decreases significantly after 6 hours of storage time compared to Li-ion energy storage, which has a rather constant cost as time increases. This figure is from https://www.echogen.com/energy-storage/etes-benefits/*

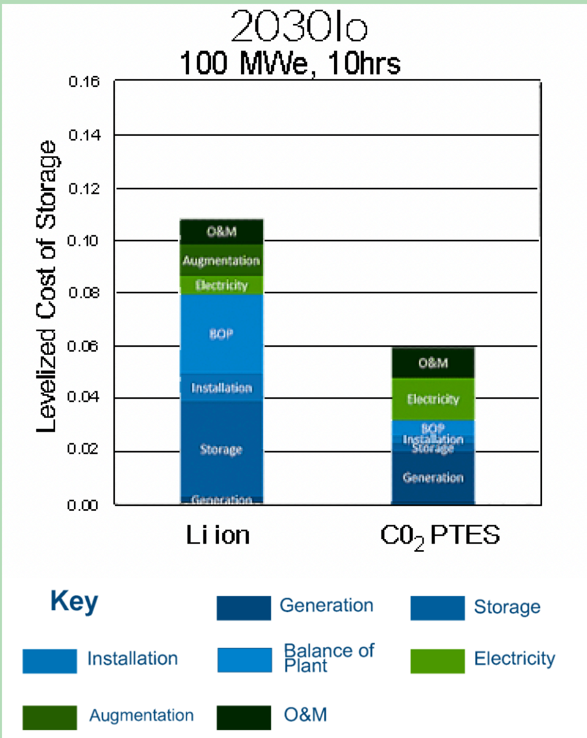

Figure 8: Echogen ETES 2030lo Capex Comparison, 100 MWe. ETES cost per kWh decreases significantly after 6 hours of storage time compared to Li-ion energy storage, which has a rather constant cost as time increases. Figure from https://www.echogen.com/energy-storage/etes-benefits

Environmental Impact of Production and Usage

The lifetime of ETES is estimated to be a typical industrial equipment guarantee of 30 years. The storage materials used for ETES are water (+ 10% propylene glycol) and sand.[79] Materials used for construction are carbon steel and stainless steel. Echogen as the technology developer, not the manufacturer, cannot provide any supply chain assessments.[80] However, considering the common distribution of carbon steel and stainless steel and their domestic sources of supply, there is a low risk of supply chain disruption.[81]

Echogen ETES uses CO_2 as the working fluid, and the thermophysical properties of this fluid offer cost and safety advantages. CO_2 is significantly less hazardous than Li-ion or other chemicals often used as working fluids. The company sources its CO_2 from the same supply chain that the beverage/food industry uses for cost efficiency.[82] There are around 5-10 tons of CO_2 in one ETES, which runs in a closed-loop system.[83] ETES has a seal to hold back CO_2 pressure, but leaks around 1 ton of CO_2 per month.[84] Echogen is working on reducing this leakage.[85]

Takeaways

For urban spaces, ETES has two advantages over the currently popular lithium-ion batteries: reduced environmental footprint and enhanced safety. The company claims that the technology is designed to be low-cost, physically safe, environmentally safe, non-seasonal, and non-geographically restricted.

Company Profile: ESS Inc.

Establishment of the Company and its Technology Offering

ESS Inc. manufactures the Energy Warehouse™ (EW), which is a low-cost, long-duration iron flow battery for commercial and utility-scale energy storage applications.[86] The battery can supply 4+ hours of flexible energy capacity.[87] ESS promotes their battery as being the long-life energy storage solution for renewable energy infrastructure that is more environmentally friendly than lithium storage batteries.

ESS Energy Warehouse™ (EW) is commercially available, and can be used for many applications in the utility, commercial, and industrial markets, both on- and off-grid, including:[88]

- Renewable energy time shifting
- Demand charge management
- Time of Use (TOU) tariff arbitrage
- Energy security
- Utility ancillary services
- Deeper penetration of renewables
- Demand response
- Capacity reserve
- Infrastructure support
- Run generators at peak efficiency
- Microgrid stabilization, energy shifting

Energy Potential for Energy Delivery

The ESS Energy Warehouse™ (EW) has an energy storage capacity of 400 kWh, a 25-year design life, and can be configured with variable power to provide storage durations of 4 to 12 hours. Its specific features are:[89]

- **Configurable Range**: 33 kW-100 kW (peak power)
- **Storage Duration**: 4 - 12 hours
- **Usable Energy**: 400 kWh
- **Round Trip Efficiency** — a phrase that describes how much energy the storage system is able to discharge after charging: 75% DC-DC, e.g. if the battery is charged with 100 kWh, one should be able to discharge 75 kWh of electricity from the battery.
- **Response Time**: Less than 1 second.
- **Lifetime**: The battery can be recharged for more than 20,000 cycles.
- **Cooling/air conditioning requirement**: None.

Figure 9: Timeline and Projects of ESS Energy Warehouse. The total exceeds 10 MWh contracted. This is provided by Aram B. Zamgochian, Senior Director of Strategic Partnerships at ESS Inc.

