ELECTRIC POWER
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Energy Efficiency Technology Readiness Guide

2013 Update

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ABSTRACT

As electric power companies strive to meet increasing end-use energy efficiency requirements, they must make decisions about which technologies seem most promising in terms of availability for wide deployment and providing persistent energy savings while also being cost-effective and likely to be adopted by customers. To help electric power companies with these decisions, EPRI has developed this Technology Readiness Guide to provide a readiness assessment of technologies in various stages of development as well as enabling comparison among these technologies.

This report provides an overview of EPRI's revised energy efficiency technology readiness framework, which includes a technology development pipeline, technology readiness levels and a technology assessment process. The technology assessment process is used to identify the status of a technology with respect to the stages of the technology pipeline. The process uses readiness criteria to assess the current confidence in the value and the technical and commercial risk of the technology. Each technology undergoes a comprehensive assessment that includes required and scored criteria, criteria weighting and an estimation of its technical energy efficiency potential. Following the overview of the technology readiness framework, assessment results for energy efficiency technologies are provided in readiness briefs, organized according to the stages of the technology development pipeline. These technologies are currently being or have been evaluated in multiple EPRI efforts, including the Technology Innovation program, the collaborative End-Use Energy Efficiency and Demand Response research program and various supplemental projects, including the Energy Efficiency Demonstration and Coordinated Early Deployments of Efficient End-Use Technologies.

Keywords

Energy efficiency
Demand response
Power quality
Grid impacts

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1
ENERGY EFFICIENCY TECHNOLOGY READINESS

Many electric power companies in the United States are facing increasing end-use energy efficiency requirements. As of 2013, 26 states have energy efficiency resource standards[1] and several others have pending or established energy efficiency goals. The states in various stages of development; while many states have focused on energy efficiency for decades, others are just beginning to develop energy efficiency programs.

Although a variety of energy efficiency technologies are becoming available, utilities need to know which technologies will provide persistent energy savings, be cost-effective, and inspire customer adoption, and when they will be ready to be deployed into utility programs. To help electric power companies cost-effectively address these questions, EPRI developed this Technology Readiness Guide in 2012. This 2013 update includes additional technologies and updates a number of the technologies in the 2012 report.

The objectives of this document are to provide utilities with a readiness assessment of technologies in various stages of development as well as enabling comparison among these technologies. The technologies in the guide are currently being assessed in multiple EPRI efforts, including the *Technology Innovation* program, the collaborative *End-Use Energy Efficiency and Demand Response* research program (Program 170), and various supplemental projects.

EPRI's Energy Efficiency Technology Development Pipeline

Assessing these technologies uses the process developed in EPRI's Coordinated Early Deployments project. The foundation of this process is the energy efficiency technology development pipeline, which is shown in Figure 1-1. The purpose of the pipeline is to accelerate the readiness of emerging efficient technologies for utility energy efficiency programs. The pipeline has five stages, which are discussed below.

Technology Scouting: the pipeline starts with scouting for promising new technologies that may eventually be candidates for utility programs. The EPRI *Technology Innovation* program is one avenue for promising new technologies to enter the pipeline; national labs, universities, and other sources are also important avenues.

Assessment and Laboratory Testing: the most promising technologies are introduced into EPRI's *End-Use Energy Efficiency and Demand Response* program for testing and assessment in EPRI's extensive test laboratories.

[1] *The 2013 State Energy Efficiency Scorecard*. ACEEE, Washington, DC, 2013. E13K.

R&D Field Tests and Demonstrations: field tests are conducted on a scale of tens to hundreds of units for technologies whose lab performance warrants further scrutiny. EPRI's *Energy Efficiency Demonstration* project (EE Demo) is one example of field testing. The project validates technical performance and energy savings of hyper-efficient technologies at residential and commercial sites using instrumentation and monitoring to measure performance.

Coordinated Early Deployments: this stage offers a larger-scale technology test to statistically validate or confirm results from earlier stages, while minimizing risks in case the results are not as positive as expected. Market barriers such as supply chain inadequacies and customer resistance are also addressed during early deployment. This stage develops creative strategies to overcome supply chain or market opportunities that had not been previously identified.

Full Program Rollout: this final stage is the full rollout of the technology in a utility energy efficiency program.

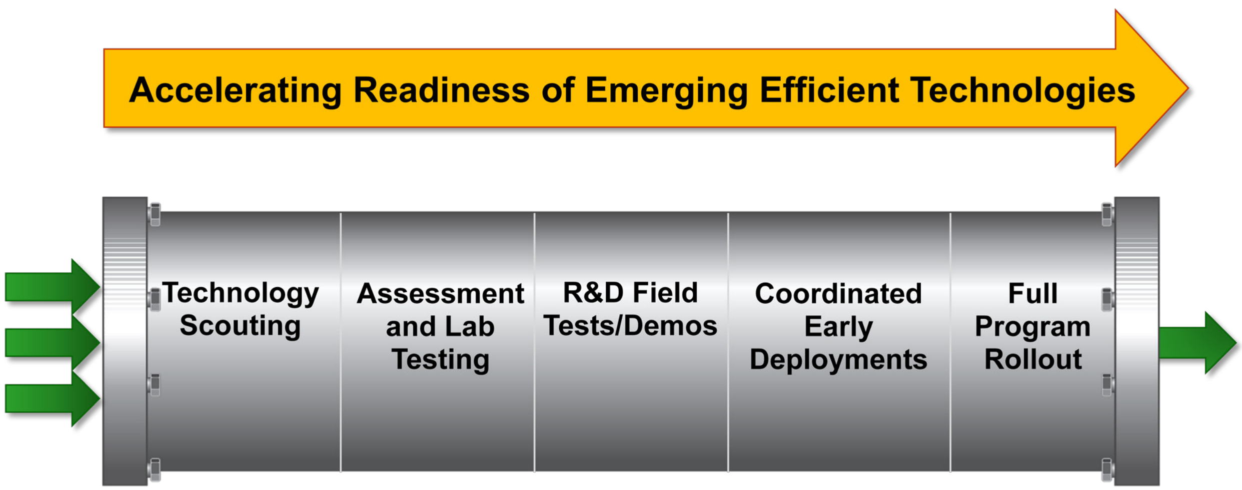

Figure 1-1
Energy Efficiency Technology Development Pipeline

EPRI's efforts are focused on technologies with high potential value and some technical and commercial risks. In the early stages of the pipeline when technologies are being scouted and assessed through lab testing, there is little certainty of value and considerable potential risks. To continue progressing through the pipeline, the certainty of value of each technology must increase while the technical and commercial risks decrease.

Technology Readiness Levels

EPRI is using the Technology Readiness Level (TRL) approach to describe the stages of development of technologies in EPRI research. The TRL approach was originally developed by the National Aeronautic and Space Administration (NASA) to manage NASA's space-related R&D. The TRL describes the maturity of a particular technology and enables a consistent comparison of maturity among different types of technologies. The TRL approach has become widely recognized as a valuable technology assessment tool, and is used by the U.S. Department of Energy, the U.S. Department of Defense and the European Space Agency, among others.

EPRI adapted NASA's TRLs to the research and development of technologies related to the generation, delivery and use of electricity. Figure 1-2 illustrates the nine TRL stages, which are shown in the inner part of the figure. The EPRI activities that correspond to the TRL stages are shown in the outer circle.

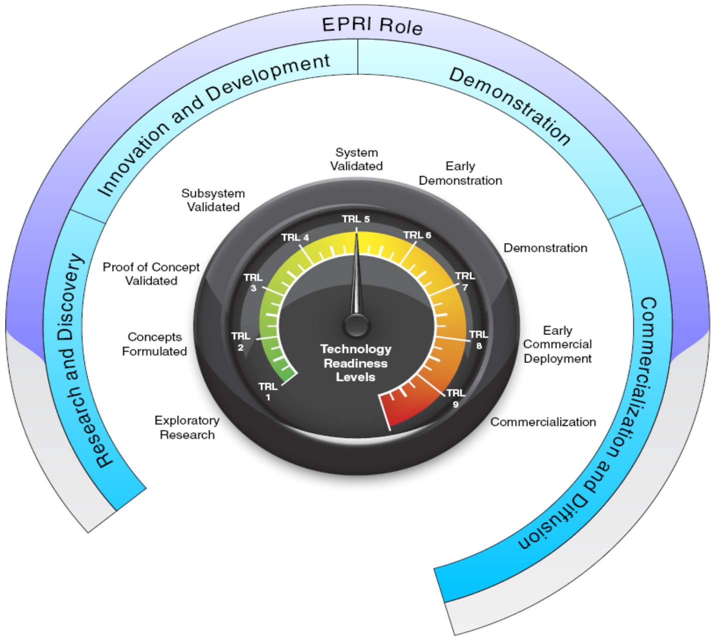

Figure 1-2
Technology Readiness Levels

EPRI has further adapted TRLs to the readiness of technologies for utility energy efficiency programs. The way that TRLs relate to the energy efficiency technology pipeline is shown in Figure 1-3.

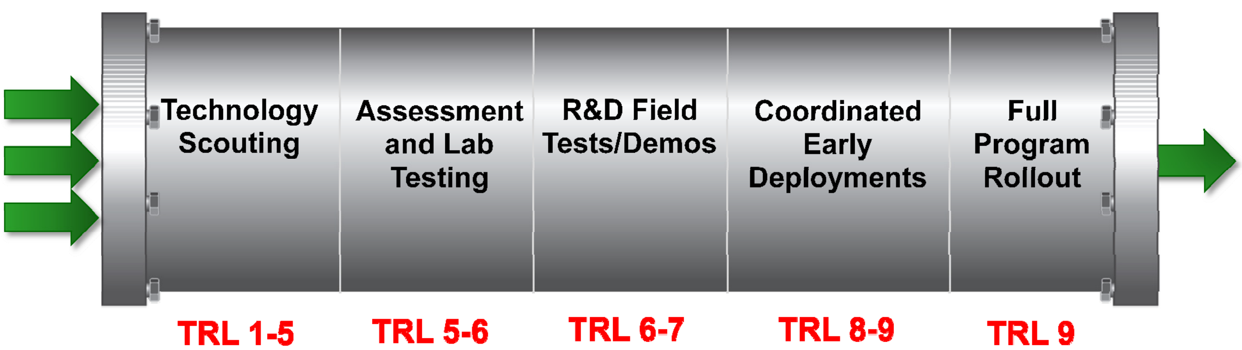

Figure 1-3
Technology Development Pipeline Mapped to Technology Readiness Levels

Technology Readiness Assessment Process

The technology readiness assessment process is designed to identify the status of a technology with respect to the stages of the pipeline. The process uses readiness criteria that assess the current confidence in the value and the technical and commercial risk of the technology. The process was developed in close collaboration with EPRI's utility advisors. Two types of readiness assessment criteria were developed: required criteria and scored criteria.

Required Criteria

Required criteria have been developed for each pipeline stage. These are pass/fail criteria, allowing a qualitative assessment to determine in which stage the technology best fits. The pass/fail approach means that if a technology fails to meet the criteria at any level, it goes back into an earlier stage of the pipeline. In addition, required criteria are additive. For example, at the final stage, all preceding required criteria must have been met.

Table 1-1 lists the required criteria for each pipeline stage. The first column lists the five screens, and corresponds to the pipeline stages. The second column lists the required criteria that must be met for each stage. The last column lists the focus of the criterion; whether it is related to the value of the technology or its technical or commercial risk. As an example, to qualify for assessment and lab testing, the technology must have the following to meet the required criteria:

- Claimed ***energy savings*** that need to be objectively assessed to evaluate ***value***.
- Experience indicating ***good functional performance***, addressing ***technical risk***.
- Indication of ***scalability*** to serve a large market, addressing ***commercial risk***.

Table 1-1
Required Criteria for Technology Development Pipeline Stages

Screen	Required Criteria	Focus
To Qualify for TI Funding	Significant energy savings potential	Value
	Sound science	Technical Risk
	Addresses a real need	Commercial Risk
To Qualify for Assessment & Lab Testing	Promising energy savings claimed; needs objective assessment	Value
	Experience to date indicates good functional performance	Technical Risk
	Scalable - product can be scaled to serve large market	Commercial Risk
To Qualify for Field Tests/EE Demo	Objective energy savings results from lab or other sources	Value
	Functional performance - no major showstoppers	Technical Risk
	Commercially available at least in small quantities	Commercial Risk
	UL rated	Commercial Risk
To Qualify for Coordinated Early Deployments	Estimated energy savings are documented from units in field	Value
	Demonstrated in field - the technology works	Technical Risk
	Commercially available but limited market penetration	Commercial Risk
	Meets other standards / standards are sufficiently developed	Commercial Risk
To Qualify for Utility Programs	Refined / deemed energy savings	Value
	Line of sight to acceptable TRC and payback	Commercial Risk
	Positive consumer adoption experience	Commercial Risk
	Supply chain - positive progress	Commercial Risk

Readiness Score

Once the technology has been slotted into a stage the EPRI team further investigates and assigns a score from 0 to 100 depending on the progression of the technology through the pipline. A summary of this investigation for each technology can be found in the "Requirements to Advance to the Next Stage" section of the readiness brief. As shown in Table 1-2, each level of the pipeline is assigned a range of corresponding readiness scores.

Table 1-2
Required Criteria for Technology Development Pipeline Stages

Readiness Level	Technology Scouting	Assessment and Lab Testing	R&D Field Tests/Demos	Coordinated Early Deployments	Full Program Rollout
Corresponding Readiness Score	0 to 20	21 to 40	41 to 69	61 to 80	81 to 100

Scored Criteria

A technology is assessed against a set of criteria. These scored criteria fall into eight categories, each of which has one or more criteria, as shown in Table 1-3. Each of the criteria is scored based on how the technology compared to the designated baseline. The table also provides a description of the considerations given to each criterion assessed.

Scoring provides a standardized approach that quantifies results and enables a method of comparison among technologies within a given stage. Scores are meant to compare the technology to existing technologies and among other technologies in the same stage of the pipeline. Scoring also allows for the creation of a radial diagram that graphically shows the summarized assessment results for each category. A score within a category can be achieved a number of ways, allowing for tradeoffs among criteria for a single technology. For example, high results for any one criterion can offset low results in another criterion within the same category. Furthermore, a low result in any category identifies that category as a potential barrier where focus is needed.

Table 1-3
Table Listing Criteria And Consideration for Each Readiness Category

Category	Criteria	Considerations
Energy Savings	Energy savings	The savings compared to the technology it replaces expressed as percent per unit.
	Peak demand savings	The coincident peak demand savings compared to the technology it replaces expressed as percent per unit.
Customer Benefits	Customer benefits/acceptance	Customer-specific benefits excluding bill savings, such as improved illumination, lighting color, safety, productivity, comfort, control, satisfaction. Acceptance such as ease of use, appearance, likeableness.
Economics	Current first cost as percentage of replaced technology	If retrofit, compare to a new replacement.
	Estimated future cost in five years as percentage of replaced technology	Consider how the technology price might reduce due to mass production, or whether patent ownership may keep price high longer, or other price impacts.
	Current Total Resource Cost (TRC)	Calculate the total resource cost based on current first cost.
	Future TRC	Calculate the total resource cost based estimated first cost in five years
Technical	Technical risks/issues: risk of the technology not performing as expected or issues related to use.	Performance and durability, failure rate, life, obsolescence, reliability, uptime, availability, component reliability, cooling or heating of vicinity, noise, other negative impacts, non-standard installation, needs additional equipment or maintenance, uses excessive water, ease or difficulty of measurement and verification (M&V), communications interoperability, retrofit or new construction...
	Regional applicability: applicability of the technology in multiple regions.	Climate zone specificity, consumer interests, existing technology use, retrofit or new construction.

Table 1-3 (Continued)
Table Listing Criteria And Consideration for Each Readiness Category

Category	Criteria	Considerations
Market Supply	Health of manufacturing sector.	Number of manufacturers: are they concentrated in one or two organizations or is there diversity? Financial strength and viability of suppliers, quality control, equipment issues, strategic approach, U.S. vs. non-U.S. suppliers, global materials issues...
	Distribution capability.	Capability of distributors to distribute the technology, retail availability of product for residential and distribution availability for commercial customers....
	Service capability.	Service capability to service technology in the field, availability of trained or trainable contractors, local/regional training and support; certification and how available it is for manufacturer in-house or 3rd party contractors, (closed vs. open), value of contractors to recruit customers...
Environmental Health & Safety	Human health and safety impacts.	Emissions, EMF, UV, effect on building health, provoking seizures, illnesses…
	Environmental impacts.	Disposal/end of life issues (e.g. mercury), outgassing, water use, land use, impacts on endangered species, dark skies...
Connectivity	Demand response readiness	Capability of the technology to respond to a signal by dynamically changing its electricity consumption, for example, as demand limiting or variable fast response, while having limited impact on consumer comfort, productivity, or safety. Is the functionality in place? If not, consider how soon the capability could be available to respond automatically to a signal.
Grid Impacts	Source of power quality issues	Is the device itself contributing to power quality issues on the grid?
	Susceptibility to power quality issues	Susceptibility of technology to transients, low power factor, flicker, grounding, harmonics, inrush current, electromagnetic and radio interference, overvoltage, voltage sags, and other compatibility phenomena.

Technology Assessment

The technology is assessed by addressing the considerations for each category using results of EPRI research including lab and field tests where available. Each criterion is assigned a score of -2 to 2, with 2 representing an improvement from the existing technologies and -2, a decline. The readiness scoring levels associated with each criterion are shown in Table 1-4 and Table 1-5.

Table 1-4
Readiness Scoring Levels

		Readiness Levels *-2 = low/negative* *2 = high/positive*				
Category	**Criteria**	**-2**	**-1**	**0**	**1**	**2**
Energy Savings	***Energy Savings***	< -20%	-10%	0%	10%	20%
	Coincident peak demand savings	< -20%	-10%	0%	10%	20%
Customer Benefits	***Customer benefits/acceptance***	Significantly fewer customer benefits than replaced technology	Fewer customer benefits than replaced technology	Same as replaced technology	More customer benefits than replaced technology	Significantly more customer benefits than replaced technology
Economics	***Current first cost***	See Table 1-5				
	Estimated future first cost in 5 years					
	Total Resource Cost	<0.50	0.75	1.00	1.50	>2
	Future TRC	<0.50	0.75	1.00	1.50	>2
Technical	***Technology risk/issues***	Higher risk/more issues than baseline technology.		No change from current practices		Lower risk/less issues than baseline technology.
	Regional applicability	Applies to less regions than the baseline technology.		Applies to similar regions as baseline technology.		Applies to more regions than the baseline technology.
Supply Chain	***Health of manufacturing sector***	Weaker than baseline technology.		Equally strong compared to baseline technology.		Stronger than baseline technology.
	Distribution capability	Less capability than baseline technology.		Equal capability compared to baseline technology.		More capability than baseline technology.
	Service capability	Less capability than baseline technology.		Equal capability compared to baseline technology.		More capability than baseline technology.
Health/ Environment	***Human health impacts***	Technology has **(A)** more of an impact on human health (or provides less benefits) than previous technology and **(B)** resolution is challenging.		No change from current technology	Impact is a potential improvement to human health	Technology has less of an impact on human health (or provides more benefits) than previous technology.
	Environmental impacts	Technology has **(A)** more of an impact on the environment (or provides less benefits) than previous technology and **(B)** resolution is challenging.		No change from current technology		Technology has less of an environmental impact (or provides more benefits) than previous technology.
Connectivity	***Demand response readiness***	Less aspects of the technology have the ability to provide demand response capabilities than the previous technology.		The technology has the ability to provide the same amount of demand response as the previous technology.		More aspects of the technology have the ability to provide demand response abilities than the previous technology.
Grid Impacts	***Source of Power Quality Issues***	Technology more likely to cause events.	Technology somewhat more likely to cause events.	Technology no more likely to cause events.	Technology somewhat less likely to cause events.	Technology less likely to cause events.
	Susceptibility to Power Quality Issues	Technology more susceptible than previous technology.	Technology somewhat more susceptible than previous technology.	Technology no more likely to be susceptible compared to current technology.	Technology somewhat less susceptible than previous technology.	Technology less susceptible than previous technology.