Projected Cost

- **Low LCOS** — ESS claims to address a broader range of energy and power applications at a lower Levelized Cost of Storage (LCOS) than other energy storage technologies on the market; however, the company does not provide specific cost figures.[90]
- **Reduced Shipping Cost** — ESS EW is shipped in a dry state and is hydrated onsite.[91]
- **Insurance Coverage** — ESS Inc. has partnered with Munich RE (a reinsurance company based in Munich, Germany) to launch industry-first insurance coverage of their flow batteries, which gives all ESS long-duration storage solutions a full 10-year performance guarantee, regardless of project size or location.[92]

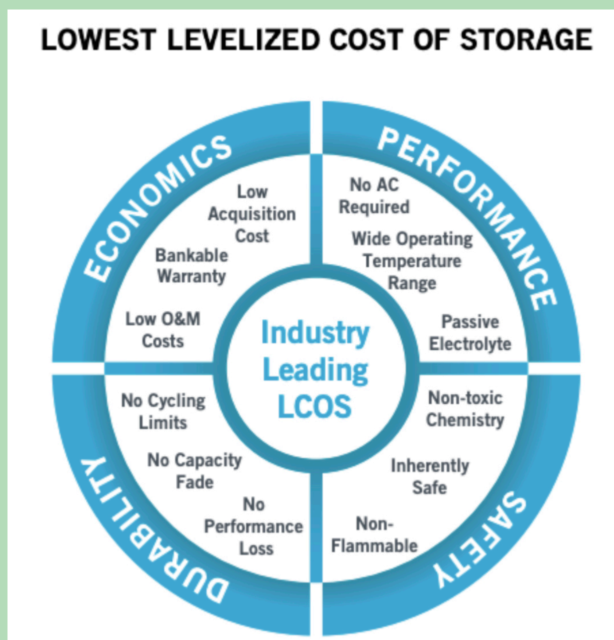

Figure 10: Components of LCOS Specific to the Energy Storage Industry. Provided by ESS Datasheet for 400 kWh Energy Warehouse™ Iron Flow Battery

Environmental Impact of Production and Usage

ESS claims that all of the materials associated with their batteries, including the electrolytes ($FeCl_2$, KCl, H_2O), are non-toxic, non-flammable, and 100% recyclable.[93] ESS batteries are composed mostly of off-the-shelf industrial components, and their sealed systems require no augmentation.[94] ESS promotes their products as offering fast and easy permitting with no hidden liabilities or hazmat compliance plan requirement.[95]

Takeaways

The electrolytes ESS EW uses have significant advantages compared to widely-used lithium-ion batteries from environment, health, and safety perspectives. ESS flow batteries have little to no fire risk or chemistries that pose human health risks. Their longer-duration capability compared to their lithium-ion counterparts is ideal for large-scale, long-duration storage because they can store large amounts of energy using scalable tanks of relatively low-cost electrolyte. Their ability to ramp up or down with no degradation helps combat the intermittency issues from using renewable energy generation

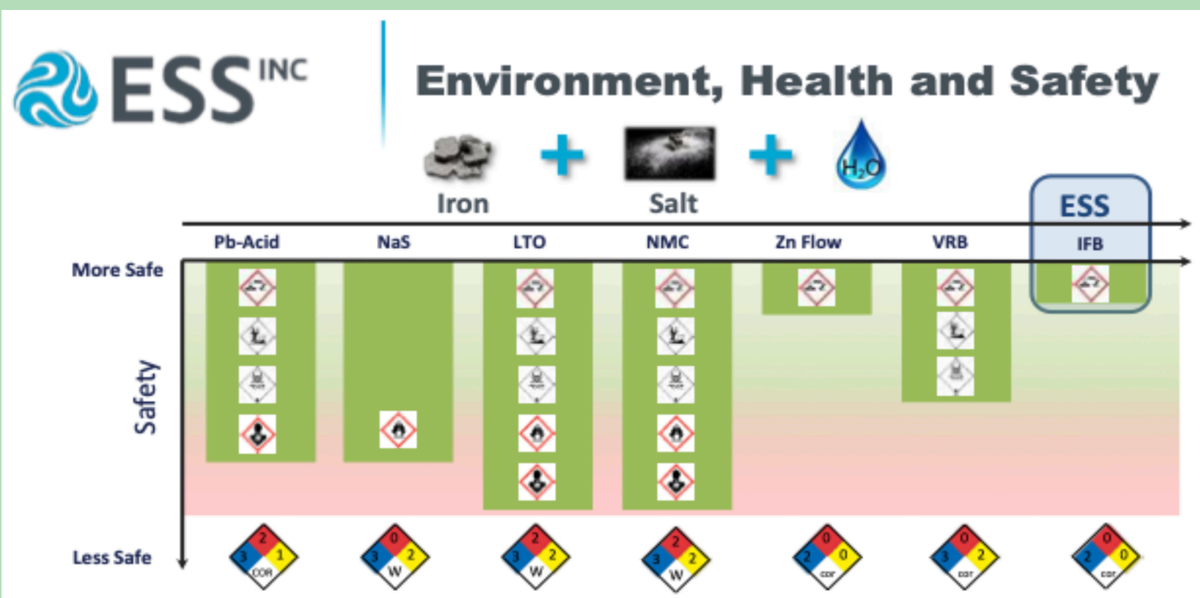

***Figure 11**: ESS Inc. Environment, Health and Safety (EHS) Chart. ESS EW uses iron, salt, and water together as the electrolytes, therefore reducing hazardous and toxic risk. These earth-abundant elements are also recyclable. This figure is provided by ESS One Pager.*

Company Profile: NETenergy

Establishment of the Company and the Research Project

NETenergy is a thermal energy storage (TES) company, based in Chicago, IL.[96] The company participates in the Wells Fargo Innovation Incubator, through which they are working with National Renewable Energy Laboratory (NREL) to integrate a phase change composite (PCM) TES into an existing air conditioning technology.[97] This product aims to dispatch renewables such as solar energy efficiently, to meet fluctuating demand from the grid. It is intended for application in small commercial buildings for cooling (mostly) and heating.[98] NETenergy and NREL also work with industry partners such as Emerson and Ingersoll Rand to optimize this thermal battery and bring it into commercially available AC systems.[99] A first-generation prototype has been produced to test the battery's weight, leakage, and stability.[100] Ramin Faramarzi from NREL states that the product is currently at stage four of readiness according to the Technical Readiness Level by DOE (Stage 1: conceptual stage of research and development, Stage 9: fully commercially ready).[101]