Table 1-5
Readiness Scoring Levels - Costs

		Readiness Levels *-2 = low/negative*				*2 = high/positive*
		-2	**-1**	**0**	**1**	**2**
Economics *If retrofit, compare to new replacement. Include life of the energy savings of the technology (energy savings persistence)*	**TI**	*>5x*	*3x*	*1x*	*0.9x*	*<0.8x*
	Lab	*>4x*	*2.5x*	*1x*	*0.85x*	*<0.7x*
	Demo	*>3x*	*2x*	*1x*	*0.8x*	*<0.6x*
	Early Deployments	*>2x*	*1.5x*	*1x*	*0.75x*	*<0.5x*
	Program	*>2x*	*1.5x*	*1x*	*0.75x*	*<0.5x*
	* Scores are determined by the relative cost of the technology compared to the baseline given the placement of the technology on the pipeline.					

Weighting of Scored Criteria

The scored criteria do not each carry an equivalent importance. Furthermore, importance varies with stage of the pipeline. The importance of scored criteria was determined by utility collaborators and EPRI experts using a ranking exercise. The ranking resulted in weighting of each category and criterion for each pipeline stage. The weightings are used to adjust the scores to account for category and criterion importance.

Criteria Weighting

The eight categories were ranked for each pipeline stage and their criteria given a corresponding weighting in percentage. As shown in Table 1-6, each of the specific criteria shown in the second column is assigned a specific weighting percentage. The criteria weighting change less through the stages of the pipeline as compared to the category weighting. Some criteria retain the same weighting throughout the pipeline stage.

For example, in the energy savings category, the criterion of energy savings is given a weighting of 70%, while peak demand savings is given a weighting of 30%. Both of these ratings remain consistent throughout the pipeline stages. This outcome agrees with the utility collaborators' perspective that energy savings is the key focus of these technology assessments, while peak demand savings are important, but to a lesser degree.

In the economics category, there are four criteria: current first cost, future first cost, total resource cost test, and future total resource cost test. The current costs become more heavily weighted in the later stages of the pipeline as the technology moves toward deployment. The future costs, by comparison, decrease in weighting in the later stages of the pipeline.

Table 1-6
Criteria Weighting

Category	Criteria	Criteria Weighting				
		Technology Scouting	***Lab***	***Demo***	***Deployment***	***Program***
Energy Savings	**Energy Savings**	70	70	70	70	70
	Coincident peak demand savings	30	30	30	30	30
Customer Benefits	**Customer benefits/acceptance**	100	100	100	100	100
Economics	**Current first cost**	0	10	20	20	20
	Estimated future first cost in 5 years	40	40	30	30	30
	Total Resource Cost	0	10	20	20	20
	Future TRC	60	40	30	30	30
Technical	**Technology risk/issues**	85	85	80	70	70
	Regional applicability	15	15	20	30	30
Supply Chain	**Health of manufacturing sector**	50	50	50	50	50
	Distribution capability	25	25	25	20	20
	Service capability	25	25	25	30	30
Health/ Environment	**Human health impacts**	60	60	50	40	40
	Environmental impacts	40	40	50	60	60
Connectivity	**Demand response readiness**	100	100	100	100	100
Grid Impacts	**Source of Power Quality Issues**	50	50	50	50	50
	Susceptibility to Power Quality Issues	50	50	50	50	50

Category Scoring

Assessment scoring integrates the criteria weighting analyses to determine a final scored criteria assessment for each category. To accomplish this, the score for each criterion is multiplied by its weighting. The weighted scores are summed for each category. EPRI developed spreadsheets to perform these calculations.

Figure 1-4 shows the results of such an analysis for electrochromic windows as listed in the technology scouting stage of the pipeline.

For savings compared to the technology it replaces , the criteria weighting is 70% per unit. NREL research shows savings of up to 1/8th (12.5%) of energy used in U.S. buildings. This corresponds to a readiness level of 1 because it is at least a 10% improvement in energy usage over the previous technology. To achieve the weighted score, the criterion weighting is multiplied by the score, which yields a weighted score of 0.7.

The same calculation applies to the peak demand savings of 16%. This corresponds to a 2 because it is closer to a 20% increase than 10%. The score is multiplied by the criterion weighting of 30% equals a weighted score of 0.6.

The two weighted scores are then summed to yield a weighted score of 1.3.

Technology Assessed:	Traditional Insulation Building Windows					Readiness Levels				
"Control" Technology:	Building Windows with Electrochromic Coatings					-2 = Worse 0 = Same 2 = Better ...as compared to control technology				
Category	Criteria	Criteria Weighting	Comments	Readiness Score	Weighted Readiness Score	-2	-1	0	1	2
Energy Savings	Savings compared to technology it replaces, percent per unit.	70%	Savings vary largely by building type, number of windows, existing window technology, and climate. The highest savings are expected to be observed in office buildings with a large number of windows. NREL predicts that insulated electrochromic windows could save an eighth (1/8th) of all energy used in U.S. buildings. EPRI plans to do preliminary testing early next year.	1	0.7	<-20%	-10%	0%	10%	20%
	Coincident peak demand savings compared to technology it replaces, percent per unit.	30%	No testing has been performed so coincident savings is unknown. NREL performed simulations which estimated a 16% reduction in peak electrical demand. EPRI plans to do preliminary testing early next year.	2	0.6	<-20%	-10%	0%	10%	20%
				Total	1.3					

70% x 1 = 0.7

0.7 + 0.6 = 1.3

Figure 1-4
Assessment Scoring for Electrochromic Windows

Once the scoring for all categories is complete, the results are graphed using a radial chart. The radial chart shows the weighed category total. The chart indicates positive results closer to the outside of the graph and negative closer to the center. A very promising technology will have scores closer to the outside ring (blue), indicating it is better than existing technologies in that particular category. A score closer to the center (red) indicates a technology is less promising for that particular category. If a technology is about the same, its score falls on the line between the red and blue areas of the radial diagram. A sample radial chart for electrochromic windows is shown in Figure 1-5.

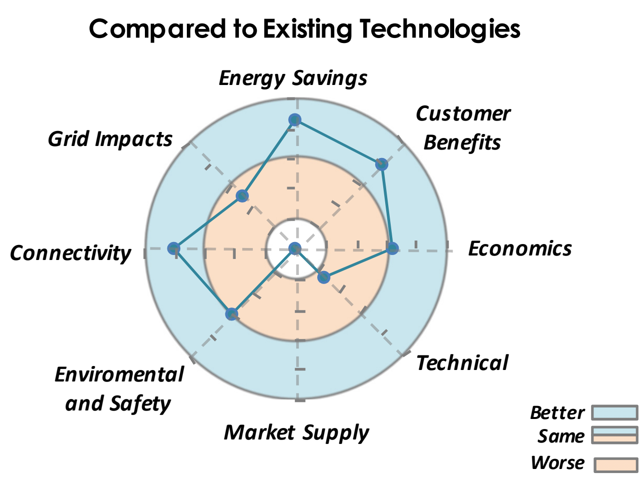

Figure 1-5
Radial Chart for Electrochromic Windows

Technical Energy Efficiency Potential

In addition to comparing scores of technologies within a pipeline stage, another comparison is the technical energy savings potential for the technology. Technical energy savings potential shows the highest achievable level of energy savings for a technology. While this result does not indicate the actual savings that could be achieved, it provides a meaningful comparison of energy savings potential across four census divisions (West, Midwest, South, Northeast).

EPRI conducted a national analysis of energy savings potential and released the results in 2009.2 The same methodology was used for the results shown for each technology.

Technical potential represents the savings due to energy efficiency programs that would result if all homes and businesses adopted the technology being assessed, regardless of cost. Replacement of the technology is assumed to occur at the end of its useful life by the technology under assessment. Technical potential does not take into account the cost-effectiveness of the measures or any market barriers.

Technology Readiness Briefs

The remainder of this document provides technology readiness briefs for technologies assessed in EPRI's research in energy utilization, including the *Technology Innovation* program, the *End-Use Energy Efficiency and Demand Response* research program, and various supplemental projects, including the Energy Efficiency Demonstration and Coordinated Early Deployments. The technologies are grouped in chapters by pipeline stage.

Included in this report are the readiness briefs from the 2012 report; a number of which have been updated due to the availability of new information.

Technology Scouting

- Electrochromic Windows – Residential, Commercial
- Membrane Dehumidification – Commercial

Assessment and Laboratory Testing

- CO_2 Heat Pump Water Heaters, EcoCute – Residential
- Virtual Audit Technology – Commercial

R&D Field Tests and Demonstrations

- CO_2 Heat Pump Water Heater – Commercial
- Controllable LED High Bay Lighting – Commercial
- Evaporative Cooling – Data Centers
- Heat Pump Water Heaters – Commercial
- High Efficiency Clothes Washers and Dryers – Residential

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[2] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010 - 2030).* EPRI, Palo Alto, CA: 2009. 1016987.

- LED Replacement for Fluorescent Troffer Lighting – Commercial
- Submersion Cooling – Data Centers

Coordinated Early Deployments

- Automated Airflow Management System – Data Centers
- DC Power – Data Centers
- Ductless Variable Capacity Heat Pumps – Residential
- Dynamic Power Management – Data Centers
- Heat Pump Water Heaters – Residential
- High Efficiency Refrigerators – Residential
- Thermal Energy Storage for HVAC Systems – Commercial
- Variable Refrigerant Flow – Commercial
- Voltage Optimization – Residential

Full Program Rollout

- 2X High-Efficiency Incandescent Lamps – Residential
- Server Power Supplies – Data Center
- Reduced Consumption Halogen – Residential
- LED Street and Area Lighting – Commercial
- LED Lamp – Residential

Each technology readiness brief provides a summary of the technology, including:

- The technology's readiness score as determined by the scoring process described above.
- Year of the last update to the brief.
- A photograph or graphic of the technology.
- A radial diagram showing the components of the technology readiness score.
- A brief description of the technology.
- Assessment results, which describe the technology in terms of the readiness categories and criteria.
- Load shape or other key performance results.
- Technical potential for energy efficiency by four census regions.
- Requirements for advancing to the next stage of the pipeline.

2
TECHNOLOGY SCOUTING STAGE TECHNOLOGIES

The required criteria for this stage are:

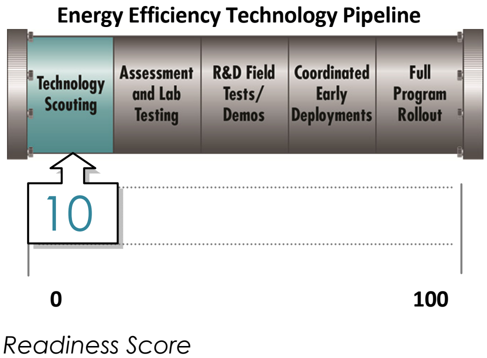
- Significant energy savings potential with this technology.
- Based on sound science.
- Addresses a real need.

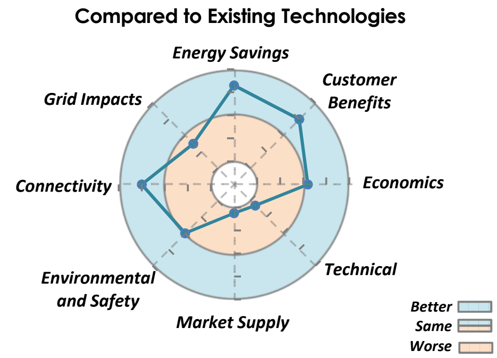
Technology Scouting

- Electrochromic Windows – Residential, Commercial
- Membrane Dehumidification – Commercial

Electrochromic Windows – Residential, Commercial

Readiness Brief – Energy Utilization, Power Delivery & Utilization **2012**





Technical Description

Electrochromic devices are multilayered stacks of thin-film materials that reversibly change transmittance with the application of voltage. When used in windows, voltage can be used to change both the amount of visible light and infrared (IR) light transmitted into the building. Energy savings are achieved by reducing cooling and lighting loads. Some manufacturers can coat electrochromic material directly on the window pane. Electrochromic windows are available in a variety of window pane types such as insulated double- or triple-pane glass. EPRI is engaged in early research to develop electrochromic coatings that can be applied to existing windows, eliminating the need to replace windows for retrofit applications.

The National Renewable Energy Laboratory (NREL) found that though the technology requires electricity to save energy, it is expected to consume less power than a 75-watt lamp for 1,500 square feet of electrochromic glass.

Other technologies such as high efficiency glass, solar screens, and a variety of window films can block infrared and visible light but none of them are able to dynamically change based on lighting and seasonal controls.

Assessment Results

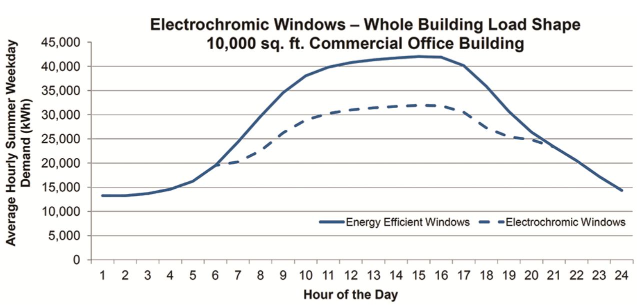
Energy Savings

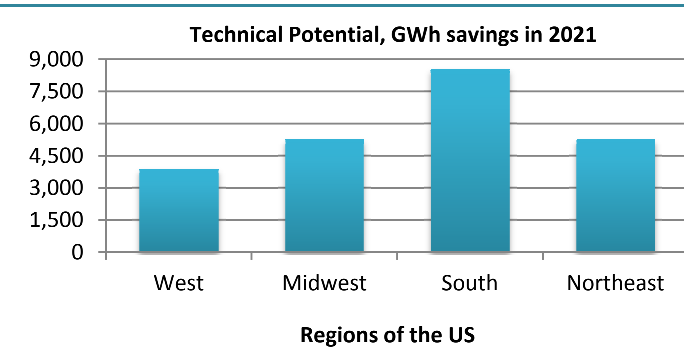
Energy Savings: Savings vary largely by building type, number of windows, existing window technology, and climate. The highest savings are expected to be observed in office buildings with a large number of windows. NREL predicts that insulated electrochromic windows could save an eighth of all energy used in U.S. buildings. EPRI plans to do preliminary testing next year.

Coincident Peak Demand Savings: No testing has been performed so coincident savings is unknown. NREL performed simulations which estimated a 16% reduction in peak electrical demand. EPRI plans to do preliminary testing early next year.

Customer Benefits

Customer Benefits and Acceptance: Benefits for occupants include the ability to control natural light and comfort while maintaining visibility. The ability to control natural light allows occupants to use daylighting and potentially reduce lighting loads. The technology also reduces glare and fading.





Economics

Current First Cost: Electrochromic windows are three times more expensive than energy efficient windows but installed costs are only about twice as expensive. Today's uninstalled prices are about $50 per sq. foot of electrochromic glass compared to about $15 per sq. foot of energy efficient glass. Installation costs are expected to be slightly higher for electrochromic windows.

Total Resource Cost: The TRC for a 10,000 sq. foot building with 200 sq. feet of windows is estimated at 1.33.

Estimated Future First Cost in 5 Years: Manufacturers expect a price drop over the next five years as performance improves, volume increases, and production becomes more efficient. Development of electrochromic coatings that can be applied to existing windows will lead to even lower costs to building owners by eliminating the need to replace new windows. These coatings are expected to have electrochromic as well as low emissivity properties.

Future TRC: If coatings are developed that substantially reduce the price of achieving electrochromic windows, then the TRC is likely to increase.

Technical

Technology Risk and Issues: Manufacturers are working to reduce costs. Some cost reductions may have an impact on reliability and performance. For example, organic designs with lower production costs have been tested but either perform poorly or degrade more quickly than current products. Testing performed at NREL showed that many, but not all, lower-cost products and prototypes have performed poorly in stress-testing and some have had their color changing properties degrade sooner than expected.

Regional Applicability: No regional constraints but the effectiveness of the technology would depend on the amount of solar energy that is currently absorbed through windows. This technology would be especially useful in the Sunbelt.

Supply Chain

Health of Manufacturing Sector: Moderate manufacturing sector. There are industry leaders that create related products for different markets, such as auto-dimming automotive mirrors, dimmable eyeglasses and space coatings, indicating that capabilities exist. Major glass manufacturers have also been involved historically with electrochromic development but details are not publically available. Many electrochromic window manufacturers appear to produce product in small volumes which may not be able to meet market demands.

Distribution Capability: Distribution capability exists through manufacturers and authorized retailers.

Service Capability: Because electrochromic windows require a separate controller for each set of panes, existing building services personnel would need additional training to install and maintain this technology. After-market problems may require manufacturer-provided services.

Health and Environment

Human Impact: No known human health impacts.

Environmental Impact: No known environmental impacts.

Connectivity

Demand Response Readiness: Demand response could be achieved by dynamically controlling electrochromic windows and balancing lighting and cooling loads. The technology could potentially receive demand response signals if proper controls are added.

Grid Impacts

Source of Power Quality Issues: Electrochromic windows are not expected to be the source of power quality issues.

Susceptibility to Power Quality Issues: The technology would be more susceptible to power quality issues than traditional windows due to the increased presence of electronics within the device. Further research must be done to determine exact susceptibility issues but overall impact is expected to be minimal.

If windows are powered by solar or batteries then power quality issues are expected to be of low concern.

Requirements to Advance to Next Stage

EPRI through its Technology Innovation program is engaged in development of scalable electrochromic windows with the potential for lower costs. The project will also evaluate the efficiency of the technology. With positive results with respect to scalability, costs, and efficiency, the technology will move to the next stage of the pipeline.

Membrane Dehumidification – Commercial

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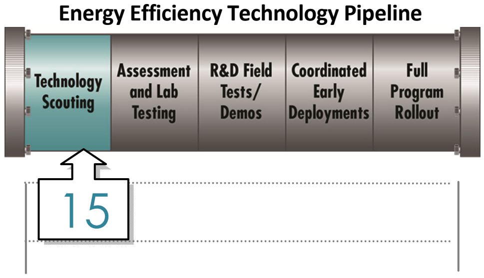
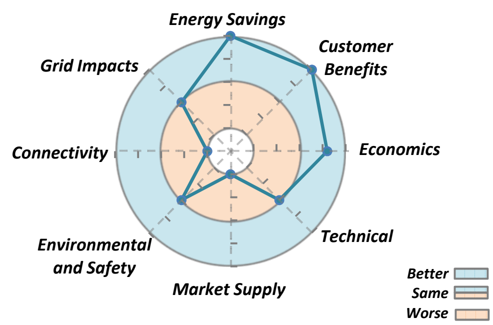
Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Dehumidification is an important part of climate control in commercial buildings because occupants, traffic, and venting introduce humidity into the structure. Traditionally, dehumidification was achieved by overcooling the supply air to remove moisture and then reheating the air to the proper temperature. Although energy intensive, commercial spaces must maintain proper humidity levels and incorporate external air. In regions with humid outside air, buildings with high occupancy, or other moisture loads, this causes a great need for dehumidification.

Existing dehumidification systems use traditional over-cooling, desiccants, enthalpy wheels, heat pipes, and dual-path systems. There is also a relatively new technology: ionic membrane dehumidification.

One type of membrane dehumidification uses solid-state polymer ionic membranes (SPE) to decompose water molecules. Once decomposed into ions, the hydrogen ions migrate through a membrane where they bond with oxygen atoms from ambient air. This technology can also be used to humidify air by running the process in reverse. Polymer ionic membranes are similar to membranes used in fuel cell technologies.

Another type of membrane dehumidification uses osmotic membranes that pull humidity out of building airflow using osmosis. Return air runs adjacent to outdoor air separated by the membrane. This type of dehumidification can also be implemented by passing humid air across a membrane that separates the air from a hydrophilic salt mixture. Because salt water is hydrophilic, it pulls the moisture out of the air.