Energy Potential for Energy Delivery

- **Combating Variations in Energy Demand** — thermal energy storage achieves energy efficiency by using energy generated during times of low demand to power the grid when demand increases again.[102]

- **Highly conductive graphite from PCM** — PCM used in this thermal storage is processed into graphite, which then goes through chemical processes to become a highly conductive material. It is able to change phase rapidly to discharge for cooling and to charge in 2 to 3 hours.[103] During low power hours, PCM can be fully discharged without a compressor. With some power demand, PCM needs to be charged with a compressor. The research team is working with Emerson to research and develop the controller for this discharging process.[104]

- **Downsized Compressor, Same Cooling** — the compressor is a key contributor to power consumption, accounting for around 80%.[105] For example, 5 tons of cooling refers to 5kW worth of heat removal capability. NREL research aims to use a 4kW compressor to provide the same tonnage of cooling.[106]

Projected Cost

A rough estimate is not possible — the research group currently focuses on the physics and thermal science of the product and will tackle weight issues next.[107] Analysis of cost effectiveness follows this research and development stage.

Environmental Impact of Production and Usage

Energy efficiency improvements achieved through a smaller compressor offer significant environmental impact. The 5-ton units discussed in the previous example are ubiquitous in California. Sizable energy savings could be achieved if all 5-ton units transitioned to a downsized compressor. Relevant pollutants are also reduced through increased energy efficiency. Carbon dioxide emissions are decreased by energy storage during the cooling seasons.

Takeaways

While this technology is still in its research and development stage, one can easily predict the market for cooling, thermal energy storage, and the integration of both for comfortable urban living on our increasingly warming planet.

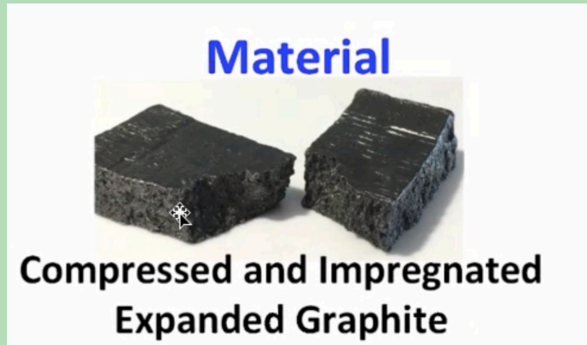

***Figure 12**: Photos of Graphite. Graphites act similar to sponges that can be compressed and expanded. This is provided by Ramin Faramarzi from NREL.*

IV. 3 — A Pioneering Company in Solar Powered Adsorption

Air conditioning emerged in the 1960s across America to provide refuge on warm, summer days.[108] Benefits ranged from better sleep to improved productivity for workers, but most notable were the significant human health impacts.[109,110] While human's thermoregulatory systems dissipate heat and maintain homeostasis, extreme temperatures can contribute to the breakdown and failure of these processes, resulting in heat-related illness and death. Warm weather can exacerbate chronic illnesses, including cardiovascular, respiratory, and cerebrovascular diseases.[111]

Prior to the widespread adoption of air conditioning systems, there were approximately 25.2 days of extreme temperature, (greater than 80°F) per year, resulting in 12,000 premature fatalities annually in the US. If scaled with US population growth and temperature increases, that value would have risen to 20,000 deaths per year from 1960 through 2004. However, though the frequency of extremely hot days increased during that time period, air conditioning reduced the death rate dramatically to 5,600. Today, AC saves approximately ~18,000 lives per year.[112]

> Today, AC saves approximately 18,000 lives per year.

However, this life-saving technology comes at a cost. Modern cooling units run on exorbitant amounts of electricity. While cooling systems have become significantly more efficient, requiring 30-50% less energy than in the 1970 for the same degree of cooling, the Department of Energy reports that air conditioning units for residential buildings can consume over 2,000 kWh in a year, translating to 3,500 lbs of carbon dioxide and 31 lbs of sulfur dioxide.[113] Commercial buildings demand even greater supplies of electricity for cooling, with 30-ton AC systems for very large commercial buildings requiring as much as 63,493 kWh per year.[114]

The quandary is clear: global warming creates a greater demand for air conditioning, but air conditioning depends on large amounts of electricity that are often associated with greenhouse gas emissions, increasing global warming and, in turn, the need for more air conditioning. Models predict an additional 80 days of extreme temperatures (over 80℉) by the end of the century.[115] Following this trend, air conditioning unit installation is projected to rise from 1.6 billion as of 2019 to 5.6 billion by 2050.[116] This increased cooling demand across city types will translate to an additional 0.2EJ-1.5EJ of electricity use per year by 2030.[117] The emissions of hydrofluorocarbons alone from these systems could generate an additional 0.4℃ of warming by 2100.[118] Without new action, we are trapped in a positive feedback loop of increased temperatures begetting greater AC demand, begetting greater power demand and emissions, begetting increased temperature.

If we could convert all air conditioning to a renewable energy source, what might be the savings? We were able to do a back-of-the-envelope estimate of this by drawing on the following data: the highest reported kWh/year demands for a large commercial AC systems, L.A. County electricity charges, average monthly temperatures, and emissions per kWh (see Appendix 3 for details). We found that transitioning a single Los Angeles commercial building's 30 ton air conditioning system from fossil fuel-based electricity to in-house renewable electricity could save over 30 tons of CO_2 emissions per year and over $3658 per year in electricity costs. For simplicity, this value does not account for demand charges, but if it did contain demand charges the savings could be even greater.[119]

The International Renewable Energy Association recommends solar cooling (i.e. any air conditioning system drawing from solar power) as the best option for established cities because it can easily be integrated into existing building infrastructure. For example, connecting AC systems to rooftop solar panels and battery storage systems is becoming increasingly popular in the residential sector.[120] Further, solar cooling has an advantage over other types of solar applications such as solar heating, in that the greatest demand for cooling occurs mid-day - when solar radiation is at its most intense. Five variations of solar cooling have received the greatest research and development attention:

1. Absorption Cooling
2. Adsorption Cooling
3. Rankine Cycle Heat Engine Cooling
4. Desiccant Cooling
5. Ejector Cooling[121]

Models predict an additional 80 days of extreme temperatures (over 80°F) by the end of the century.

However, despite considerable market potential, we were surprised to find relatively few solar cooling companies in our search. Fahrenheit, a company specializing in adsorption cooling, is discussed below. As demand in this arena increases and more solar cooling companies emerge, this framework can be implemented to assess different technologies and determine which may be worthwhile to implement.

Adsorption chillers depend on a refrigerant, whereby energy to drive the cooling process is pulled from waste heat, such as exhaust or steam from industrial processes or heat directly generated from solar panels. In contrast with conventional air conditioners which require large amounts of electricity, adsorption chillers are highly efficient, consuming electric power comparable to that required for a few incandescent light bulbs. Another key signature of adsorption chillers is that solid materials - such as silica, activated carbon, and zeolite - are used as the desiccant. Since adsorption cooling eliminates the need for chemicals like lithium bromide, ammonia, CFCs, or freons required in conventional systems, the risks of hazardous material leaks and aggressive corrosion is diminished. The maintenance and upkeep costs are minimal, thanks to limited moving parts and the absence of corrosive liquid, such as lithium bromide salt, as the desiccant. See Figure 13 for details on Fahrenheit's adsorption systems.

A single Los Angeles commercial building's 30 ton air conditioning system from fossil fuel-based electricity to in-house renewable electricity could save over 30 tons of CO_2 emissions per year and over $3658 per year in electricity costs.

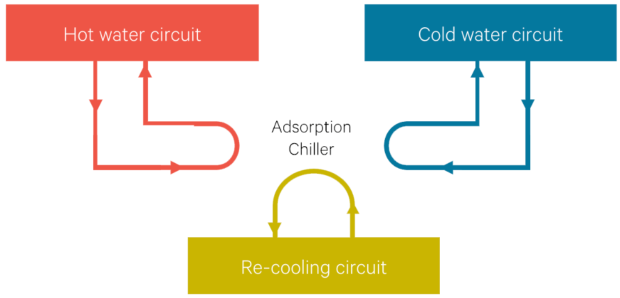

***Figure 13**: This figure outlines the cooling process implemented in Fahrenheit's adsorption systems. The red box depicts the "hot water circuit" in which heat from the solar thermal system is utilized to warm the water, which then serves as the energy source for the system. The blue box depicts the "cold water circuit" in which energy is used to cool the water and send it out for cooling. Finally, the "re-cooling circuit" operated to dissipate residual heat. This figure was sourced from https://fahrenheit.cool/de/technologie/#integration*

Company Profile: Fahrenheit

Establishment of the Company and its Technology Offering

Fahrenheit originated in Germany in 2002 under the original name SorTech AG, born out of field testing of adsorption technology versus absorption technology at the Fraunhofer Institute for Solar Energy Systems (ISE).[122] Ultimately, ISE's research indicated that adsorption was more promising, due to lower costs, reduced maintenance, non-toxic and non-corrosive materials, and increased flexibility in the face of variable temperatures. Fahrenheit's first commercial adsorption chillers reached the market in 2008. Since then, their product has undergone innovations in the form of new adsorbent materials and the emergence of hybrid chillers. They have integrated their adsorption cooling technology with solar thermal systems, enabling them to be powered by solar thermal energy. Fahrenheit notes that this combination offers the greatest potential during summer months, when temperatures, available solar energy, and AC demand all increase.[123]

On their website, Fahrenheit provides an overview of five large scale projects around the world that have implemented their adsorption cooling technology powered by a solar thermal system. Projects range from cooling capacities of 6 kW to 150 kW, at locations from Germany to Ukraine.[124] These sample projects illustrate Fahrenheit's ability to service commercial scale projects in Los Angeles.

FAHRENHEIT
Cooling Innovation.

Potential for Energy Delivery and Energy Savings

- **Energy Source** — pulls energy from water heated by the solar thermal system to power the adsorption cooler.[125]
- **Improved Efficiency** — reduces electricity requirements for cooling by 60-80%, compared to a compression system.[126,127]
  - **Lower Evaporation Temperature** — cooling occurs in vacuum inside system, which enables water to evaporate at lower temperature; less energy required to heat water.[128]
  - **Optimal Heat Exchange** — zeolite crystals "grown" on heat exchanger rather than attached, improving energy density, power density, and heat transfer.[129]
- **Cooling Capacity**
  - Silica Systems: up to 100 kW
  - Zeolite Systems: up to 75 kW
  - Hybrid Systems: up to 135.5 kW[130]

Projected Cost

- **Concrete Cost Estimates Not Available** — numerous dynamic factors lead to variation in cost on a project by project basis.[131]
- **Rough Cost Estimate** — Adsorption cooling costs estimated to be as much as two to three times that of conventional systems, due to a smaller production scale and demand for adsorption chillers.[132]
  - **Example**: Silica gel-based chiller system eCoo10 has a listed price of 14,000€ (approximately $15,882 by current conversion rates), however this value rises to 20,000€ ($22,689) when the required supplemental products - including a dry recooler, pumps, and piping - are taken into account.[133]
- **Affordability on Commercial Scale** — as system size increases, the cost per ton generally decreases, making this product more viable for large scale, commercial projects.[134]

Environmental Impact of Production and Usage

Fahrenheit dissipates the environmental burden of their products by ensuring that they can be used for a long time and use low impact materials. One benefit of Fahrenheit's adsorption technology is the lack of moving parts, limiting the mechanical wear common to conventional compression systems.[135] Additionally, because the adsorption materials (silica gel or zeolite) do not age, systems utilizing them can run continuously for decades, with minimal maintenance on certain features every one to three years.[136]