Economics

Current First Cost: Products are not widely available, but initial estimates predict that membrane dehumidification will be priced competitively with existing methods of dehumidification. In new buildings, the adoption of supplemental dehumidification technologies allows for a reduction in the size of building cooling systems, which could lead to

Assessment Results

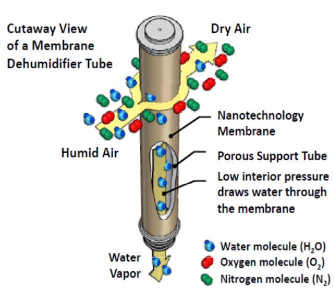
Energy Savings

Energy Savings: ARPA-E estimates that if successful, membrane dehumidification will be 50% more efficient for dehumidification and/or cooling of hot/humid air than traditional air conditioners. Savings would be greatest in areas with high humidity and large cooling loads. Overall HVAC load savings are expected to be as high as 30%.

Coincident Peak Demand Savings: Peak demand savings would vary greatly depending on climate, type of building, and existing dehumidification systems but could be as high as 30% for the building load. Locations in which dehumidification is needed in the winter could see a 100% reduction of the cooling load during cold months because the over-cooling method would no longer need to be used. The highest savings would be realized in humid regions in which year-round dehumidification is needed.

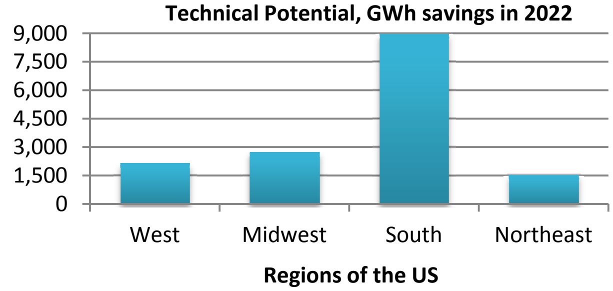
Customer Benefits

Customer Benefits and Acceptance: Membrane dehumidification allows for efficient dehumidification of air without the air coming into contact with chemicals, as opposed to desiccants—in which air contacts desiccant (chemical) materials. In addition, the membrane is expected to be compact and virtually maintenance free. Membrane dehumidification is noiseless, which can have a positive impact on building occupants. Ionic membrane dehumidification can also be designed to use silver ions within the membrane to kill bacteria in the air.



Source: ARPA-E

Technical Potential, GWh savings in 2022



additional cost savings.

Total Resource Cost: Because the technology is still in development, there is insufficient information to determine the total resource cost (TRC). Any estimates would likely change when the technology hits the market.

Estimated Future First Cost in 5 Years: As with most products in development, the cost is expected to decrease after the technology hits the market.

Future TRC: After the technology is developed, the TRC is expected to increase as costs decrease.

Technical

Technology Risk and Issues: Research is still being performed on the various forms of membrane dehumidification. So far, the technology appears to be maintenance free and without any major technical risks. However, further research on use of membrane dehumidification in large-scale commercial applications is needed.

Regional Applicability: The technology should function in all climate zones; however, it is expected to perform best in humid climates.

Supply Chain

Health of Manufacturing Sector: There are a few manufacturers who produce ionic membrane dehumidifiers, but the products are designed to remove humidity from industrial cabinets. There appear to be no manufacturers of either type of membrane dehumidification for commercial applications.

Distribution Capability: No distribution capabilities yet. The companies that currently apply the technology in industrial applications do not appear to have distribution capability in place for other products in commercial spaces.

Service Capability: In the commercial sector, the service required for the technology is unknown.

Health and Environment

Human Impact: No significant change from current technology. Membrane dehumidifiers make no sound, which can increase the quality of life for building occupants.

Environmental Impact: No significant change from current technology.

Connectivity

Demand Response Readiness: Because of the passive nature of the technology, demand response is not expected to be a potential feature.

Grid Impacts

Source of Power Quality Issues: No power quality events would be expected to occur as a result of this technology.

Susceptibility to Power Quality Issues: The technology is not expected to be susceptible to power quality events.

Requirements to Advance to Next Stage

Membrane dehumidification technologies are available to remove humidity from industrial cabinets but are still being researched for use in commercial climate control systems. This technology will move on to the lab testing stage once several products reach the market. Upcoming milestones include the completion of ARPA-E's project on membrane dehumidification; the project website lists the project end date as mid-2014.

3
ASSESSMENT AND LABORATORY TESTING STAGE TECHNOLOGIES

The required criteria for this stage include the required criteria for the previous stage, plus the following:

- There are promising energy savings claimed; needs objective assessment.
- Experience to date indicates good functional performance.
- Scalability – the technology can be scaled to serve a large market.

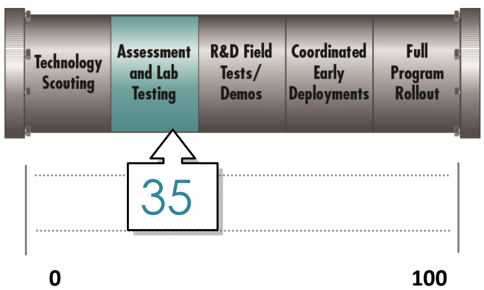
The technologies assessed in this stage are:

- CO_2 Heat Pump Water Heaters, EcoCute – Residential
- Virtual Audit Technology – Commercial

CO_2 Heat Pump Water Heaters, EcoCute – Residential

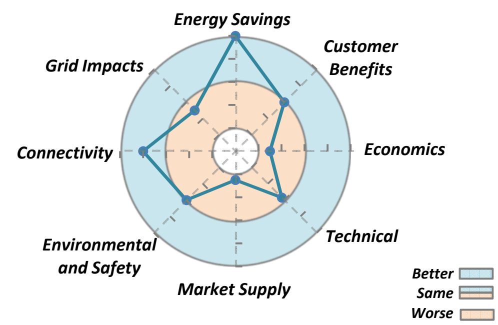
Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

The term “EcoCute” translated from Japanese means “natural refrigerant heat pump water heater.” The carbon dioxide-based heat pump technology was jointly developed by Tokyo Electric Power Company, Denso Corporation, and Central Research Institute of Electric Power Industry. The team developed the high efficiency compressor technology, the compact heat exchanger, and the system control logic that takes advantage of time-of-use electric power rates. The development started in 1999 and the first commercial EcoCute system was introduced in Japan in 2001.

The use of CO_2 as a refrigerant allows for HPWHs to be effective at lower ambient temperatures and increased COP over traditional HPWHs. The EcoCute technology addresses several of the limitations of conventional HPWHs through the use of innovative design. The thermodynamic characteristics of the CO_2 cycle allow the transfer of more thermal energy per cycle, resulting in a higher coefficient of performance for the EcoCute machine. The EcoCute cycle also operates at a higher final temperature than most conventional vapor-compression cycles, allowing an EcoCute HPWH to heat water to a higher temperature than a conventional HPWH. Losses caused by reabsorption of thermal energy into the refrigerant during expansion of the CO_2 cycle are overcome in the EcoCute design through the use of a special expander, allowing more of the thermal energy to pass into the hot water.

Assessment Results

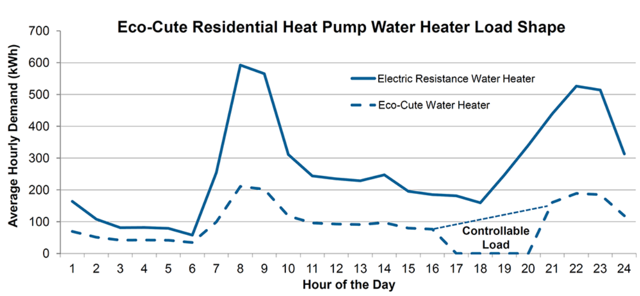
Energy Savings

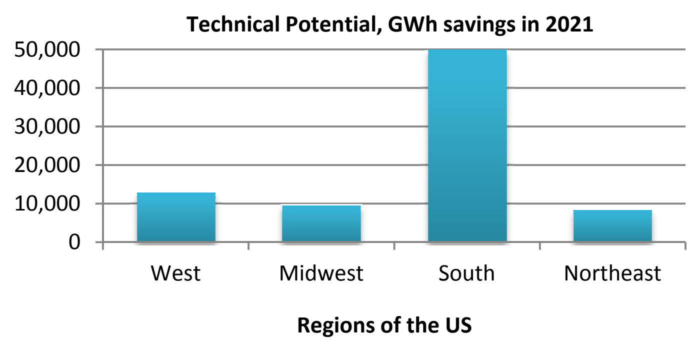
Energy Savings: EPRI lab testing of an EcoCute water heater showed savings of 73% (coefficient of performance (COP) of 2.76), when compared to an electric resistance water heater. However, field studies show that savings are not considerably higher than traditional heat pump water heaters unless the unit is either operating within an area with lower ambient temperatures or is fed very cold inlet water.

Coincident Peak Demand Savings: EPRI lab testing demonstrated peak savings of 76% without taking advantage of scheduling features. The EcoCute system was created with load control in mind so the unit operates on a time-based schedule. This ensures off-peak reheating of the water tank. In addition, the unit does not include any resistive elements.

Customer Benefits

Customer Benefits and Acceptance: Increased controls present on Japanese models provide controls that increase the user’s ability to control the unit and its energy consumption. Additional remote controls are provided so users can alter the output temperature for different rooms. Acceptance is common in Japan and other parts of the world.





Economics

Current First Cost: The unit under test cost about $3-5,000. This is about 14 times the cost of a standard $350 electric resistance water heater.

Total Resource Cost: EcoCute TRC is estimated at 0.7 due to the high cost of the unit.

Estimated Future First Cost in 5 Years: The technology is expected to be more expensive than the replaced technology due to high operating pressure and the relatively low number of CO_2 compressor manufacturers.

Future TRC: TRC is expected to stay around 0.7 due to the inherent high-costs of technologies used within the EcoCute water heater.

Technical

Technology Risk and Issues: Lab tests showed good performance and increased energy efficiency compared to standard electric resistance water heaters. Additional considerations must be taken as units may have exterior compressors and interior water storage tanks so water lines may have to be run to the unit. Additional maintenance may be required. Dangers include high water temperatures (~170 degrees) and high operating pressure in the compressor. However, with proper installation and operation, there is no increased risk.

Regional Applicability: Better range than most HPWHs but still to be determined for some climates. Systems have shown to be effective across Japan, China, and Europe. The use of CO_2 as a refrigerant allows the unit to be more effective at colder temperatures when compared to traditional HPWHs.

Supply Chain

Health of Manufacturing Sector: Very weak. No large water heater manufactures in the USA manufacture EcoCute water heaters. The only major manufacturer that exists in the USA is Daiken. However, Daiken does not have a large presence in the water heating market.

Distribution Capability: Very weak. No distribution channels exist for companies that produce EcoCute water heaters.

Service Capability: Service exists but may not exist in every city. Service on CO_2 compressors may prove difficult in certain regions because it would require specially trained staff and most likely a visit from the manufacturer. Plumbing could be provided by a traditional plumber.

Health and Environment

Human Impact: With proper installation and location, human health impacts are minor and solvable. Possible mold growth if proper drainage for evaporator is not provided. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: Refrigerant use occurs in occupied space but negative impacts are minimized or eliminated in the design. Leakage is not an environmental issue because the refrigerant used is CO_2 which is not harmful in the quantities used. CO_2 is a non-flammable, non-ozone depleting gas.

Connectivity

Demand Response Readiness: EcoCute is designed for load control. Additional functionality may need to be added for units to accept demand response signals. The unit operates on a time-based schedule for ensuring off-peak reheating of the water tank.

Grid Impacts

Source of Power Quality Issues: Technology slightly more likely to cause events compared to electric resistance water heaters. Proper design should reduce or eliminate power quality issues. Increasing the number of compressors on the grid, as would occur with increasing HPWH adoption, may increase the impact of slow voltage recovery which can reduce system voltage. This could occur after a voltage sag or outage when the heat pump water heater compressors turn back on.

Susceptibility to Power Quality Issues: No unique power quality issues for the technology when compared to electric resistance water heaters. Controls associated with heat pump technologies may be susceptible, and individual results will vary based on the quality of the product design.

Requirements to Advance to Next Stage

For this technology to move to field tests or EE Demonstration, the technology needs to achieve UL rating and be made available in the US by manufacturers.

Virtual Audit Technology – Commercial

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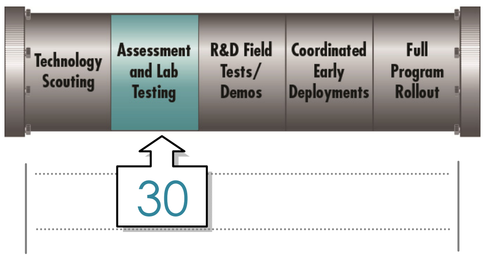
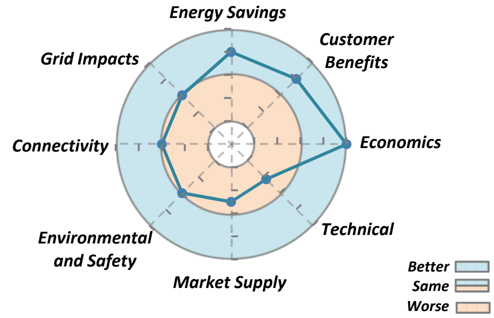
Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

A virtual audit is the off-site analysis of building data to understand how energy is used and where it is wasted in an attempt to lower an electricity bill, reduce facility consumption and contribute to system wide efficiencies. Virtual means that the analysis forgoes a traditional physical walkthrough and review of schematics by an energy expert. Instead, advanced algorithms are used to disaggregate load data and, in conjunction with geographic location and local weather, to identify potential energy savings opportunities. This information is analyzed to reveal how efficiently a building uses energy, and provides a platform to benchmark the energy performance of the building, develop recommendations for both energy-saving retrofits and customized operational procedures, and monitor and verify savings and performance over time. Audits can be performed either as a one-time service or as a recurring progress report.

Virtual audits differ from physical energy audits because they can provide ongoing reports to help track savings and provide energy savings advice. Typically, the services provided are tailored for each customer. Virtual audits are able to provide estimated savings for a large number of buildings and identification of the buildings that have the highest potential for energy savings, after which a more detailed audit is performed.

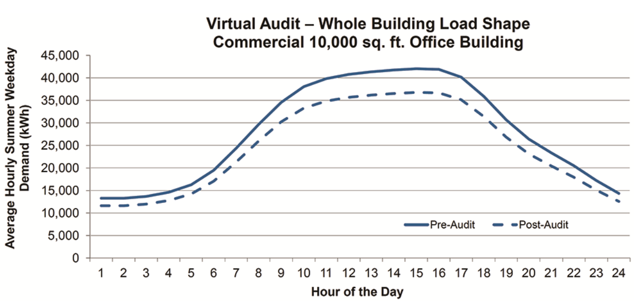
Assessment Results

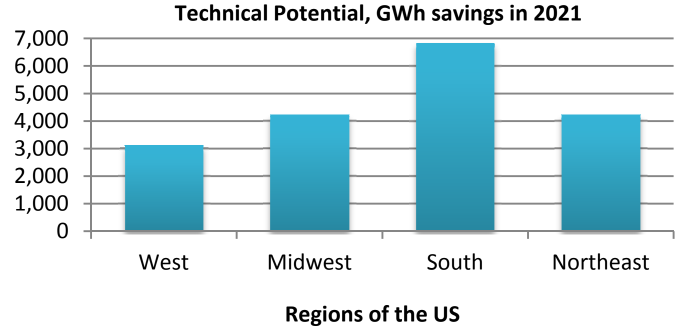
Energy Savings: Potential savings will vary site-to-site based on current efficiency as well as geographical characteristics. Vendors claim building energy savings in the range of 5% to 15%.

Coincident Peak Demand Savings: Coincident peak demand savings will vary depending on current building systems and usage, especially for HVAC units and lighting. Vendors claim building demand savings in the range of 5% to 15%.

Customer Benefits

Customer Benefits and Acceptance: A virtual audit can provide more customer benefits than the traditional method of physically identifying areas for potential energy savings. Specifically, the technology enables the customer, utilities or building owners, to perform energy audits without being intrusive to building tenants. This allows for multiple audits to be performed quickly across a large portfolio of buildings. Building owners and utilities are also able to perform additional audits to measure energy savings progress without significant increases in cost.





Economics

Current First Cost: The technology is designed for large companies and utilities that are interested in understanding the energy use in hundreds to thousands of buildings. Current methods include physical audits, which can run $2,500 or higher, and monitoring, which can run $1,200 and require additional analysis costs. The cost of a virtual audit is typically 50-90% less than a physical audit but pricing depends on the number of buildings in a portfolio and the type of audit selected.

Total Resource Cost: The TRC for a 10,000 sq. ft. building is about 3.7 assuming average whole building energy savings of 10% at a cost 50% lower than physical audits.

Estimated Future First Cost in 5 Years: Future first costs are assumed to be the same as current first cost.

Future TRC: Based on the assumption of future first costs remaining the same as current first costs, the TRC remains at 3.7 for a 10,000 sq. ft. building.

Technical

Technology Risk and Issues: While there is not enough experience to accurately assess risks, a slight increase in risk would be expected with virtual audits. Simulation results may not accurately identify savings potential depending on the quality of the algorithm and number of variables collected. To offset the risk, a calibration methodology is used.

Regional Applicability: A benefit of virtual audits is that they are not limited by regional aspects.

Supply Chain

Health of Manufacturing Sector: The health of the manufacturing sector is weak. Only a few small companies provide virtual audits. Some have developed advanced proprietary algorithms, which tends to differentiate these suppliers.

Distribution Capability: Distribution of virtual audits is performed by the manufacturers themselves and is already in place.

Service Capability: No additional service is needed for this technology.

Health and Environment

Human Impact: No change is expected from virtual audits over current technologies. There are no human health risks.

Environmental Impact: No change is expected from virtual audits over current technologies. There are no environmental risks.

Connectivity

***Demand Response* Readiness:** This technology is a service provided to customers to improve efficiency within buildings. However, the technology could help identify potential demand response capabilities.

Grid Impacts

Source of Power Quality Issues: No expected power quality issues.

Susceptibility to Power Quality Issues: No expected susceptibilities to power quality issues.

Requirements to Advance to Next Stage

This technology needs objective testing before it can advance to the next stage of the pipeline. Tests of one or two sites are needed to compare the results and value of a virtual audit with that of a physical audit and/or load monitoring. These tests will provide information needed to determine virtual audit accuracy and verify disaggregation of whole-building load data. Positive results will enable the technology to advance to the demonstration stage where many sites would be tested.

4

R&D FIELD TESTS AND DEMONSTRATIONS STAGE TECHNOLOGIES

The criteria for this stage include the criteria for the previous stages, plus the following:

- There are objective energy savings results from lab or other sources.
- The technology has shown functional performance; there are no major showstoppers.
- The technology is commercially available, at least in small quantities.
- The technology is UL rated.