Fahrenheit chillers are composed of valuable materials such as copper, steel, and aluminium. As such, upon reaching the end of their lifetime, it may be financially beneficial to recycle all parts.[137] Further, while one might assume that creating a vacuum within the chiller would demand massive amounts of materials to combat atmospheric pressure, the vacuum shell is designed in close contact around the internal structure, enabling Fahrenheit to construct the shell from thin sheets of stainless steel. This innovation reduces both material and construction needs.[138]

In terms of climate change implications, conventional cooling agents such as R410 and 134a generally have high global warming potential (GWP). In contrast, Fahrenheit relies on refrigerants with little to no GWP, such as water, and alternative energy sources, such as solar. Though full lifecycle analysis of Fahrenheit's production impacts is not available, the chiller's upfront resource demands are likely greater than that of a comparable classical system. However, the reduced electrical needs and longevity of the system once the technology is in place redeem the sustainability of Fahrenheit's adsorption chillers.[139]

Takeaways

The most compelling element of Fahrenheight's adsorption chiller technology is the responsible selection of materials, from water as a refrigerant and silica or zeolite as the adsorption surface to a thin stainless steel encasing. The results include greatly reduced emissions and materials use.

V. Conspicuous Gaps in Available Information

Our examination of emerging renewable energy technologies revealed a startling scarcity of data regarding the environmental impacts of specific emerging renewable energy technologies. As nations and large corporations strive to achieve aspirational renewable goals, it is important that their investments and choices be well-informed on financial, environmental, and social costs. Pressing forward in decision-making without complete information has historically yielded negative results. One such example was the adoption of refrigerants containing chlorofluorocarbons (CFC) in air conditioning units in the 1920s. At the time, CFCs were seen as a safer alternative to toxic refrigerant options such as ammonia, methyl chloride, and sulfur dioxide. Chlorofluorocarbons were selected exclusively on the basis of boiling point, flammability, and toxicity, without attention to potential environmental impacts of the chemical.[140] In the 1970's, after fifty years of commercial use of CFCs, scientists discovered the link between the chemical's release into the atmosphere and destruction of the ozone layer that shields the earth from harmful UV rays. Following this discovery, phasing out CFCs in refrigeration units around the world became a decades long ordeal. This tale of caution makes clear the value of developing as complete an understanding of emerging technologies as possible, before widespread rollout to the market.[141]

In terms of environmental impact, most renewable energy technologies have obvious benefits in reduced greenhouse gas emissions per kWh energy production. However, the creation of renewable energy technologies, from harvesting of raw materials to the manufacturing of a final product, could be associated with environmental effects that make some technologies significantly more beneficial overall than others.

In searching the literature, we were surprised by how little we could find regarding the possible environmental impacts of specific emerging technologies. Terminology used in the search included various combinations of the words and phrases "manufacturing," "production," "environmental impact," "cradle to grave analysis," "life cycle analysis," "benefits," "consequences," and "raw materials" with the names of the emerging technology considered here. We did uncover some life cycle analyses, but these analyses were general and did not discriminate between the different emerging technologies.

One potential reason for this information gap is limited incentive to support the needed research. Companies manufacturing renewable energy technology are usually given the benefit of the doubt by consumers – who automatically associate "renewable" with "environmentally friendly". In addition, many of the technologies explored in this report have only existed for a decade or less, or may not yet be commercially available. There is usually a considerable time lag between when a product is first designed and released, and when researchers do a formal life cycle analysis.

Regardless of the underlying causes, the absence of research on the environmental impacts of new renewable energy technologies has serious implications and represents an important path for further study. In order to make well-informed decisions in today's dynamic energy landscape, a complete understanding of technologies' environmental impact from production to end-of-life is critical.

VI. Regulations and Incentive Programs that Matter

Local, state, and federal regulations and incentive programs can influence the cost, feasibility, and speed with which commercial production of new technologies can be scaled up. To assess these regulatory constraints, the Database of State Incentives for Renewables and Efficiency was examined. The database lists 3,567 regulations and incentives related to energy across the U.S., and for each regulation, provides a brief summary of key information such as incentive or permitting type, eligible renewables or technologies, applicable sectors, and expiration date.[142] It was impractical to examine all 3,567 regulations and incentives. Consequently, we limited our examination to only those that were relevant to California and that applied to Los Angeles County. That filtering yielded 52 regulations and incentives. We then further restricted our analysis to those that met the following three criteria: 1) eligible renewables or technologies needed to include a variation of "solar cooling," "cooling," "solar energy," "solar photovoltaics," or "battery storage," 2) the applicable sector category needed to include "commercial," and 3) the policy's expiration needed to be a future date. This restriction yielded 14 regulations and incentives, which can be found in Appendix 4. Of these 14, four stood out as having the potential to substantially impact costs, profits, or delays of implementation for projects because of their scope, the incentives they offered, or the permitting process they regulated. The four regulations and incentives discussed in detail are:

1. The Business Energy Investment Tax Credit
2. Property-Assessed Clean Energy Programs
3. The Loan Guarantee Program
4. The Statewide Solar Permitting Standards

1. Business Energy Investment Tax Credit

The Federal Government introduced the Business Energy Investment Tax Credit, alternately called the Solar Investment Tax Credit, in 2006 to encourage growth of the U.S. solar industry.[143] Businesses in the commercial sector implementing one of numerous technologies – including solar photovoltaics – are eligible for these tax credits, meaning that companies adopting solar powered windows would qualify.[144] Additional requirements for eligibility include:

- The business must be subject to federal income tax;
- The business must be located within the U.S.;
- The technology system must be previously unused and not intended for swimming pool heating.

Tax credits are awarded on the basis of the total cost of the project, including equipment costs (ie the photovoltaic panels), installation costs, associated materials (i.e., transformers and breakers), and energy storage systems.[145] Depending on when construction began and the year of service commencement, the policy offers a federal tax credit of between 10% and 30% of the total cost of the project, with this value decreasing incrementally with time since the policy's implementation, as can be seen in Figure 14.[146]

Given the financial burden of federal income taxes for companies as well as the potential financial and environmental benefits of solar windows discussed above, companies that invest in solar windows and pursue this tax credit opportunity stand to see significant financial gain.

2. Property-Assessed Clean Energy Programs

One potential barrier to implementation of renewable energy technologies may be high system and installation costs. In an effort to address this deterrent, local, state, and federal loan programs exist to encourage commercial businesses to invest, such as the Property-Assessed Clean Energy (PACE) programs offered by local California governments and authorized through the Municipal Energy Districts policy.[147] PACE programs offer

Project Construction Commenced By	Open for Service	Tax Credit
1/1/2006 - 12/31/2019	Before 2024	30%
1/1/2020 - 12/31/2020	Before 2024	26%
1/1/2021 - 12/31/2021	Before 2024	22%
12/31/2021 - N/A	After 12/31/2023	10%

***Figure 14**: Above are the guidelines for tax credit eligibility, illustrating how values scale down with time. The "Project Construction Commenced By" column indicates the dates between which construction needs to have begun, while "Open for Service" refers to the date by which the commercial building must be fully operational.*

up to 20 year loans for a wide variety of clean energy projects, from renewable energy installation to efficiency improvements.[148] In particular, the California Energy Commission cites photovoltaics, high efficiency HVAC systems, and high-efficiency windows as being sound investments for PACE products, increasing chances of application approval for businesses seeking to implement the solar AC and solar window systems described above. Additional standards for eligibility include a clean property title and up-to-date payments for property taxes and mortgages.[149]

In California, 13 PACE programs service commercial projects, including Los Angeles County PACE.[150] The benefit of county-scale programs is that each program is better able to assess and serve regional needs.[151] The Los Angeles County PACE programs allow for full repayment through assessment of property tax bills, and given that PACE allows for repayment to be spread over up to 20 years, companies stand to see net financial benefit over the full term of the loan. Additional benefits include reductions in operating costs, as companies become less grid-reliant or more energy efficient, increases in property value, and the potential to simultaneously qualify for tax incentives or rebate programs.[152]

3. Loan Guarantee Program of DoE

At the federal level, the Loan Guarantee Program of the Department of Energy helps connect individuals to funding for projects implementing technology intended to “avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases.”[153] Given that the technologies discussed here offer solar energy alternatives to fossil fuels, companies seeking to implement solar AC or solar windows stand to qualify. The Loan Programs Office was created in 2005 by the Energy Policy Act and has over $40 billion appropriated for these energy related projects.[154] The goal of the program is to encourage early commercial adoption of new technologies, such as those discussed in this report. Loan payment plans may extend up to 30 years.[155]

4. Statewide Solar Permitting Standards

Through the Statewide Solar Permitting Standards policy, California sets limits on the permitting fees cities and counties can levy for building improvements and solar installations to eliminate barriers for potential implementers. The policy applies to solar photovoltaic based renewables, among others.[156]

1. Fees cannot be set significantly higher based on project value, in order to avoid disincentivizing larger, more efficient projects such as might be found at the commercial scale.
2. Fees are prohibited from exceeding reasonable cost estimates of the service provided.
3. For commercial solar energy systems, implementers can expect a maximum of $1,000 for systems up to 50kW, with an additional $7 charged per kW up to 250kW, and an additional $5 per kW beyond 250kW.[157]

The text of the policy specifies these restrictions as applying to roof-mounted PV systems, rather than ground mounted, but window based PV is not mentioned. This is likely because solar windows were still in an early development stage when the policies setting these standards were signed in 2012. As such, solar AC systems with roof mounts certainly stand to qualify for these fee restrictions, and solar windows may be considered on a case by case basis.

VII. Moving Forward

There are clearly huge decarbonization opportunities presented by emerging technologies such as solar windows, energy storage, and solar cooling in urban settings. To fulfill this potential, there is a need for serious examination of unintended environmental impacts during the production stage and usage of such technologies. In addition, the new technologies will work best if adopted as an integrated system. One of the companies investigated in this report, NETenergy, provides an example of combining energy storage with existing air conditioning technologies. In general, all new technologies need to be examined from a system perspective — what are the impacts of the environment and social systems, and how do they integrate with existing infrastructure and other new technologies — as none of these technologies will ever exist in isolation.

All new technologies need to be examined from a system perspective — what are the impacts of the environment, social systems, and how do they integrate with new existing infrastructure and other new technologies — as none will ever exist in isolation.

VIII. Appendices

Appendix 1: Companies Initially Contacted for Interviews

	Company Name	Type of Technology
1	UbiQD, Inc. Nanomaterials	Solar Windows - quantum dots
2	Solar Gaps	Solar Windows - Blinds
3	NEXT Energy Technologies	Solar Windows
4	Physee	Solar Windows
5	Onyx Sola	Solar Windows
6	Solar Windows Technologies Inc.	Solar Windows
7	Ubiquitous Energy	Solar Windows
8	Fahrenheit	Solar Cooling - Adsorption Chillers
9	Hydrostor	Solar Cooling - Absorption Chillers
10	HotSpot Energy/Chiltrix	Solar Cooling - Absorption Chillers
11	Adroit Solar	Solar Cooling
12	Cool X Energy	Solar Cooling
13	ConEdison Battery Storage Solutions	Long Duration Energy Storage
14	Kilowatt labs	Long Duration Energy Storage
15	ESS INC	Long Duration Energy Storage
16	NET Energy	Long Duration Energy Storage
17	Highview Power (CRYOBattery)	Long Duration Energy Storage
18	Energy Vault	Long Duration Energy Storage
19	Primus Power	Long Duration Energy Storage
20	Form Energy	Long Duration Energy Storage
21	Echogen	Long Duration Energy Storage
22	EOS	Long Duration Energy Storage