The technologies assessed in this stage are:

- CO_2 Heat Pump Water Heater – Commercial
- Controllable LED High Bay Lighting – Commercial
- Evaporative Cooling – Data Centers
- Heat Pump Water Heaters – Commercial
- High Efficiency Clothes Washers and Dryers – Residential
- LED Replacement for Fluorescent Troffer Lighting – Commercial
- Submersion Cooling – Data Centers

CO_2 Heat Pump Water Heater - Commercial

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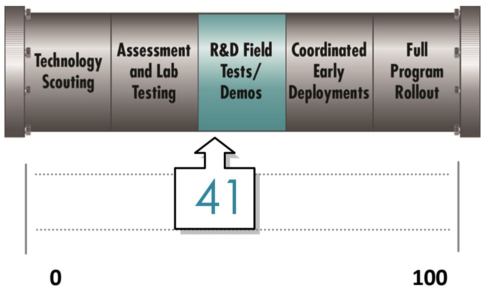
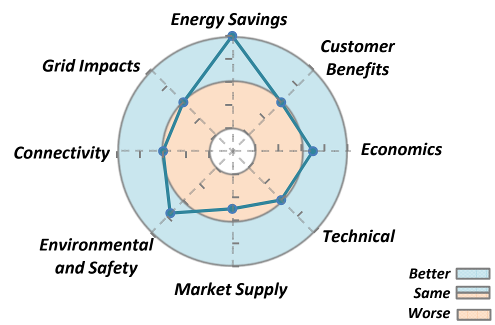
Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Commercial CO_2 Heat Pump Water Heaters (HPWHs) operate the same as the residential version. However, commercial HPWHs are purchased as a set of components as opposed to a single package, which enables customers to design a system to fit their application. The operating temperature of traditional commercial HPWHs is 140°F (60°C) whereas the outlet temperature of the commercial CO_2 HPWH is higher – capable of a range between 150°F (66°C) and 190°F (88°C). If even higher water temperatures are needed—such as for chemical-free cleaning at 170°F (77°C)—supplemental heat is required. Unlike resistive water heaters, commercial CO_2 heat pump water heaters can recover heat from nearby sources such as warm-water discharge and process heat. The exhaust air is available to pre-cool for cold water storage.

EcoCute was jointly developed by Tokyo Electric Power Company, Denso Corporation, and Central Research Institute of Electric Power Industry. The team developed the high-efficiency compressor technology, the compact heat exchanger, and the system control logic that takes advantage of time-of-use electric power rates. The development started in 1999, and the first commercially-available residential EcoCute system was introduced in Japan in 2001. EcoCute, translated from Japanese, means natural refrigerant heat pump water heater.

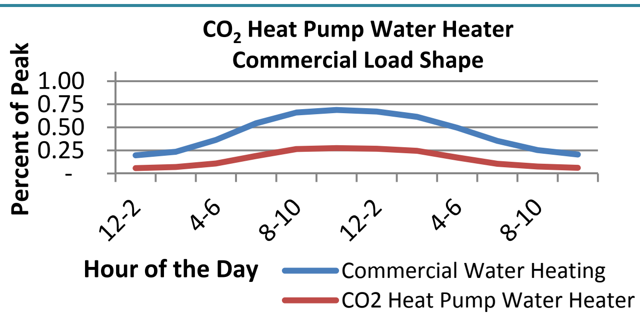
The use of CO_2 as a refrigerant allows HPWHs to be effective at lower ambient temperatures offering an increased coefficient of performance (COP) over traditional HPWHs. The thermodynamic characteristics of the CO_2 cycle enables the transfer of more thermal energy per cycle. The improved design permit more efficient transfer of the thermal energy from ambient air to the water.

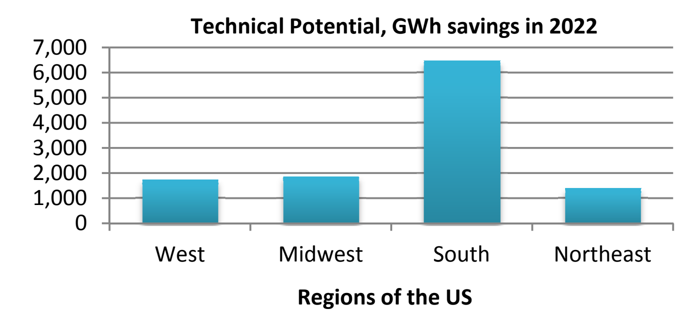
Assessment Results

Energy Savings

Energy Savings: Results from EPRI's lab testing indicate that CO_2 heat pump water heaters could save as much as 70% of annual energy use in commercial water heaters. Actual savings will vary depending on the specifics of the installation and configuration of the system. Systems that use space cooling and take advantage of waste heat sources will see additional savings from space cooling effects to building thermal load. The ability to make use of waste heat increases the potential for energy savings. Energy savings exist compared to both gas and electric water heaters but, in general are greater compared to electric water heaters.

Coincident Peak Demand Savings: Laboratory data suggests demand savings of 25–60% compared to similar sized water heaters using electric resistance elements. The amount of demand savings is in proportion to the sizing of the compressor and storage tank, which in turn depends on the rate of recovery. For a given recovery rate, a slower rate allows for a smaller compressor and larger tank while a quicker rate requires a larger compressor and smaller tank. Ultimately the design is determined by the business process.





Customer Benefits

Customer Benefits and Acceptance: There is opportunity for improvement in comfort when the heat pump is configured to provide space cooling and dehumidification. Because the system uses discreet parts instead of a unitary package there is greater opportunity to optimize the configuration through placement to take advantage of the availability of waste heat. Examples include commercial kitchens and heated process streams.

Economics

Current First Cost: Commercial CO_2 HPWHs are expected to cost between $40,000 and $45,000, not including installation, which varies depending on the design of the site and if additional pumps and heat exchangers are required.

Total Resource Cost: A favorable TRC is likely based on a theoretical example in which a CO_2 HPWH replaced an existing electric resistance water heater—and space cooling is used to offset chiller operation. The result was a TRC that ranged between six and nine. The range is the result of uncertainty in coincidence of the load. The TRC is expected to be lower for applications in which space cooling is not used and waste heat is not leveraged. Furthermore, in the field, the replaced technology may be either gas or electric. In installations in which gas is the existing technology, the payback will be longer because of the increased efficiency of water heaters using natural gas compared to electric resistance.

Estimated Future First Cost in 5 Years: Cost is high because of limited production quantities. Manufacturers predict that with increased production numbers the cost may decrease to between $30,000—40,000. Competition from additional manufactures will also lead to a reduction in price.

Future TRC: If the predicted reduction in price occurs the TRC is expected to improve.

Technical

Technology Risk and Issues: No change from compared to existing technology assuming proper design. System location, tank size and compressor size must be properly coordinated to ensure that outlet temperature specifications are met and satisfy the demands of the process. Proper coordination of installation and maintenance are needed. The range of ambient temperature can limit performance without proper system design; however, the use of CO_2 as a refrigerant increases the range of acceptable ambient temperatures. In cases with very low ambient temperature, supplemental backup heat may be needed—otherwise, the demand may not be met.

Regional Applicability: HPWHs perform well in warmer climates, particularly in the Southern United States and portions of the west census regions where available heat is readily available. Interestingly, savings may be highest in colder climates with low inlet water temperatures provided either waste heat is available or exhaust cooling is needed. The potential for savings is higher for colder inlet water temperatures because HPWHs have highest efficiency when the temperature difference is the greatest. Under this condition CO_2 refrigerant is better than traditional working fluids such as R-410A.

When commercial HPWHs are located within a facility—particularly with a heat source nearby—the unit's performance is not limited by regional climate. The use of a constant source of waste heat within a facility has the potential to eliminate seasonal and regional impacts.

Supply Chain

Health of Manufacturing Sector: The manufacturing sector was scored as moderate because there is only one U.S. manufacturer - Mayekawa. Mayekawa manufactures a variety of compressor products and presents a strong presence in that industry, but a much smaller presence in the water heating industry.

Distribution Capability: The distribution sector is strong for the one available manufacturer. Distribution is managed through an internal sales team and several distributors that represent all of their industrial products.

Service Capability: The manufacturer has a long-established base of service contractors. Service capability is expected to improve over with time and with increased adoption of the technology.

Health and Environment

Human Impact: With proper installation and location, human health impacts are minor and solvable. Mold growth is possible if proper drainage for the evaporator is not provided or becomes inoperable. Because CO_2 is environmentally benign and not a health hazard in low quantities, there is an incremental advantage over R-410A systems in the uncommon event of a refrigerant leak.

Environmental Impact: Refrigerant leakage is not an environmental issue because the refrigerant used is CO_2—which is not harmful in the quantities used.

Connectivity

Demand Response Readiness: Commercial HPWHs could provide demand response, but that functionality is not currently available from products in the market. It is possible to adjust outlet water temperature during operation and disable the resistive element, which would prevent the HPWH from adding to the electric peak. Additionally, HPWHs could be configured to operate on a time-based schedule to ensure off-peak reheating of the water tank.

Grid Impacts

Source of Power Quality Issues: The technology is slightly more likely to cause events compared to electric resistance water heaters. However, proper design should either reduce or eliminate power quality issues. Increasing the number of compressors on the grid—as would occur with increasing HPWH adoption—may increase the power system requirement for reactive power in order to prevent slow voltage recovery or voltage collapse after a voltage sag or outage when the HPWH compressors turn back on.

Susceptibility to Power Quality Issues: No unique power quality issues for the technology compared to electric resistance water heaters. Controls associated with heat pump technologies may be susceptible; individual results will vary based on the quality of the product design.

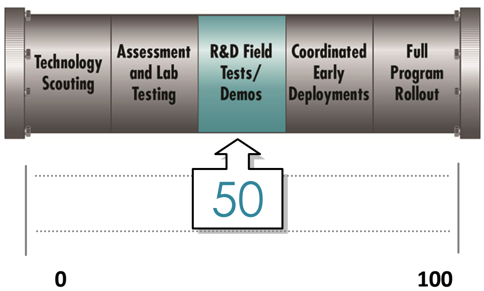
Requirements to Advance to Next Stage

A field study of these units is needed for commercial CO_2 heat pump water heaters to advance to the next stage. The functionality and savings have been proven in lab testing, but more data on field performance and the average costs and considerations for installation are needed. In addition, information is needed from real-world installations on the impact of space cooling on water heater performance.

Controllable LED High Bay Lighting – Commercial

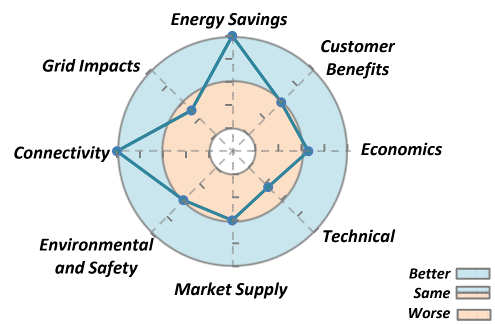
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

High-bay lighting is found in industrial or commercial buildings with high ceilings. Most people experience high-bay lighting in big box stores, but it is also commonly found in warehouses, manufacturing plants, gymnasiums, and anywhere else that lights are mounted 20 ft (6 m) or higher.

The lighting load on a commercial building can account for a large portion of annual electrical usage. Depending on the facility, some high-bay lights remain on at all times—even when the area is not being used. Lighting controls on high-bay lighting can reduce the amount of unnecessary lighting while ensuring that a proper amount of light is available when the area is occupied. The controller does this by using occupancy sensors, scheduling, and daylight sensors. Controllers vary in complexity: simple systems include motion sensors on each fixture; advanced systems include control panels with scheduling and other complex controls.

Light-emitting diode (LED), induction, fluorescent, and high-intensity discharge (HID) technologies are all high-bay lighting systems that can be managed by control systems. Fluorescent, induction, and HID technologies can be dimmed about 50% while some LEDs can be dimmed up to 10%. With dimming there is a potential for reduced lifetime. HID fixtures must be retrofitted with specialized dimmable ballasts, which can be an expensive process because of the time requirements of the swap. Although LEDs are the most expensive option, they provide the greatest savings and longest lifetime and are the most flexible with regard to control. Therefore, this Technical Brief focuses on LEDs.

Assessment Results

Energy Savings

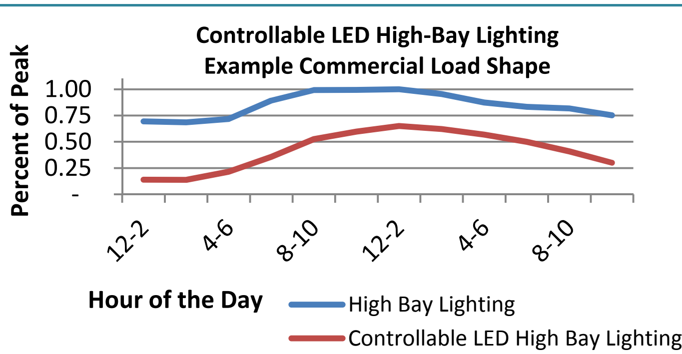
Energy Savings: Energy savings are directly related to the energy consumption of the chosen lighting technology. The energy savings of adding controls to a high-bay fixture are expected to be 25–95%. Savings depend on several factors such as minimum allowed light levels, traffic within the facility, and base technology. Greater savings are expected when the original technology is HID replaced with a more efficient technology such as LEDs combined with controls.

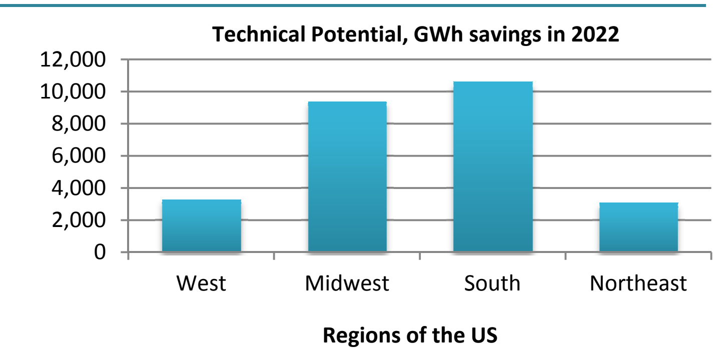
In addition to energy savings in the fixture, there is an ancillary benefit from the reduction in heat generated by the fixture that reduces the load on the cooling system.

Coincident Peak Demand Savings: Coincident peak demand savings are expected to exceed 25% depending on system design: commercial lighting loads are not expected to vary hour-to-hour during business hours.

Customer Benefits

Customer Benefits and Acceptance: There is a level of convenience and added safety that comes with lights automatically controlled. Controls can interact with additional lighting sources—such as solar—and dim the high-bay lights appropriately. Furthermore, some systems incorporate energy monitoring features so that occupants can view lighting energy consumption.





Economics

Current First Cost: The cost of installing controls for light fixtures varies depending on the complexity of the control system. The cost of LEDs are typically twice that of HID fixtures. However, when adding controls the cost may be similar. Cost will change depending on the number of fixtures installed, wattage, and the complexity of the control system. The per fixture cost increases as the number of fixtures decreases because many systems have a minimum cost for the control panel and associated components. It is more economical to select controllable high-bay LED lighting during builds or scheduled upgrades because the installation costs are expected to be similar, depending on the complexity of the controllable system.

Total Resource Cost: An example case with twelve 180-watt (W) LEDs with motion sensing capability replacing twelve 400-W metal-halide lamps with a runtime of 3,100 hours per year has a TRC of 1. The same analysis assuming a new installation (with equal installation costs) has a TRC of 8.

Estimated Future First Cost in 5 Years: The cost of LED controllable high-bay lighting is expected to decrease, but not dramatically.

Future TRC: The TRC is expected to increase slightly in both cases as the cost of LED and lighting controls drops.

Technical

Technology Risk and Issues: The use of controls is not standardized in lighting systems—many use closed protocol wired/wireless systems. Some standardization is beginning to occur, but this process, and market forces, may take several years to stabilize. Building designers are required to pay attention to the capabilities of both the controls and the light fixtures to ensure compatibility.

Regional Applicability: No regional limitations; controllable high-bay lighting is applicable in every region.

Supply Chain

Health of Manufacturing Sector: Strong manufacturing sector with major and minor manufacturers producing controls for a variety of lighting technologies.

Distribution Capability: Distribution capability is well developed; major manufacturers with pre-existing distribution channels sell this technology.

Service Capability: As with any new building system, maintenance staff is required to learn how to operate new control systems—but manufacturers may be required to perform maintenance on equipment. Capability exists with expected increases in strength and availability as the market develops.

Health and Environment

Human Impact: No significant change from current technology. Safe operation and installation per widely-accepted codes and standards eliminate any human health impacts. Lighting controls must be configured to properly illuminate areas to the appropriate OSHA-required light levels.

Environmental Impact: No change from current technology. Controllable high-bay lighting does not create an environmental risk.

Connectivity

Demand Response Readiness: Lighting controls are able to reduce light output to reduce building power consumption while minimizing impact on occupants. Building managers could identify non-essential lights to dim or shut off completely. In addition, lights can be configured to dim to various light levels, depending on the severity of the event. Some manufacturers have products that can receive demand response signals. Lighting can create load reduction without a secondary peak load upon recovery.

Grid Impacts

Source of Power Quality Issues: No power quality events are expected from the technology, but outlier products may present unforeseen issues.

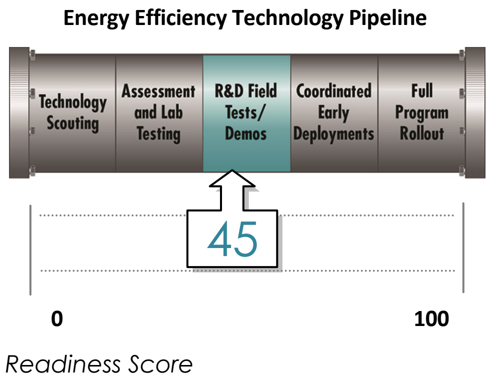
Susceptibility to Power Quality Issues: Controls associated with controllable high-bay lighting may be susceptible; individual results will vary based on the quality of the product design.

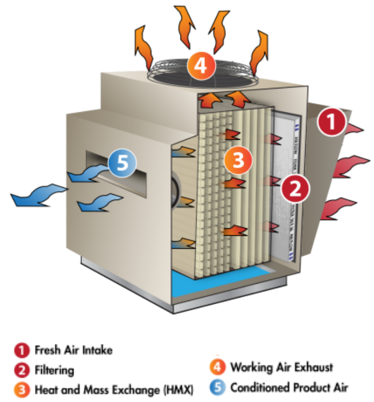
Requirements to Advance to Next Stage

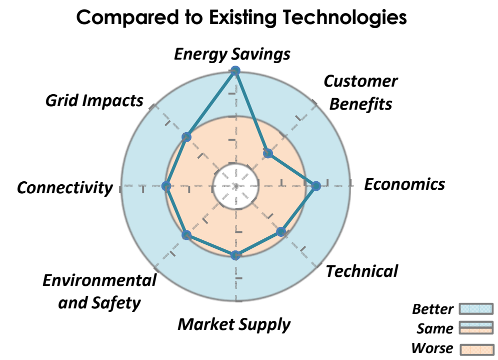
Field demonstrations are recommended for this technology to advance to the early deployment stage of the pipeline. It is evident that controllable LED fixtures will provide savings to an electric utility's customers. However, because of the range of products available, price spread, it is recommended to determine whether advanced systems can provide additional energy savings such as savings from customer behavior impacts. Savings are expected to vary depending on the application. Field demonstrations should create a clearer picture of where are the best opportunities for controllable lighting and identify barriers to adoption. While utility intervention may not be necessary because customers are adopting this technology without utility intervention, the resulting energy savings are not well understood.

Evaporative Cooling – Data Centers

Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**







Technical Description

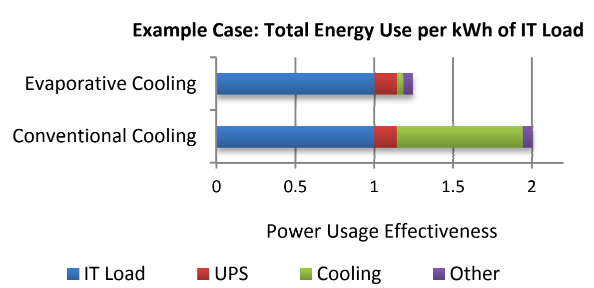
Large data centers (mid-tier and enterprise-class), which make up at most 1% of U.S. data centers, are already energy efficient. However, the remaining 99% have significant room for improvement in energy efficiency. Small data centers are found in most commercial buildings, including office buildings, hospitals, universities, city halls, and supermarkets.

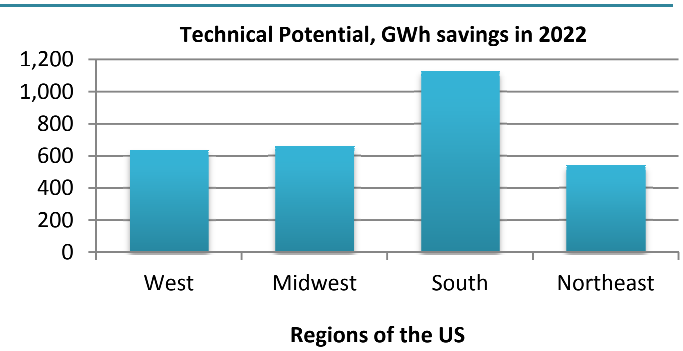
The cooling loads in small data centers account for 30-40% of the energy used by the data center. Computer room air conditioners (CRAC) are designed to provide cool air to the racks to prevent servers from overheating. Traditional data center cooling is accomplished with vapor-compression or chilled-water systems. Evaporative cooling has the ability to provide cooling using the latent heat of vaporization of water and in the process use significantly less energy than conventional cooling systems.

With conventional equipment, the higher the incoming air temperature, the more energy the AC equipment must use to lower the indoor temperature. However, chilled water is not necessary for evaporative coolers to replace traditional systems. Evaporative coolers work by evaporating water into the air. When water evaporates, it absorbs a considerable amount of heat. An evaporative cooler takes advantage of that concept, evaporating water into the air and drawing that heat of evaporation from the air, reducing the temperature. One manufacturer claims that the air temperature can be dropped 18–25 degrees using evaporative cooling methods.

Evaporative cooling is not to be confused with evaporative pre-cooling, in which water is sprayed into the air surrounding the outdoor unit to lower the ambient temperature of the cooling coils. Evaporative cooling is performed on the air entering the building and pre-cooling on the outdoor air surrounding the coils.

There are two types of evaporative coolers: direct and indirect. Direct evaporative coolers (swamp coolers) reduce the temperature of inlet air by passing air through a moist environment. This lowers the temperature of the inlet air, reducing the amount of sensible heat the AC must remove from the space to reach the temperature setpoint. These can be used alone or as a pre-cooling stage in a hybrid system. In direct evaporative coolers, the air flowing through the building comes in direct contact with water—increasing the humidity and possibly requiring additional equipment to remove. For this reason, direct evaporative cooling is not usually viable when humidity reduction and temperature reduction are both needed. Indirect evaporative cooling works similarly to direct cooling but does not introduce humidity into the internal air system. Indirect evaporative cooling is not typically used for pre-cooling. Two streams of air are used: one with higher relative humidity/lower temperature, the other with higher temperature/lower relative humidity. They are run through a heat exchanger that allows the thermal energy in the warm/dry stream to pass to the cooler stream which reduces the temperature of the air entering the building without introducing additional humidity. The moist working air is typically exhausted.





Assessment Results

Energy Savings

Energy Savings: Cooling systems account for 30–40% of data center usage; EPRI estimates that evaporative coolers can typically save up to 90% of total cooling energy consumption in the case of a complete HVAC replacement. On the higher end of the savings are pure evaporative cooling systems, typically located in cool, dry locations. At the lower end are systems that require supplemental heating and/or humidity control. Overall, the savings to the cooling load accounts for 15–35% of total data center energy use.

Coincident Peak Demand Savings: Coincident demand savings will vary depending on climate. In a hybrid system the winter demand is lower because it leverages the naturally cool/dry air outdoors. On a particularly hot summer day, supplemental cooling may be needed, which will reduce the amount of savings. Overall savings are expected to be between 50 and 90%, with the highest percentage of savings in the winter and lower percentage in the summer. However, the overall reduction is expected to be larger in the summer when the peak is much higher because of cooling loads.

Customer Benefits

Customer Benefits and Acceptance: Compared to traditional direct-expansion and chiller-based CRACs, evaporative cooling has lower maintenance costs—the system is simple with easy component access. It requires less space (units are located outdoors) and can easily be installed on traditional systems because of its modular nature.

Economics

Current First Cost: First costs vary by installation but are expected to be a fraction of the total cost of a new CRAC. The total payback of a retrofit evaporative cooler is estimated at 2–3 years.

Total Resource Cost: A data center in Colorado retrofitted with indirect evaporative coolers is estimated to have a TRC score between 3 and 4, depending on the cost of installation and any additional avoided maintenance on the original system.

Estimated Future First Cost in 5 Years: The cost of evaporative coolers may decrease—minimally. Nevertheless, the first cost is still a small percentage of the cost of a separate HVAC unit.

Future TRC: TRC is expected to increase slightly but still be ~3 to 4.

Technical

Technology Risk and Issues: Direct evaporative cooling introduces humidity into the air, which can be problematic for computers. Increased humidity may lead to condensation, which increases the possibility of corrosion and other issues. In addition, no evaporative cooling technology provides dehumidification—if humidity rises within the data center, alternative methods must be used to remove it.

If no conventional HVAC system is used, a chiller may be required to cool the water at the warmest times during the day. The use of a chiller allows for a greater drop in temperature. However, the majority of the cooling is provided in the evaporation of water into the air stream. In addition, increasing the operating temperature of data centers allows for additional energy savings and more flexibility for the cooling system.

Although there are design risks with this technology, organizations such as Google and Facebook have deployed evaporative cooling at their data centers. Facebook had a condensation problem but corrected it by making changes to the data center's control system—demonstrating that technology risks can be overcome with proper design.

Regional Applicability: Limited but multiple regional applicability. Energy savings impacts will vary depending on design temperature of the geographic location. Evaporative cooling is more effective in warmer, drier climates.

Supply Chain

Health of Manufacturing Sector: Several manufacturers produce commercial-size evaporative coolers.

Distribution Capability: Distribution capability is in place and will increase with market development.

Service Capability: Service capability is in place. Capability exists with increasing strength and availability as market develops.

Health and Environment

Human Impact: No significant change from current technology. Safe operation and installation eliminate any human health impacts.

Environmental Impact: Water usage of evaporative coolers may appear to be an issue but water used to generate energy savings at the device accounts for even greater water savings at the power plant during the generation process.

No refrigerant is used in pure evaporative cooling systems—an environmental benefit over existing technologies.

Connectivity

Demand Response Readiness: Data centers will not provide demand response capability. Reduced load is not possible based on demand response signals because it could cause downtime or insufficient bandwidth. Because the energy demand of the data center servers does not vary largely based on workload, the demand is relatively steady-state throughout the day.

Grid Impacts

Source of Power Quality Issues: This technology is not expected to be the source of any power quality events.

Susceptibility to Power Quality Issues: The technology would not be susceptible to power quality events.

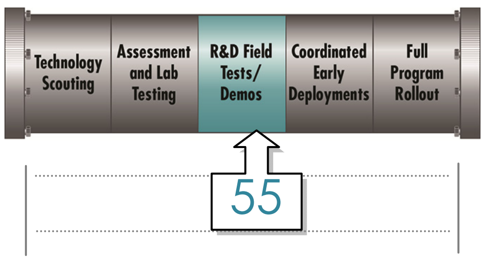
Requirements to Advance to Next Stage

Evaporative cooling is not a new technology, but its application to data centers is growing in popularity. Because the functionality of evaporative cooling has already been proven in other commercial applications, further investigation of its general functionality is not necessary. However, data center operators are under pressure to maintain a high uptime percentage. Because the cost of downtime can be significant for the data center's customers, there is reluctance to incorporate new technologies. Therefore, for evaporative cooling in data centers to move into the early deployment stage of the pipeline, field demonstrations should be conducted to determine performance specific to data center applications. Demonstrations should also provide insight into the benefits and technical risks that may appear for data center applications.

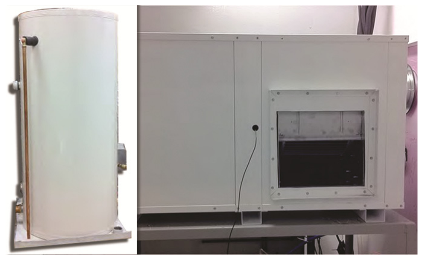
Heat Pump Water Heaters – Commercial

Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

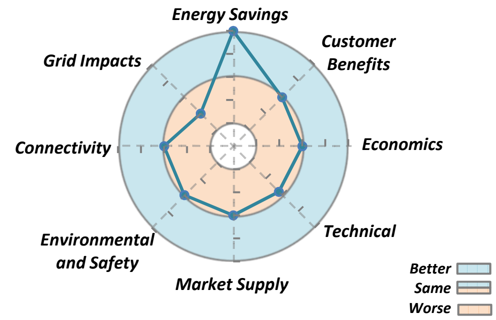
Energy Efficiency Technology Pipeline



Readiness Score



Compared to Existing Technologies



Technical Description

Traditional electric resistance water heaters use resistance heaters to increase water temperature to the desired temperature. Heat pump water heaters use electricity to mechanically draw heat from the surrounding environment. This is done using the vapor compression cycle which can be found in refrigerators as well as air conditioners. The refrigerant is driven by a compressor through an expansion, evaporation, compression, and condensation cycle which allows for the heat to be transferred from the surrounding air to the water within the tank.

Commercial heat pump water heaters operate the same as do those designed for residential use. However, commercial heat pump water heaters are purchased as a set of components as opposed to a single package as with residential heat pump water heaters. This allows customers to design their system to properly fit the application. The operating temperature of commercial heat pump water heaters is typically about 140°F so in applications requiring higher temperatures, such as chemical-free cleaning at 170°F, the heat pump should be paired with supplemental heat or used for pre-heating.

Assessment Results

Energy Savings

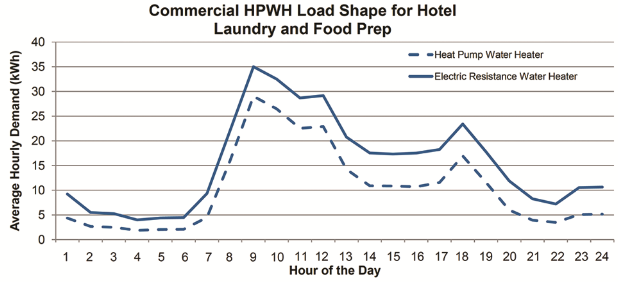
Energy Savings: EPRI lab and field testing shows 65% savings over a standard electric resistance water heater. In the best case operation, 75% was measured. Units with properly sized tanks can provide additional savings because of a reduction in the need for electric resistance backup. EPRI field studies show savings of 60-72% when compared to electric resistance water heaters.

Coincident Peak Demand Savings: Opportunities for peak reduction will be determined by the application. For example, in a hotel, the load may be primarily for laundry cycles, which if performed at night would provide minimal peak reduction. If hot water is used during the day, then peak reduction may occur. Sites can be designed to have varying amounts of backup heat. If a site has a large storage tank, peak reduction could be as high as 75%. With a small storage tank, resistive heating elements may be used for periods with sizeable water usage, potentially limiting the peak reduction capability.

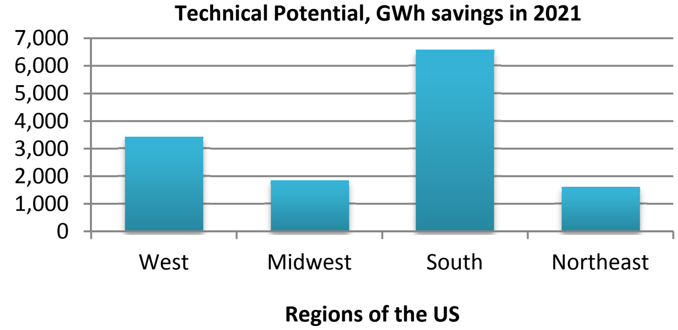
Customer Benefits

Customer Benefits and Acceptance: Same customer benefits as the replaced technology. Some opportunity for improvement in comfort when the heat pump can provide space cooling and dehumidification.

Commercial HPWH Load Shape for Hotel Laundry and Food Prep



Technical Potential, GWh savings in 2021



Economics

Current First Cost: Commercial HPWHs are more than twice as expensive as electric resistance water heaters. The installation cost is 125% as much as electric water heaters. An example of commercial HPWH costs is $70k versus $12k for a baseline unit at a large 5,000 gallon a day site. A smaller system can cost $12k where a similar electric resistance water heater would cost $4k.

Total Resource Cost: The TRC at today's price is estimated at 4.84.

Estimated Future First Cost in 5 Years: Commercial heat pump water heater costs are likely to remain greater than 150% of the price of standard electric resistance water heaters over the next five years. Reduction in cost may occur if widespread adoption of the technology takes place. Adoption is not likely without intervention.

Future TRC: Since a reduction in cost is not likely in 5 years the TRC is expected to remain 4.84.

Technical

Technology Risk and Issues: No change from current technology with proper design. Commercial HPWHs must maintain the correct output temperature for a business to continue to operate properly. The location, tank size, and compressor size must be taken into account to ensure temperature requirements are met. Additional installation and maintenance cost may apply to retrofits and replacement installations due to the compressor's location and necessary piping. Ambient temperature may limit performance without proper system design. In cases with low ambient temperature, backup heat may be needed or the demand may not be met.

Regional Applicability: Current HPWHs perform best in warmer climates particularly in the South and portions of the West census regions. Savings may be lower in colder climates. When commercial units are located within a facility, particularly with a heat source nearby, the unit's performance will not be limited by regional climate. Efficiency will increase with colder water supply assuming ambient temperature is sufficiently high.

The highest savings occurs when water temperature is low such as in northern climates, when space cooling can be used, or where there is a heat recovery opportunity.

Supply Chain

Health of Manufacturing Sector: Health of manufacturing sector is strong. There are a few primary manufacturers within the USA; Colmac, A.O. Smith, and Nyle.

Distribution Capability: Distribution networks are in place through authorized dealers. One manufacturer uses regional distributors to sell units where the other uses in-house authorized dealers.

Service Capability: Service capability is in place in support of other technologies but familiarity is low. Some additional service required, but availability of HVAC repair personnel and plumbers imply strong service capability.

Health and Environment

Human Impact: With proper installation and location, human health impacts are minor and solvable. Possible mold growth if proper drainage for evaporator is not provided. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: No change from current technology. No environmental impacts known or cited. Refrigerant use occurs in occupied space but negative impacts are minimized or eliminated in the design.

Connectivity

Demand Response Readiness: Commercial heat pump water heaters would allow for grid demand response but no functionality in place. Technology would be able to adjust water temperatures during certain times of operation and could possibly have the resistive element disabled, keeping the unit from electrically peaking. Commercial units have less sophisticated controls compared to residential HPWHs so the functionality would need to be added.

Grid Impacts

Source of Power Quality Issues: Technology slightly more likely to cause events than electric resistance water heaters. Proper design should reduce or eliminate PQ issues. Increasing the number of compressors on the grid, as would occur with increasing HPWH adoption, may increase the impact of slow voltage recovery which can reduce system voltage. This could occur after a voltage sag or outage when the heat pump water heater compressors turn back on.

Susceptibility to Power Quality Issues: No unique power quality issues of the technology compared to electric resistance water heaters. Controls associated with heat pump technologies may be susceptible, and individual results will vary based on the quality of the product design.

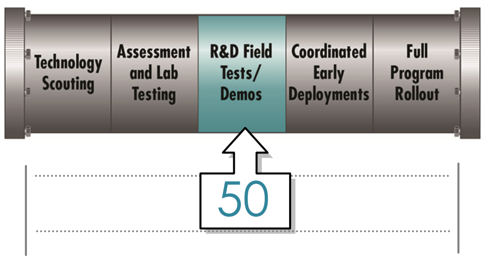
Requirements to Advance to Next Stage

For commercial heat pump water heaters to be qualified for Coordinated Early Deployments, field tests need to be conducted that document energy savings and demonstrate that the technology performs and has no reliability issues.

High Efficiency Clothes Washers and Dryers – Residential

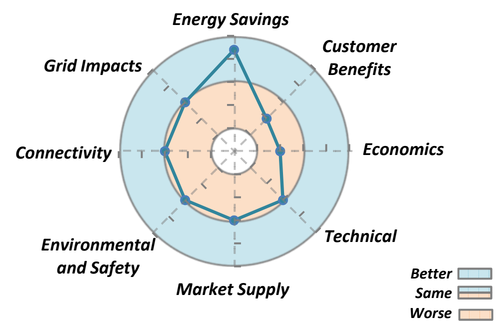
Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Automatic clothes washing and drying machines use various cycles to fill, empty, wash, spin and heat in an attempt to remove dirt and kill germs without excessive fading of dyes, wrinkling, or excessive use of energy and water. Advanced models offer high speed spin cycles to remove water from fabrics in order to reduce the amount of water removed by the dryer. Newer washers have integrated heating elements to boost the temperature of the water for washing or sterilization.

Front loaders and advanced top loaders reduce water requirements and thus reduce the energy used to heat water. The most radical change in clothes washer design is the emergence of models that use significantly less water than clothes washers of the past. These are typically horizontal-axis and front-loading designs, although advanced top-loader models also increase efficiency using altered agitator designs and cycling of clothes through a reduced stream of water. Use of high-pressure sprays for rinsing rather than using full tubs of water also decreases water use.

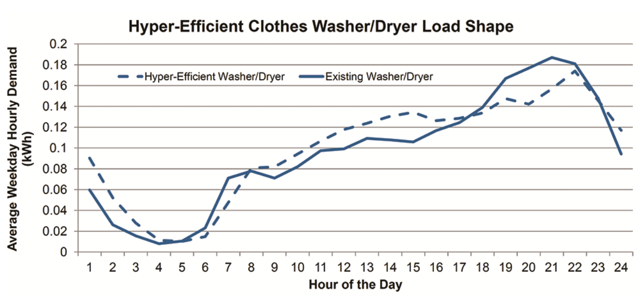
The efficiency of motors, which move the agitator or spin the drum, also affects energy efficiency. To reduce energy requirements, many appliance manufacturers use washer designs that rely on permanent-magnet synchronous motors instead of split-phase, AC induction motors. Eliminating the belt transmission system and connecting the motor directly to the drum can also reduce energy use. High spin speeds are designed to reduce overall laundry energy use. Efficient motors spin the washer drum two or three times faster, ideally at about 1,400 to 2,000 rpm, to extract water. Dryers consume a large percentage of the laundry load energy use so reducing the amount of water in clothes after washing is designed to reduce the amount of time needed for drying. Advanced software, sensors, and controls permit greater automation of washing machine operation. Water levels, motor operation, wash time, and spin speed can be more precisely controlled as more sophisticated controls are built into the system.

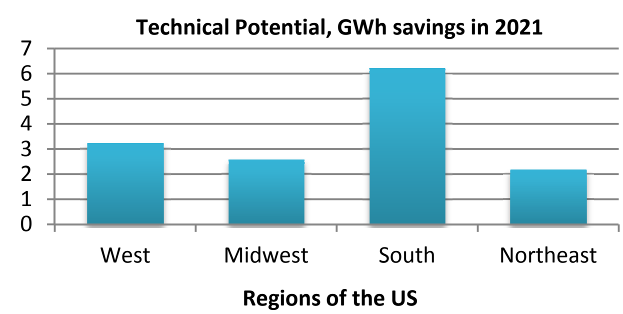
Assessment Results

Energy Savings

Energy Savings: The U.S. Environmental Protection Agency (EPA) reports that ENERGY STAR certified clothes washers use about 20% less energy and 35% less water. EPRI Data suggests that energy efficient clothes washers can lead to savings greater than 30% for a combined washer and dryer cycle. The high spin-speed of the high efficiency washer removes significantly more water from the clothes that leads to a reduction in overall dryer run time resulting in a reduction in the energy consumed by the dryer. Energy savings is also expected because of a reduction in hot water use.

Coincident Peak Demand Savings: Peak demand savings are expected from the clothes washer however the savings are not expected to be significant. Dryers will run for less time, which may lead to savings, however EPRI data suggests that usage is not typically coincident to system peaks.





Customer Benefits

Customer Benefits and Acceptance: ENERGY STAR rated clothes washers use 35% less water than non-certified units. Overall customer feedback from EPRI field testing was positive in regards to cleaning performance and operability. Features differ largely between manufacturers and can include advanced controls to reduce dryer run time and increased front panel options.