Appendix 2: Sample of Interview Questions For Echogen Energy Storage (ESS)

1. History & Establishment: First, we would like to learn about how Echogen and its energy storage project started. Can you tell us a little bit about the history of the company and ETES?
2. Energy Saved: What is the energy storage capacity of ETES? Could you compare energy storage capacity ETES has compared to Li-ion storage and traditional batteries packaged as fixed cells or modules? And how does ETES maximize the storage's efficiency levels?
3. Projected Cost: On your company's website, I read that Lithium-ion storage pack capital cost is predicted to drop to $73/kWh in 2030, could you give us a quantitative prediction on the cost of ETES?
4. Life Cycle Analysis: Another thing we would like to include in our report is information about the life cycle of products. What is the lifetime of ETES? Where do you source your materials from? At the end of their lifetime, how is ETES disposed of? Can they be recycled?
5. Environmental Benefit: We're also hoping to measure the environmental impacts of producing technologies. You mention on your website that ETES uses CO_2, as an alternative to lithium-ion batteries. What are the environmental benefits of this? How does your company assess its environmental impacts? Is there an industry standard for this? Or, could you point us in the right direction or let us know any resources where we can find information on supply-chain environmental impacts?
6. Legislation: Is there any significant legislation relating directly to the implementation of energy storage systems, impacting either the manufacturing process or your customers? Such as rebate or tax incentive programs?

Appendix 3: Savings Possible in Transitioning to Solar Cooling

In order to calculate potential emissions and cost savings, we considered a scenario in which a company switched from a conventional cooling system hooked up to a fossil-fuel dependent grid to a solar cooling system. In the U.S. Department of Energy's *Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Small, Large, and Very Large Commercial Package Air Conditioning and Heating Equipment* report, the highest recorded energy demand from a "very large" commercial AC system is 63,493 kWh/year.[158] We multiplied this value by the emissions generated per kWh of electricity (0.99 lbs CO_2/kWh) to find that annual emissions savings could be as much as 62,858 lbs of CO_2.[159]

In calculating potential electricity cost savings, we assumed our sample building fell into the "Large Commercial and Multi-Family Service" category for Los Angeles Department of Water and Power (LADWP) commercial rates. Figure 15 overviews the various charges that contribute to a commercial building's total electricity costs for a year.

For simplicity, demand charges and adjustment billing factors were neglected. Service Charge per Month was neglected because it is a flat rate that the commercial building would need to pay if they were receiving any electricity from LADWP, even if they transitioned to solar cooling. The power demand in kW required for

Month	Service Charge per Month	Facility Charge per kW	High Peak Energy Charge per kWh	Low Peak Energy Charge per kWh	Base Energy Charge per kWh	High Peak Demand Charge per kW	Low Peak Demand Charge per kW	Base Demand Charge per kW	Adjustment Billing Factors*
January - May	$75.00	$4.56	$0.05464	$0.05464	$0.03798	$4.30	-	-	Adjustment Factors →
June - September	$75.00	$4.56	$0.05991	$0.05365	$0.03356	$9.70	$3.30	-	Adjustment Factors →
October - December	$75.00	$4.56	$0.05464	$0.05464	$0.03798	$4.30	-	-	Adjustment Factors →

***Figure 15**: Component parts of electricity billing for Large Commercial and Multi-Family Service buildings by the LADWP in 2019. This table was pulled from: https://ladwp.com/ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-electricrates/a-fr-er-stcommindrates.*

determining the Facility Charge per kW was calculated by dividing the energy demand per year by days in a year and hours in a day.

*63,493 kWh/year * year/365days *day/24 hours = 7.248 kW*

*7.248 kW * $4.56 /kW = $33.05*

Variation in AC use between months must be accounted for because summer months tend to see a peak in use due to higher temperatures, as can be seen in Figure 16.[160] In our calculations, we made the assumptions that 72℉ was a reasonable temperature at which to turn on air conditioning and that every degree of cooling is associated with an extra 7% of energy use on average.[161]

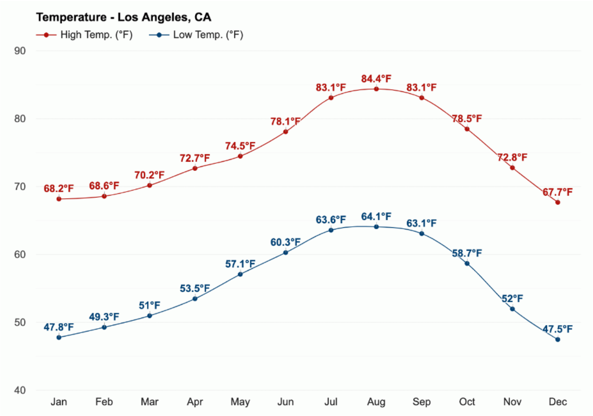

***Figure 16**: This image depicts the change in average temperature in Los Angeles over the course of a year. This figure was pulled from weather-us.com.*

With these factors in mind, we divided the 63,493 kWh annual usage by month according to temperature, as seen in Figure 17.