Economics

Current First Cost: Price varies but on average the pair will cost about 150% more. High efficiency washers range from $550 to $1000 compared to standard clothes washers that are typically $450-$550. Dryers with advanced moisture controls can cost around $700 while traditional dryers cost about $500.

Total Resource Cost: The TRC is not favorable because of the high costs of washer and dryer pairs.

Estimated Future First Cost in 5 Years: The price of advanced washers and dryers are expected to remain high because of the way they are marketed to the consumers as premium products.

Future TRC: If prices do not drop, the TRC is not expected to become favorable. As more high-efficiency washers and dryers are purchased by consumers, the overall baseline efficiency will increase making it more difficult to obtain a favorable TRC unless a specific group within the baseline is identified as ideal for replacement.

Technical

Technology Risk and Issues: No technical issues were observed during EPRI field testing.

Regional Applicability: Appliances are applicable in all regions. Because clothes washers and dryers are located in temperature controlled spaces, they are expected to perform independent of climate zone.

Supply Chain

Health of Manufacturing Sector: A very strong manufacturing sector exists. Manufacturers of advanced washers and dryers include major appliance manufacturers such as GE, Kenmore, LG, Miele, Samsung, and Whirlpool.

Distribution Capability: A strong distribution channel exists as manufacturers have products available for wholesale purchase though vendors as well as available to end users in retail chains.

Service Capability: Service can be provided through a variety of sources. Appliance repair companies exist but manufacturers are the primary source for repairs to newer models. Large retail stores such as Sears also provide repair services.

Health and Environment

Human Impact: No hazards to human health with proper installation and use. Mold risk in front loading washing machines can be avoided by leaving the door open per manufacturer's instructions. Fire and dust hazards exist for clothes dryers if proper ventilation is not given to the unit.

Environmental Impact: No change in environmental hazards from existing technology.

Connectivity

Demand Response Readiness: Technology has the ability to provide demand response if controls are integrated. Washer and dryers could limit demand by delaying wash and dry cycles, modifying cycle time to reduce peak loads, manage water usage to reduce water heating loads, and use smarter cycle choices. GE is running pilot programs using these technologies in their products. In EPRI's Energy Efficiency Demonstration it was found that homeowners' laundry schedules do not coincide with times of utility peak demand.

Grid Impacts

Source of Power Quality Issues: Low likelihood of power quality issues are expected from hyper-efficient clothes washers and dryers.

Susceptibility to Power Quality Issues: Low likelihood of power quality issues. New features, including smart displays, may be susceptible to power quality issues.

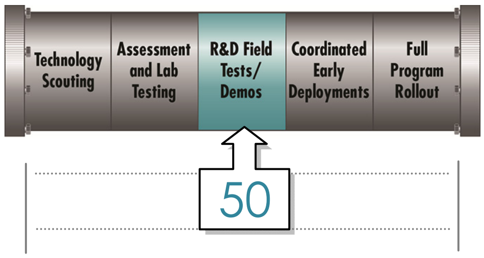
Requirements to Advance to Next Stage

The Energy Efficiency Demonstration results indicated that utilities cannot expect washers and dryers to provide energy savings by simply offering a new washer and dryer. More focus is needed in respect to the type of equipment being replaced. Work is also needed to quantify the energy savings possible from specific measures such as spin speed, dryness control, and consumer behavior.

LED Replacement for Fluorescent Troffer Lighting – Commercial

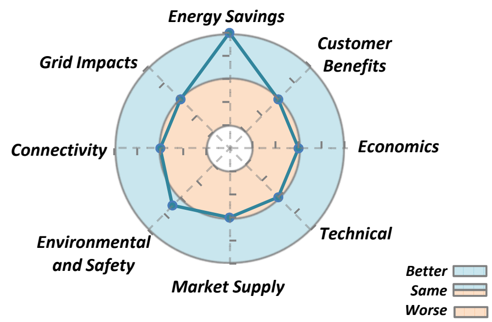
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Troffer light fixtures are present in almost all commercial buildings and contain several linear fluorescent tubes. Fluorescent tubes are available in numerous sizes, but there are three dominate sizes, which differ in diameter: T12, T8, and T5. As of July 14, 2012, the manufacturer of most commercial T12 lamps and all magnetic ballasts (commonly used with T12 fixtures) was phased out because of Department of Energy (DOE) light mandates. Instead, manufacturers' technologies and production are focused on the more efficient T8 and T5 systems and electronic ballasts.

Light-emitting diode (LED) replacements for troffer lighting are available as tube replacement, troffer retrofit, and complete troffer replacement. LED tube replacement products resemble linear fluorescents and are compatible with existing connectors inside troffers. Some LED replacements are compatible with the existing fluorescent ballasts, others require the installation of a LED driver and either the bypassing or removal of the fluorescent ballast, and some operate directly utility power, but also require either the bypassing or removal of the fluorescent ballast. An LED retrofit kit may not utilize all of the LEDs' benefits; however, the market continues to innovate. Most retrofit kits attach to the top portion of existing troffers, which allows the top of the fixture to be undisturbed. These products typically require the addition of a LED driver and the removal or bypassing of the existing ballast. Complete troffer replacements are new fixtures specifically designed for LEDs, but have the same look and dimensions of traditional fluorescent troffers. Complete replacements typically provide the greatest savings because they are specifically designed for use with LED light sources. This is important because LEDs are point sources, and the fixture can benefit from this if they are designed to direct light in the desired direction. LED replacements produce less light than fluorescents but are designed to prevent wasted light. Finally, because LEDs do not radiate heat in the same way as incandescent lamps, heat sinks must be used to remove generated heat. Retrofit applications are improving rapidly and viable solutions exist within this market space.

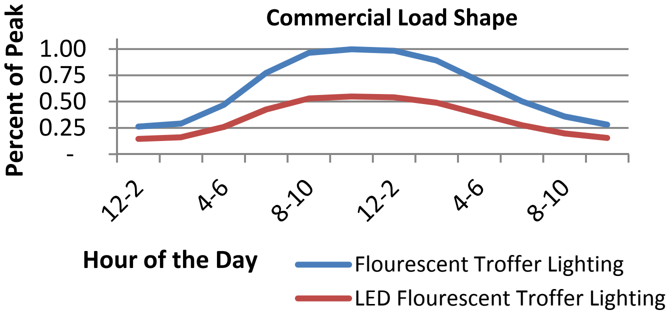
Assessment Results

Energy Savings

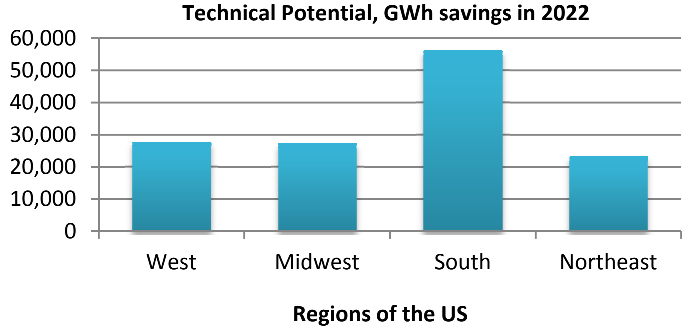
Energy Savings: EPRI testing shows that energy savings of LED replacements for fluorescent troffer lighting is between 10 and 60%. The savings will depend on the replaced fluorescent technology as well as whether the replacement is a retrofit or complete troffer replacement. However even within each replacement category, there are variations in savings from model to model.

Coincident Peak Demand Savings: Peak demand savings between existing four tube florescent fixtures and LED retrofits or replacements vary between 10% and 60%, depending on system design and installed LED product. Commercial lighting loads are not expected to vary hour to hour during business hours.

LED Replacement for Fluorescent Troffer Lighting Commercial Load Shape



Technical Potential, GWh savings in 2022



Customer Benefits

Customer Benefits and Acceptance: Although LED based products have longer advertised life spans than traditional linear fluorescents, fluorescent lighting companies continue to improve their products. Some manufacturers are producing T8s with advertised lifetimes longer than those of LEDs. Longer lifetime fluorescents reduce the number of lamp changes which will reduce maintenance cost and labor for fluorescent technologies.

Retrofits may reduce installation time because removal of the old troffer is not required (although the fluorescent ballasts typically must be bypassed or removed). Some retrofit LED solutions use magnets or sticky pads to attach

LEDs and drivers to the fixture. Alternatively, drop-in kits include the drivers within a tube that plugs into the existing linear fluorescent connectors. Retrofitting fluorescent troffer lighting may also reduce the number of lamps within a fixture because some retrofit products provide more light than a single fluorescent lamp.

Economics

Current First Cost: Full replacement 2- x 4-ft (0.6- x 1.2-m) LED troffers cost between $200 and $400; cost difference is based on lumen output and design. Retrofit kits are similarly priced, but some are as low as $100. Most LED tubes cost between $50 and $75 each. However, because retrofits do not require the removal of old fixtures, installation costs are reduced.

Total Resource Cost: In most cases, TRC is expected to be favorable; however, there are many products on the market—not all of them equal in features and functionality. In addition, architectural fixtures may have a TRC score less than 1 because energy savings is not the primary function of the fixture.

Estimated Future First Cost in 5 Years: LED troffer lighting currently is sold as a premium product over linear fluorescents, but costs are expected to reduce dramatically over the next five years.

Future TRC: TRC is expected to remain favorable.

Technical

Technology Risk and Issues: Lenses in existing troffers may or may not need to be replaced by those designed for use with LEDs so that light is uniform within a room. LEDs are highly directional—and without replaced lenses, fixtures may cast bright white lines onto surfaces below. Some LED products are designed to work with existing troffer lenses.

Regional Applicability: The technology has no regional limitations.

Supply Chain

Health of Manufacturing Sector: The manufacturing sector is strong, with many major manufacturers.

Distribution Capability: Distribution capability is in place through online retailers and big box stores.

Service Capability: Service capability is in place. Service is no different from that of fluorescent troffer lamps. However, installation may require additional considerations to ensure that proper safety guidelines are followed.

Health and Environment

Human Impact: Not all troffers comply with safety standards after being retrofitted. A U.S. Department of Energy report found that more than half of the retrofit kits tested would not have passed an electrical safety inspection. Although this does not mean that the fixtures were unsafe, proper labeling, mounting, and other general installation requirements must be observed to avoid safety issues. Therefore, an effort should be made to ensure that retrofits comply with applicable UL standards once installed. Lighting manufactures and others are attractively working to address these issues and establish set standards of practice.

Environmental Impact: No change in environmental impacts compared to standard incandescent lamps and the absence of mercury in LED lamps is an environmentally beneficial difference compared to fluorescents.

Connectivity

Demand Response Readiness: No change in demand response capability compared to standard fluorescent lamps. LED lamps can be dimmed or turned off systematically if controls are developed.

Grid Impacts

Source of Power Quality Issues: Similar to fluorescents, there is little evidence of the technology causing system power quality issues, but due to the variety of products in the marketplace exceptions could occur.

Susceptibility to Power Quality Issues: There is no evidence of the technology reacting to system power quality issues any differently from fluorescents or other LED based devices.

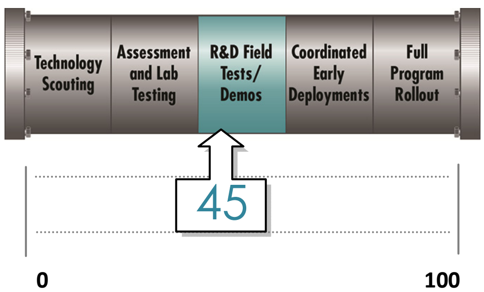
Requirements to Advance to Next Stage

The LED replacement for the troffer lighting market continues to develop as new, innovative designs reach the market. Because it is difficult to summarize the specific savings and benefits of this technology, field tests are needed to determine which designs have been beneficial in various applications. As the retrofit market improves, so do the economics—retrofits reduce the overall costs associated with adoption. Promising retrofit kits do exist, but there are also a large number of kits that do not fully leverage the benefits of LEDs. Field demonstrations may prove sufficient to move this technology to utility programs but will in any case prepare the technology for the early deployment stage.

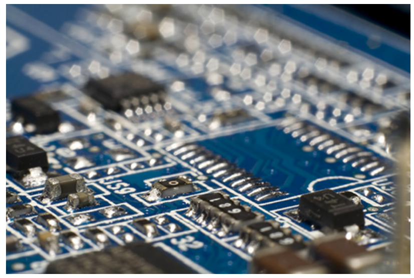
Submersion Cooling – Data Centers

Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**

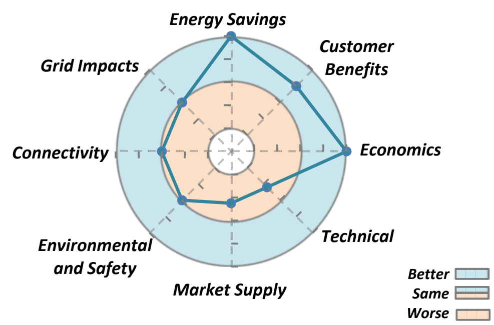
Energy Efficiency Technology Pipeline



Readiness Score



Compared to Existing Technologies



Technical Description

Larger data centers (mid-tier and enterprise-class), which make up no more than 1% of U.S. data centers, are already energy efficient. However, the remaining 99% have significant room for improvement in energy efficiency. Small data centers are found in most commercial buildings, including office buildings, hospitals, universities, city halls, and supermarkets.

The cooling loads in data centers account for a large portion of the energy used by the data center. Computer room air conditioners (CRACs) are installed to provide cool air to the racking to protect servers from overheating. This method tends toward a worst-case design approach because the data center operators do not have information on whether sufficient air is moving through the racks. If hot spots occur, operators are forced to increase airflow to that rack or possibly increase the overall size of the cooling system.

An alternative to air-cooled data center cooling methods is *submersion cooling*, in which server racks are submerged in a dielectric fluid. The fluid is circulated—by natural thermodynamics or a pump—to keep the equipment cool and eliminate the need for large, dedicated cooling units. This type of cooling has been used in transformers for more than 100 years and in super computers for decades, but its application to small servers is relatively new and not widely accepted.

Assessment Results

Energy Savings

Energy Savings: Submersion cooling systems can provide 50 to 90% savings in cooling energy use compared to conventional cooling. In addition, the removal of fans and reduction in operating temperature result in 10 to 20% reduction in server energy use. Overall, submersion cooling can result in lowered data center energy use by up to 50%.

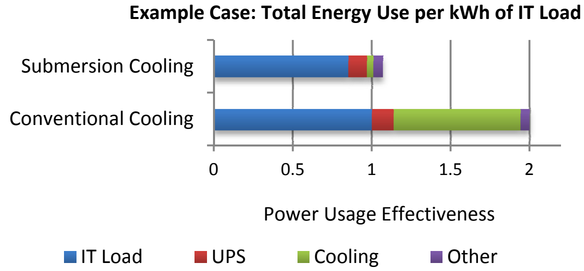
Coincident Peak Demand Savings: Load does not largely vary at data centers because the computers require only about 20% less energy when idle. The load shape is flat; therefore, savings will occur at peak times. The estimated coincident demand savings is 20%.

Customer Benefits

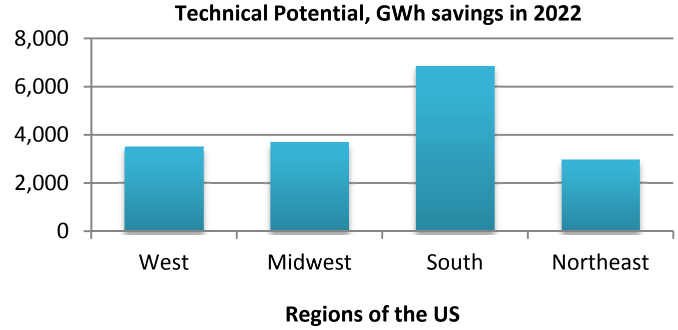
Customer Benefits and Acceptance: The elimination of CRACs and server fans reduces server room noise, eliminates the need for raised flooring, and reduces the overall footprint of the data center. This can lead to considerable cost savings when a new data center is designed: the servers could be located in a warehouse as long as it has a flat floor and electric connection.

The increased cooling capacity of fluids allows data center operators to run servers at faster processing speeds, which might reduce the number of servers required. In addition, the dielectric fluid reduces the possibility of corrosion, dust contamination, and vibration, which may lead to longer component lifetimes.

Example Case: Total Energy Use per kWh of IT Load



Technical Potential, GWh savings in 2022



Economics

Current First Cost: The use of submersion cooling in data centers reduces infrastructure costs because there is no longer a need for raised floors or CRACs/chillers. It is expected that immersion-cooled data centers are more attractive for new builds or for portable data centers. Costs are expected to be one-tenth of the initial hardware cost—but the savings can be immense when included in the design of a new data center. Savings of up to 50% can be realized in these cases because the need for AC and specialized construction is eliminated. However, retrofits will have reduced cost savings: the avoided costs associated with the CRACs and infrastructure upgrades have already been sunk in installation and purchase of the existing equipment. Manufacturers estimate that the total infrastructure cost is around $3.15/watt for their submersion cooling system and $11.50/watt for standard air cooling.

Total Resource Cost: The TRC is expected to be well over 1 in both new installations and retrofits because of the reduced cost of installation. In addition, data center load does not largely vary, so savings will likely be coincident with system peaks.

Estimated Future First Cost in 5 Years: The cost is not likely to decrease because this is a specialty technology. However, as the technology is adopted, service/training costs should be reduced as more service personnel are trained in installing and servicing this technology.

Future TRC: The TRC will only become more favorable over time. However, the average efficiency improvement with regard to cooling loads will need to be readdressed because other existing efficient cooling technologies may be adopted.

Technical

Technology Risk and Issues: One concern of server operators is the manufacturer's support of submerged equipment. However, one major manufacturer already announced that it is optimizing its technology for servers immersed in oil. The same manufacturer ran tests and has affirmed that submersion cooling technology is safe for servers and is highly efficient. However, it is not conclusive whether efficiencies would be seen for traditional heat sinks optimized for air. Another manufacturer has announced that it will provide full warranty for servers installed with a particular model submersion cooling system. In all cases, hard drives must be replaced with sealed versions or solid-state varieties. In traditional magnetic hard drives, oil can slow the magnetic head that reads data from the disks. If this head slows by too much, the hard drive will not be able to operate properly. Further testing must be performed to identify any other risks or issues.

Regional Applicability: Submersion cooling is not impacted by regional differences and has national applicability.

Supply Chain

Health of Manufacturing Sector: Moderate manufacturing sector is available. There are a few manufacturers of immersion systems and some major manufacturers of dielectric fluids.

Distribution Capability: Distribution capability exists through manufacturers. It is expected to increase with market development.

Service Capability: Service capability is in place through manufacturers. The servicing of submersion cooling systems is not difficult, but data center staff would need additional training. Manufacturers are already working toward approving submersion cooling with their equipment.

Health and Environment

Human Impact: No human health concerns are present with this technology.

Environmental Impact: No environmental concerns are present with this technology. The dielectrics used in submersion cooling are non-toxic. In older transformers, dielectric fluid contained PCBs—but this is no longer the case.

Connectivity

Demand Response Readiness: Data centers will not provide demand response capability. Reduced load is not possible based on demand response signals because it could cause downtime or insufficient bandwidth. The energy demand of the data center servers does not vary largely based on the workload, so the demand is relatively steady-state throughout the day.

Grid Impacts

Source of Power Quality Issues: The technology is not expected to be the source of power quality issues.

Susceptibility to Power Quality Issues: The technology could be susceptible, but—because of the high reliability and uptime requirements—susceptibility has been addressed in the design.

Requirements to Advance to Next Stage

Data center operators are under pressure to maintain a high uptime percentage. Because the cost of downtime can be significant for data center customers, there is reluctance to incorporate new technologies. Field demonstrations on submersion cooling should be performed to evaluate not only energy savings, but also risks and customer benefits. The additional information gained from this testing will help move submersion cooling in data centers to the early deployment stage.