Month	Avg. High Temp.	Degree Amt. Over 72F	7% per 1F Above	Factor	Proportional kWh per Month
Jan	68.2	NA	NA	1	4074.2
Feb	68.6	NA	NA	1	4074.2
March	70.2	NA	NA	1	4074.2
April	72.7	0.7	0.049	1.049	4273.9
May	74.5	2.5	0.175	1.175	4787.2
June	78.1	6.1	0.427	1.427	5813.9
July	83.1	11.1	0.777	1.777	7239.9
Aug	84.4	12.4	0.868	1.868	7610.7
Sept	83.1	11.1	0.777	1.777	7239.9
Oct	78.5	6.5	0.445	1.455	5928
Nov	72.8	0.8	0.056	1.056	4302.4
Dec	67.7	NA	NA	1	4074.2
TOTAL				15.584	63493

***Figure 17**: This figure calculates the proportion of total energy use for a large AC unit over the course of a year would be divided among months based on the assumption that temperatures over 72℉ result in a 7% energy increase per degree.*

Equipped with energy demand variation by months, we then had to account for the charge difference between usage at high, low, and base peak times. AC was assumed to run through standard business hours, from 8:00 AM to 5:00 PM and not on weekends. The hours that fall into each of the three categories are specified by LADWP in Figure 18.

Based on these values, we can see that in a typical nine hour workday, the two hours between 8:00 AM and 9:59 AM fall into the base period, the three hours between 10:00 AM and 12:59 PM fall into the low peak period, and the four hours between 1:00 PM – 4:59 PM fall into high peak period. Thus, for any given month, 2/9ths or 22% of the energy used for AC will be charged at the base rate, 3/9ths or 33% will be charged at the low peak rate, and 4/9ths or 44% will be charged at the high peak rate.

The final result of these calculations can be seen in Figure 19.

High Peak Period ***(20 hours per week)***	Monday through Friday 1:00 p.m. - 4:59 p.m.
Low Peak Period ***(30 hours per week)***	Monday through Friday 10:00 a.m. - 12:59 p.m. 5:00 p.m. - 7:59 p.m.
Base Period ***(118 hours per week)***	Monday through Friday 8:00 p.m. - 9:59 a.m. All day Saturday and Sunday

Figure 18*: This table outlines the hour ranges for which the high peak, low peak, and base energy use charges apply. This figure was pulled from ladwp.com*

Month	Facility Charge per kW	Total Facility Charge	kWh per month (scaled by monthly temp)	High Peak Energy Charge per kWh	Total High Peak Energy Charge	Low Peak Energy Charge per kWh	Total Low Peak Energy Charge	Base Peak Energy Charge Per kWh	Total Base Peak Energy Charge
January	4.56	33.05	4,074.24	0.05464	98.94	0.05464	74.21	0.03798	34.39
February	4.56	33.05	4,074.24	0.05464	98.94	0.05464	74.21	0.03798	34.39
March	4.56	33.05	4,074.24	0.05464	98.94	0.05464	74.21	0.03798	34.39
April	4.56	33.05	4,273.88	0.05464	103.79	0.05464	77.84	0.03798	36.07
May	4.56	33.05	4,787.24	0.05464	116.26	0.05464	87.19	0.03798	40.40
June	4.56	33.05	5,813.94	0.05991	154.81	0.05365	103.97	0.03356	43.36
July	4.56	33.05	7,239.93	0.05991	192.78	0.05365	129.47	0.03356	53.99
August	4.56	33.05	7,610.69	0.05991	202.65	0.05365	136.10	0.03356	56.76
September	4.56	33.05	7,239.93	0.05991	192.78	0.05365	129.47	0.03356	53.99
October	4.56	33.05	5,928.02	0.05464	143.96	0.05464	107.97	0.03798	50.03
November	4.56	33.05	4,302.40	0.05464	104.48	0.05464	78.36	0.03798	36.31
December	4.56	33.05	4,074.24	0.05464	98.94	0.05464	74.21	0.03798	34.39
SUBTOTAL		**396.6**			**1,607.25**		**1,147.21**		**508.47**
								Total Annual Charge	**$3659.53**

Figure 19*: This table outlines the calculations performed in this report to determine potential savings offered by switching from conventional cooling to solar powered adsorption cooling.*

Appendix 4: Relevant Los Angeles County Regulation and Incentive Programs

Name	Level of Government	Incentive Type	Relevant Eligible Technologies
Business Energy Investment Tax Credit	Federal	Corporate Tax Credit	Any technology using solar energy to generate electricity, provide heating or cooling, or power hybrid solar lighting systems
Modified Accelerated Cost-Recovery System	Federal	Corporate Depreciation	Solar Thermal Electric, Solar Photovoltaics, Solar Thermal Process Heat
Energy-Efficient Commercial Buildings Tax Deduction	Federal	Corporate Tax Deduction	Chillers, Windows, Air Conditioners
Renewable Electricity Production Tax Credit	Federal	Corporate Tax Credit	Solar Thermal Electric, Solar Photovoltaics
US Department of Energy - Loan Guarantee Program	Federal	Loan Program	Solar Thermal Electric, Solar Photovoltaics
Interconnection Standards for Small Generators	Federal	Interconnection	Solar Thermal Electric, Solar Photovoltaics
Property Tax Exclusion for Solar Energy Systems	State	Property Tax Incentive	Solar Thermal Electric, Solar Photovoltaics, Solar Thermal Process Heat, Solar Water Heat, Solar Space Heat
Net Metering	State	Net Metering	Wind-Energy Systems, Solar-Electric Systems, Hybrid Systems
Statewide Solar Permitting Standards	State	Solar/Wind Permitting Standards	Solar Space Heat, Solar Photovoltaics
Local Option - Municipal Energy Districts	State	PACE Financing	Unspecified
PG&E - Non-Residential Energy Efficiency Financing Program	LA County	Loan Program	Lighting, HVAC (heating and cooling), Electric Motors, LED Street Lights, Refrigeration, Food Service Equipment and Water Pumps
SCE - Non-Residential On-Bill Financing Program	LA County	Loan Program	Energy Efficiency
SoCalGas - Non-Residential Energy Efficiency Programs	LA County	Rebate Program	HVAC Systems
LADWP - Non-Residential Energy Efficiency Incentive Program	LA County	Rebate Program	Solar Photovoltaics, Chillers, Air Conditioners, Energy Management

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