5
COORDINATED EARLY DEPLOYMENTS STAGE TECHNOLOGIES

The required criteria for this stage include the required criteria for the previous stages, plus the following:

- Estimated energy savings are documented from units in the field.
- The technology has been demonstrated in the field and shown to work reliably.
- The technology is commercially available but has had limited market penetration.
- The technology meets other standards/standards are sufficiently developed.

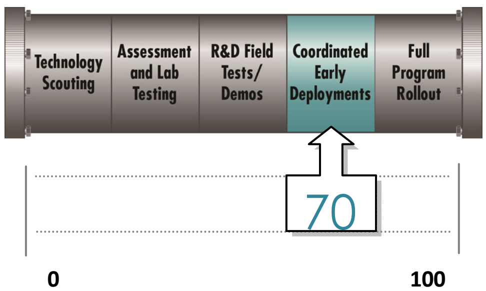
The technologies assessed in this stage are:

- Automated Airflow Management System – Data Centers
- DC Power – Data Centers
- Ductless Variable Capacity Heat Pumps – Residential
- Dynamic Power Management – Data Centers
- Heat Pump Water Heaters – Residential
- High Efficiency Refrigerators – Residential
- Thermal Energy Storage for HVAC Systems – Commercial
- Variable Capacity Heat Pumps – Commercial
- Voltage Optimization – Residential

Automated Airflow Management System – Data Centers

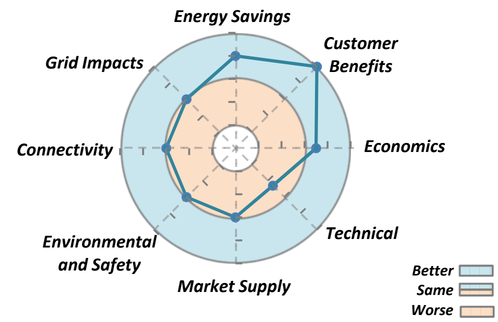
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2012**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Larger data centers, which comprise no more than 1% of U.S. data centers, are already energy efficient. However, the remaining 99% have significant room for improvement in energy efficiency. Small data centers are found in most commercial buildings, including office buildings, hospitals, universities, city halls, and supermarkets.

The cooling loads in small data centers account for a large portion of the energy used by the data center. Computer Room Air Conditioner (CRACs) are developed to provide cool air to the racks to protect servers from overheating. This method tends toward a worst-case design approach because data center operators do not have information on whether there is sufficient air moving through the racks. If hot spots occur, operators are forced to increase airflow to that rack or possibly increase the overall size of the cooling system.

Airflow management systems provide data center operators with information regarding the internal temperature of each rack. This allows the operators to properly cool the racks but also better understand the impact of changes they make to the cooling system. The use of variable-frequency drives provides energy savings by giving operators the ability to vary fan speed depending on load. Because the technology provides operators with more information about their servers as well as providing advanced controls, they can properly cool the server while saving energy. This technology can be installed as a retrofit to existing systems or installed on new systems.

Assessment Results

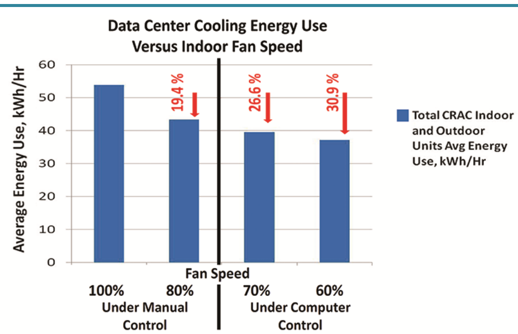
Energy Savings

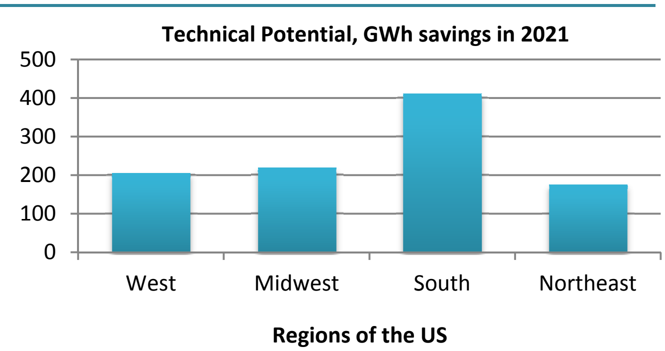
Energy Savings: EPRI field testing of a retrofit airflow management application demonstrated an 80% reduction in energy use for the fan. This translates to a 10% reduction in overall data center energy use.

Coincident Peak Demand Savings: Load does not largely vary at data centers because the computers require only about 20% less energy when idle. The load shape is flat so savings will occur at peak times. The estimated coincident demand savings is 80% for the fan. This translates to about 10% demand reduction for the data center as a whole.

Customer Benefits

Customer Benefits and Acceptance: Raising the server room temperature to reduce energy consumption appears risky to data center operators even though servers can be sufficiently cooled at higher temperatures. Airflow management systems give data center operators increased visibility of the temperature of their racks and help to identify hot spots through the use of thermal maps. The technology helps give operators confidence in their cooling system. Acceptance is slowly increasing.





Economics

Current First Cost: As a retrofit, airflow management with automatic fan control and variable speed drives costs approximately $21 per square foot of raised floor. Retrofits cost a fraction of the original cost of the cooling system.

Total Resource Cost: At today's prices and with just fan savings taken into account, the TRC is 2.91.

Estimated Future First Cost in 5 Years: Only two companies currently provide this type of system but more are expected to enter the market over time. This could potentially reduce retrofit costs by about a third to about $13 per sq foot.

Future TRC: If costs reduced by a third a TRC of 4.7 can be expected.

Technical

Technology Risk and Issues: There may be some risk in retrofitting this technology. Adding variable speed drives to existing motors, that are not rated for variable speed drives, may decrease overall lifetime of the motor. This aspect is being explored with computer room air conditioning suppliers. Communications and protocols must also be compatible with existing systems.

Regional Applicability: Airflow management is not impacted by regional differences and has national applicability.

Supply Chain

Health of Manufacturing Sector: Moderate manufacturing sector for retrofit installations. Major manufacturers include Vigilent and SynapSense. Very strong manufacturing sector for new cooling system installations with major manufacturers including Liebert and APC.

Distribution Capability: Distribution channels are in place for this technology. Both retrofitters and new installations have fully developed distribution channels through their own sales teams.

Service Capability: Service capability for this technology is in place. Service would be provided through the manufacturer. Very little maintenance required once the system is installed.

Health and Environment

Human Impact: No human health concerns are present with this technology.

Environmental Impact: No environmental concerns are present in this technology.

Connectivity

Demand Response Readiness: Data centers will not provide demand response capability. Reduced load is not possible based on demand response signals as it could cause downtime or insufficient bandwidth. The energy demand of the data center servers does not vary largely based on the work load so the demand is relatively steady state throughout the day.

Grid Impacts

Source of Power Quality Issues: Technology is not expected to be the source of power quality issues.

Susceptibility to Power Quality Issues: Technology could be susceptible but because of high reliability and uptime requirements susceptibility has been addressed in the design.

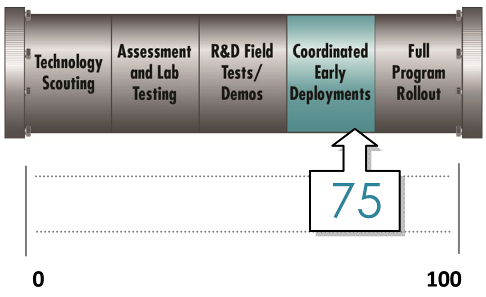
Requirements to Advance to Next Stage

The airflow management technology tested in the Energy Efficiency Demonstration resulted in energy savings. This strategy could be considered in utility energy efficiency programs. In addition, EPRI recommends early deployment projects through the Coordinated Early Deployments project to overcome market adoption barriers and to work with the supply chain to minimize barriers in supply. Conducting early deployments will help ensure success in utility programs at a lower cost and risk than launching programs at full utility rollout scale. Furthermore, through a collaborative process, utilities can learn from each other and potentially build on deployments conducted by others.

DC Power – Data Centers

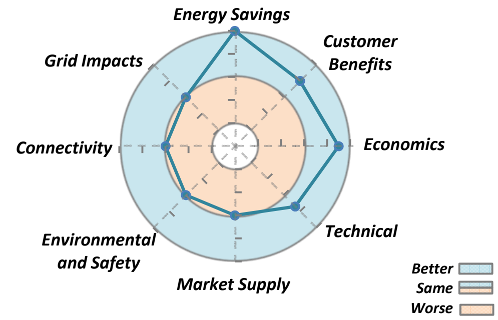
Readiness Brief – Energy Utilization, Power Delivery & Utilization 2013

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Larger data centers, which comprise no more than 1% of U.S. data centers, are already energy efficient. However, the remaining 99% have significant room for improvement in energy efficiency. These data centers are found in most commercial buildings, including office buildings, hospitals, universities, city halls, and supermarkets.

These data centers use AC power supplied to the facility. The AC power is stepped down to lower voltage and converted to DC for energy storage by uninterruptable power supply units and for use by the digital electronics in the data center servers and other IT equipment. There can be up to six or more power-conversion stages between facility power entry and the microprocessor or other data-processing circuits.

At each power-conversion stage, there are energy losses due to inefficiencies in power-conversion devices. These devices also produce heat, requiring additional cooling in the data center. The inefficient conversion and required heat removal contribute to the total power consumption of a data center. Actual power utilization by IT loads can sometimes be as low as 50% of the total input power consumption.

The initial conversion of the power supplied to the facility, or to specific server racks within the facility, from AC to DC will eliminate the multiple existing conversions from AC to DC within the facility. This will also reduce the overall heat produced. Significant energy savings have been measured in field tests and demonstrations as a result of DC power supplies.

Assessment Results

Energy Savings

Energy Savings: EPRI field testing of DC power supplies demonstrated a 15% reduction in power consumption compared to an existing traditional AC system. The results will vary depending on the type of system being compared and the efficiency of the existing system.

Coincident Peak Demand Savings: Load does not largely vary at data centers because the computers require only about 20% less energy when idle. The load shape is flat so savings will occur at peak times. The estimated coincident demand savings is 15% when compared to traditional AC systems.

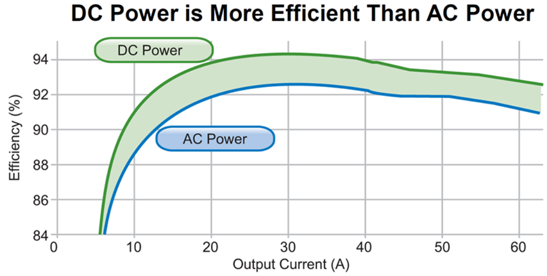
Customer Benefits

Customer Benefits and Acceptance: DC power distribution provides increased reliability over existing AC technologies. Data center staff are uneasy about switching technologies due to the importance of reducing downtime. Once accepted and installed, DC systems provide a higher level of reliability. End users would be hesitant to install this infrastructure if it meant ripping out the old AC power distribution system. However, the DC system can easily be installed as a retrofit or for expansion.

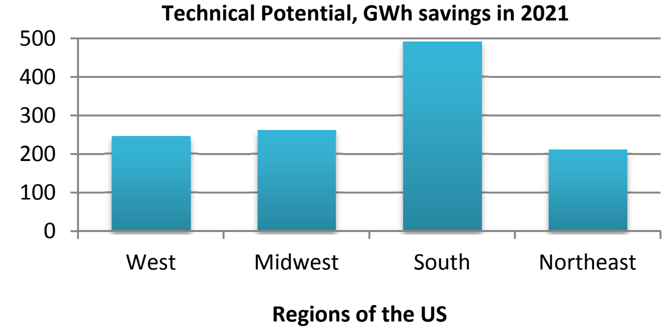
Economics

Current First Cost: DC distribution costs are expected to be 10 to 20% lower than AC systems. Cost of AC systems will range based on redundancy measures.

DC Power is More Efficient Than AC Power



Technical Potential, GWh savings in 2021



Total Resource Cost: TRC is expected to look promising for DC power supplies. Further analysis is needed on costs of retrofit DC power supplies.

Estimated Future First Cost in 5 Years: As more data centers are equipped with DC systems the cost of DC may drop 20-30%, and it is likely that AC systems could drop in price as well. The future cost is estimated to remain 10 to 20% of AC systems.

Future TRC: Future TRC is expected to look promising for DC power supplies.

Technical

Technology Risk and Issues: Fewer technology risks over existing AC systems. DC systems tend to be more reliable than AC systems because of the reduced number of conversions and less required equipment.

Regional Applicability: No regional constraints for technology and can be applied nationally.

Supply Chain

Health of Manufacturing Sector: Manufacturing sector is strong. There are two large manufacturers of DC systems, Emerson and Delta, and other large manufacturers that provide support equipment.

Distribution Capability: Strong distribution capability from manufacturer.

Service Capability: Service capability exists but electricians may need to be trained to handle 380 VDC.

Health and Environment

Human Impact: No change in human health impacts. Technology does not pose a human health risk if proper safety and handing procedures are followed.

Environmental Impact: No change in environmental impacts. DC power for data centers does not pose an environmental risk.

Connectivity

Demand Response Readiness: Data centers will not provide demand response capability. Reduced load is not possible based on demand response signals as it could cause downtime or insufficient bandwidth. The energy demand of the data center servers does not vary largely based on the work load so the demand is relatively steady state throughout the day.

Grid Impacts

Source of Power Quality Issues: Technology is not expected to be the source of power quality issues.

Susceptibility to Power Quality Issues: Technology is susceptible but because of high reliability and uptime requirements susceptibility has been addressed in the design.

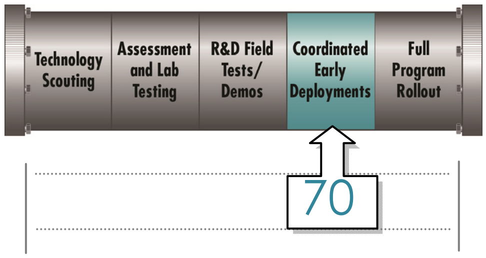
Requirements to Advance to Next Stage

The DC power supply technology tested in the Energy Efficiency Demonstration resulted in energy savings. This strategy could be considered in utility energy efficiency programs. In addition, EPRI recommends early deployment projects through the Coordinated Early Deployments project to overcome market adoption barriers and to work with the supply chain to minimize barriers in supply. Conducting early deployments will help ensure success in utility programs at a lower cost and risk than launching programs at full utility rollout scale. Furthermore, through a collaborative process, utilities can learn from each other and potentially build on deployments conducted by others.

Ductless Variable Capacity Heat Pumps – Residential

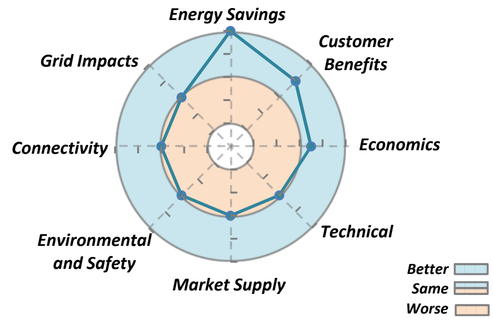
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2012**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Residential ductless variable capacity heat pumps, also known as ductless heat pumps (DHP), are variable-capacity heat pumps employing indoor wall- or ceiling-mount fan coil units that have no connecting ductwork. They are a subset of the broader family of variable-capacity heat pumps which employ variable-speed compressors, fans, and expansion valves with a wide array of indoor terminal unit options, including ductless and ducted units. Traditional split systems have a single air-handling unit that provides air to different areas of the building via ducts. A ductless heat pump has individual air-handling units in each area of the building with refrigerant lines running to each unit. These systems require only a small opening for refrigerant lines making it easier to install in buildings without an existing duct system.

The use of separate air-handling units allows for zonal temperature control. Zonal systems provide heating or cooling to individual rooms based on the thermostat set point of each respective space. Allowing occupants to set different temperatures in different zones can reduce the need for cooling in spaces that are unoccupied or are already at the desired temperature. Ductless systems avoid up to 30% of energy consumption due to duct losses as many ducts are located in unconditioned spaces such as attics or basements.

Assessment Results

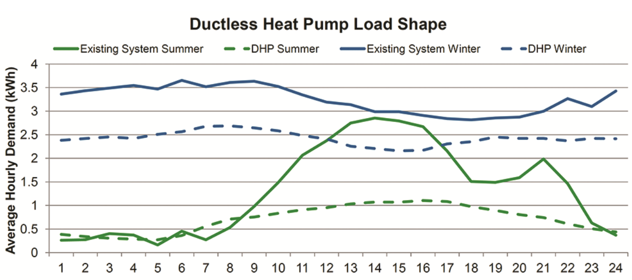
Energy Savings

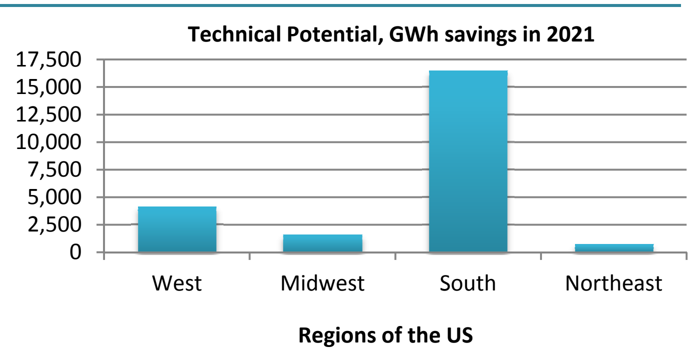
Energy Savings: In the EPRI Energy Efficiency Demonstration it was shown that savings varied depending on the specifics of the installations. Demonstration results collected by EPRI shows savings ranged from 18% to 44%.

Coincident Peak Demand Savings: EPRI field testing showed a 25% peak reduction in colder climates.

Customer Benefits

Customer Benefits and Acceptance: Increase in customer benefits, and acceptance seems strong. However, acceptance issues are not entirely captured in current research. Increase in air quality and comfort, zonal control, and the potential for heating and cooling are significant customer benefits. Ease of installation, multi-dimensional airflow diffusers, low sound level, consistent air circulation, variable output, flexibility in sizing, small outdoor compressors, auto restart, wireless controls, self-diagnostic functionality, 24 hr. on-off timer, reduced startup time, minimized temperature fluctuations, and retrofit application suggest additional customer benefits. Recent field tests indicate strong customer acceptance, but some careless installations and visual unattractiveness could lead to acceptance issues.





Economics

Current First Cost: Increased cost averages $0.80/sq. ft. compared to $2-4/sq. ft. for standard conditioning practices. 30% increase in cost over standard central ducted system.

Total Resource Cost: The TRC at today's prices is estimated at 2.17.

Estimated Future First Cost in 5 Years: Undeveloped market and custom installation indicate little reduction in cost in 5 years.

Future TRC: Since minimal cost reduction is expected, TRC expected to remain at 2.17 in five years.

Technical

Technology Risk and Issues: No change in technology risks compared to baseline. Design considerations and customer education are required to minimize risk and other issues. Proper design and installation is required to achieve expected savings and performance from the system. This includes a deep-vacuum for elements to prevent leaks, proper use to avoid unwanted simultaneous heating and cooling, and design considerations to avoid oversized or misplaced units that consume more energy without offering proper temperature or humidity control. Other issues include a need for proper drainage and a solid foundation for outdoor unit, complex controls, and a need for customer education. Ductless feature of the system reduces ducting problems such as sealing problems and improper insulation that can cause heat loss. Custom installation is required.

Regional Applicability: Multiple region applicability. Retro-fit like applications and possibility to use system for heating or cooling suggests wide regional applicability. Many units are rated to operate at subzero temperatures while maintaining efficiency.

Supply Chain

Health of Manufacturing Sector: Indication of strong manufacturing sector. Recognized manufacturers like Mitsubishi, Daikin, LG, and Fujitsu offer a variety of flexible options for interested consumers.

Distribution Capability: Distribution channels are in place. Strong manufacturing sector suggest distribution capability with products available for individual consumers who wish to purchase units.

Service Capability: Service capability exists. The need for proper installation, limited availability of qualified installation and service contractors, and additional training requirements indicate a slow growth in service capability, but some service capability does exist.

Health and Environment

Human Impact: Indication that human health impacts are minor and solvable. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: Proper installation and maintenance indicates little change from current technology. Refrigerant use occurs near occupied spaces since refrigerant lines are run to each indoor unit. Negative impacts are minimized or eliminated with proper installation.

Connectivity

Demand Response Readiness: DHP offers potential to perform as a demand response tool if the features are added. It can function as a demand response tool by turning off indoor units in certain spaces which would allow the temperature and humidity to drift but may still remain comfortable due to spill over from other areas. The units could also be disabled for short periods in each zone to minimize overall impact. Units can also be sequentially turned on to prevent demand spikes caused by starting power transients. Overall DHP system air conditioners have sophisticated controls which could be potentially controlled by demand response signals.

Grid Impacts

Source of Power Quality Issues: Technology no more likely to cause events than conventional heat pump systems. Proper design should reduce or eliminate power quality issues. Increasing the number of compressors on the grid, as would occur with increasing heat pump adoption, may increase the impact of slow voltage recovery which can reduce system voltage. This could occur after a voltage sag or outage when the heat pump compressors turn back on.

Susceptibility to Power Quality Issues: The technology has no unique power quality susceptibilities compared to standard heat pumps. Controls associated with heat pump technologies may be susceptible, and individual results will vary based on the quality of the product design.

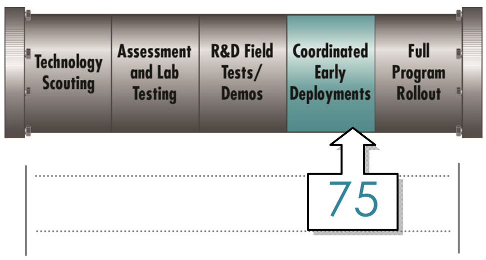
Requirements to Advance to Next Stage

The results of the DHP tests in the Energy Efficiency Demonstration showed that energy savings are possible with ductless heat pumps. The savings achieved varied significantly with home size, design and occupant behavior. The variations are not well understood. While the positive experiences with DHP adoption in the Pacific Northwest clearly indicates that the technology is already accepted in that market, the likelihood of adoption in other climates is not as clear nor are the energy savings. Early deployment projects in one or more climate zones will provide valuable energy savings results and adoption experience with which utilities will be able to develop DHP programs with higher likelihood of success.

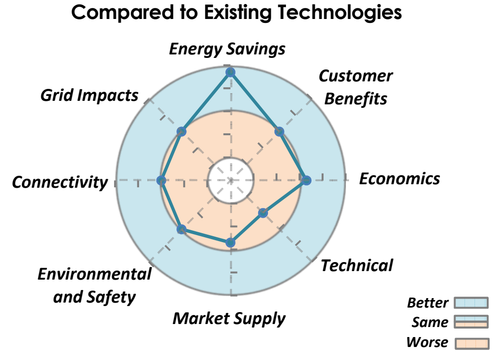
Heat Pump Water Heaters – Residential

Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

Energy Efficiency Technology Pipeline



Readiness Score



Technical Description

Traditional water heaters use resistance heaters to increase water temperature to the desired level. Heat pump water heaters use electricity to mechanically draw heat from the surrounding environment. This is done using the vapor compression cycle which can be found in refrigerators as well as air conditioners. The refrigerant within the compressor goes through an expansion, evaporation, compression, and condensation phase which allows for the heat to be transported from the surrounding air to the water within the tank.

The design of heat pump water heaters have allowed them to be placed within homes with the same or nearly the same footprint as a traditional electric resistance water heater. Most heat pump water heaters are hybrid, containing both heat pump and electrical immersion heaters, and most have control panels for temperature and mode control.

Assessment Results

Energy Savings

Energy Savings: EPRI field testing of over 150 heat pump water heaters showed substantial energy savings. When HPWHs were compared with the energy consumption of electric resistance water heaters, the heat pump water heaters used on average 50% less energy. An EPRI case study in Southern Florida showed less energy savings because the electric resistance water heaters in that region used less energy because of higher water temperatures.

Coincident Peak Demand Savings: EPRI Energy Efficiency Demonstration tests show heat pump water heaters provide minimal reduction to utility peak-day, on-peak demands. The average peak reduction is 5%. The peak demand reduction ranges from about 2-11% in winter. There is a larger reduction in summer peak but HPWHs are less of a contributor to summer peaks than winter peaks.

Customer Benefits

Customer Benefits and Acceptance: There are both benefits and customer concerns but overall the customer benefits are the same as resistance water heaters. Digital interface allows for more accessible customer interaction, and heat pump provides space cooling, possible dehumidification, and a potential to decrease mold growth in typically humid areas of homes. Customers acceptance in field tests is positive, but since units were provided free of charge, it is difficult to estimate acceptance by a standard purchaser. Increased size of water tank for 80-gallon units provides increased access to readily available hot water. Noise was noted as an issue by some homeowners as well as the cool air byproduct but these may be a function of location of the unit.

Economics

Current First Cost: Current first cost is 200% of the replaced technology based on $1000 for 50 gallon heat pump water heater versus $350 for 50 gallon electric resistance water heater.

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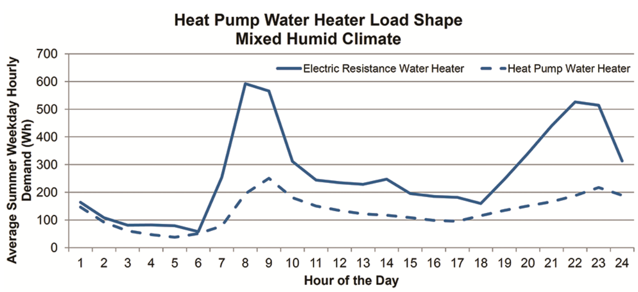
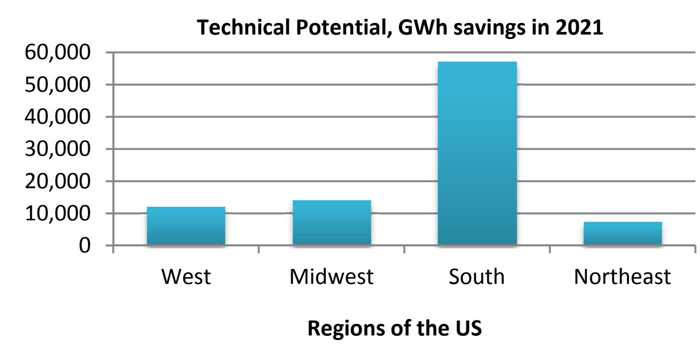




Total Resource Cost: The TRC at today's prices is estimated at around 2.

Estimated Future First Cost in 5 Years: Future first cost is 140% of replaced technology. First costs should decrease as market develops, but rate of decrease is unknown. Estimates indicate that a 1/3 price reduction is possible.

In addition, large residential water heaters, larger than 55 gallons, are federally mandated to be more efficient in 2015. This is expected to increase the cost of both electric resistance and gas water heaters because units will need additional insulation to meet efficiency mandates. This will help reduce the price difference between heat pump and non-heat pump water heaters.

Future TRC: With a 1/3 reduction in price in the future, the TRC becomes 4.

Technical

Technology Risk and Issues: Installation considerations suggest a slight change from current practices. Lab and field test results demonstrate good performance and reliability. Installation considerations include a need for drainage outlet and sufficient space and air flow. Space available may determine size of HPWH that can be installed. There is potential for unwanted space cooling and condensation accumulation; however, these can be solved with design considerations. Additional maintenance may be required.

Regional Applicability: Multiple region applicability. Current HPWHs perform best in warmer climates, particularly in the South and regions of the West census regions. However, they perform well if installed in unconditioned indoor spaces in colder climates, such as basements.

Supply Chain

Health of Manufacturing Sector: Manufacturing sector is very strong with recognized suppliers which also produce conventional electric resistance water heaters. Manufacturers include A.O. Smith, GE, Rheem, Steibel Eltron, and AirGenerate.

Distribution Capability: Strong distribution capability with retail as well as wholesale supply. HPWHs are available in local stores.

Service Capability: Service capability is in place from other technologies but familiarity is low. Some additional service required for HPWHs, but availability of HVAC repair personnel and plumbers imply strong service capability.

Health and Environment

Human Impact: With proper installation and location, human health impacts are minor and solvable. Possible mold growth if proper drainage for evaporator is not provided. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: No change from current technology. No environmental impacts known or cited. Refrigerant use occurs in occupied space but negative impacts are minimized or eliminated in the design.

Connectivity

Demand Response Readiness: No widespread adoption but technology could provide some demand response capability if connection was made. The technology is able to provide demand response functionality by heating water only during certain times of the day. The electric resistance element could also be disabled which would keep the unit from electrically peaking. Remote control features were not found to be common but one manufacturer did have a monitoring feature that could be purchased separately.

Grid Impacts

Source of Power Quality Issues: Technology slightly more likely to cause events than electric resistance water heaters. Proper design should reduce or eliminate PQ issues. Increasing the number of compressors on the grid, as would occur with increasing HPWH adoption, may increase the impact of slow voltage recovery which can reduce system voltage. This could occur after a voltage sag or outage when the heat pump water heater compressors turn back on.

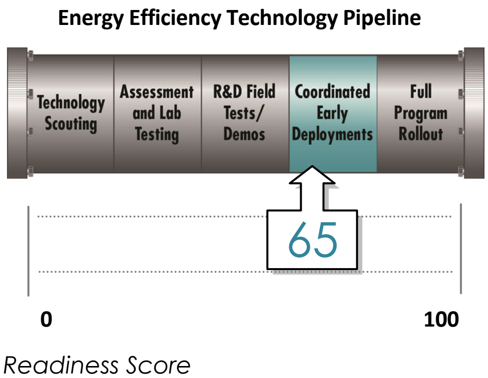
Susceptibility to Power Quality Issues: No unique power quality issues of the technology compared to electric resistance water heaters. Controls associated with heat pump technologies may be susceptible, and individual results will vary based on the quality of the product design.

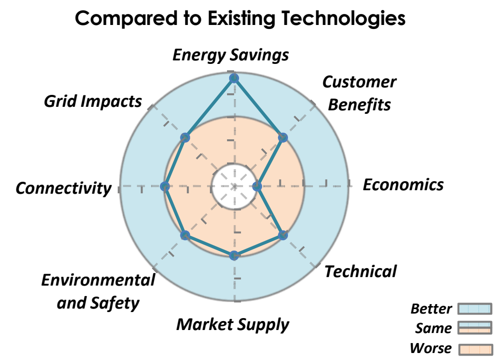
Requirements to Advance to Next Stage

The EPRI Energy Efficiency Demonstration showed strong results for HPWHs in terms of energy savings, reliability, and performance. While HPWHs have been used in several utility energy efficiency programs already, the penetration has not been as high as desired, indicating a need to address market barriers to adoption. EPRI recommends early deployment projects prior to utility full program rollout of HPWHs. In fact, EPRI is working with a number of utility collaborators on HPWH early deployments to confirm the energy savings and to test consumer adoption and supply chain promotion strategies.

High Efficiency Refrigerators – Residential

Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**





Technical Description

The heart of an advanced refrigerator is the compressor. As the major power-using component in refrigerators and freezers, increasing its efficiency increases the energy efficiency of the appliance. Most compressors operate at a single speed, but variable-speed compressors can operate at multiple speeds rather than ON mode only. As a result, the compressor can better match the load, running at lower speeds for longer periods of time, reducing energy use. The fan runs longer, which uses more energy, but losses during the OFF cycle are reduced, and heat exchangers operate more effectively as well. Electronic controls enable variable speeds, typically with inverter-driven induction motors or permanent-magnet motors. While the electronics used for control of variable-speed compressors enables more efficient operation, the electronics tend to make the units more expensive than single-speed units.

Adaptive defrost technologies are also used allowing for the defrost cycles to perform only when needed and not based on a timer. The defrost cycle can be a large load for a refrigerator so reducing the number of defrost cycles is beneficial for reducing energy use. Better insulation is also used in refrigerators which reduces thermal conductivity. Some models come with multi-compartment or drawer units as well as better sealing doors and gaskets to help reduce the amount of transferred thermal energy.

Assessment Results

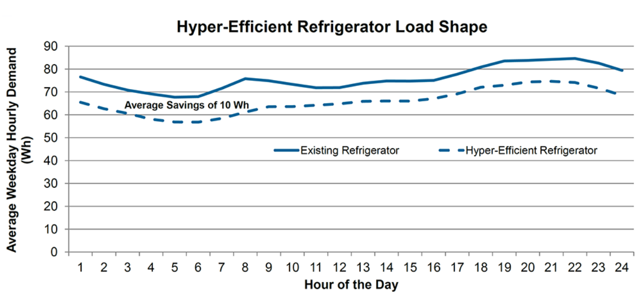
Energy Savings

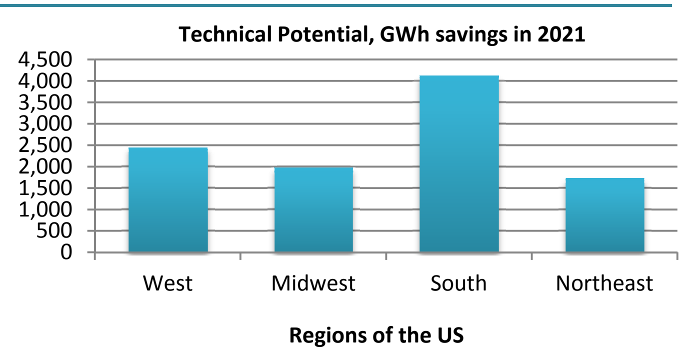
Energy Savings: Results from the Energy Efficiency Demonstration showed energy savings in two models and an increase in energy use in one model. One model had a variable-speed compressor and its energy consumption increased by 6% percent. Another model had efficient compressors and an evaporator fan. It demonstrated energy savings of 45%. The final model was equipped with an energy efficient bottom freezer drawer configuration as well as an energy efficient compressor. It demonstrated energy savings of 35%.

Coincident Peak Demand Savings: Demonstration results showed a 12% reduction in peak demand but it only accounted for a little over a watt. The daily load shape of the refrigerators measured did not indicate that power was particularly higher at any particular hour of the day.

Customer Benefits

Customer Benefits and Acceptance: Feedback was positive from homeowners in the EE Demo. Some models provide advanced controls from a built-in-screen. Features differ largely from one model to another. Overall, benefits are the same as for conventional refrigerators.





Economics

Current First Cost: Energy efficient refrigerators, the replaced technology, typically run $500 or higher in price depending on features. High efficiency refrigerators run $800 or higher, ranging from 150% to 200% higher in price.

Total Resource Cost: System provides minimal peak reduction. The TRC at today's prices is estimated at 0.42.

Estimated Future First Cost in 5 Years: First costs should decrease as market develops, but rate of decrease is unknown. Price appears to be driven by perceived value, which itself is a function of marketing and branding.

Future TRC: If costs remain the same, TRC = 0.42.

Technical

Technology Risk and Issues: No technical issues were observed during EPRI field testing.

Regional Applicability: High efficiency appliances are applicable in all regions. The technology showed energy savings in multiple climate zones in EPRI field testing. Because refrigerators are located in temperature controlled spaces energy savings are expected to be independent of climate zone.

Supply Chain

Health of Manufacturing Sector: Very strong manufacturing sector exists with products available from major refrigerator manufacturers. There are at least 35 manufacturers with high efficiency refrigerators. Samsung, LG, Whirlpool, and GE are some of those manufacturers.

Distribution Capability: A strong distribution channel exists as manufacturers have products available for wholesale purchase through vendors as well as available for end-use purchase through retail chains.

Service Capability: Refrigerator repair companies exist but manufacturers are the primary source for repairs to newer models. Large retail stores such as Sears also provide repair services.

Health and Environment

Human Impact: No human health impacts with proper use. Indication that human health impacts are minor and solvable. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: No environmental impacts known or cited. Refrigerant use occurs in occupied space but negative impacts are minimized or eliminated in the design.

Connectivity

Demand Response Readiness: Technology has the capability to provide some demand response if controls are developed. Refrigerators could respond to a utility signal to shed loads by delaying defrost, modifying the run time, reducing certain features, and changing internal temperatures. GE is running pilot programs related to this feature in their products.

Grid Impacts

Source of Power Quality Issues: No power quality issues are expected from high efficiency refrigerators.

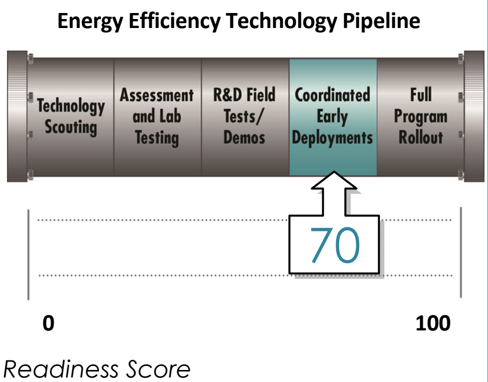
Susceptibility to Power Quality Issues: Refrigerators using adjustable speed compressors and higher efficiency compressors are not expected to be susceptible to power quality issues. New features, including smart displays, may be sensitive to power quality issues but impact to the consumer is expected to be unlikely.

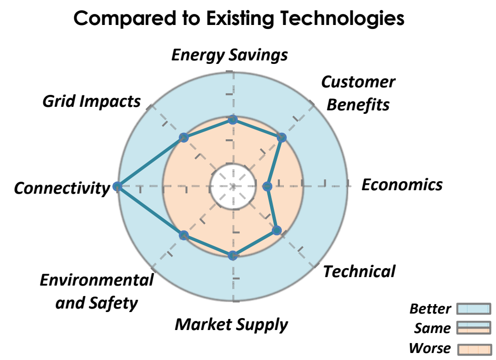
Requirements to Advance to Next Stage

Of the three models of refrigerators tested in the Energy Efficiency Demonstration, two models had consistent energy savings. These models are ready for Coordinated Early Deployments, but since there is little technical and commercial risk, the refrigerators could be included in utility energy efficiency programs.

Thermal Energy Storage for HVAC Systems – Commercial

Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**





Technical Description

Air conditioners compose a large portion of commercial loads making them an excellent target for demand reduction. Thermal energy storage offers demand reduction capability for HVAC systems.

Thermal energy storage devices capture thermal energy during off-peak hours and then release the energy to provide cooling during peak hours. Ice storage is an example of thermal energy storage.

There are two main types of thermal energy storage: full and partial. Full storage systems have the ability to *replace* the entire cooling load using thermal energy storage. Because full storage systems use ice, or other liquid, to cool refrigerant during peak hours, power consumption is reduced to the power required to run only a pump and blower. A partial storage system *supplements* cooling using thermal energy storage. The system runs 24 hours a day—at night to freeze/cool a liquid and during the day to keep the liquid cold. The power consumption of a partial system includes operation of the chiller, pump, and blower, but with less peak demand than a system without thermal storage.

Assessment Results

Energy Savings

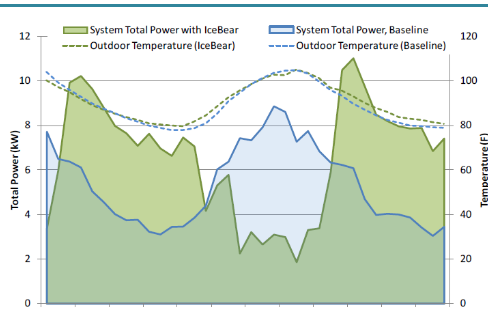
Energy Savings: The freezing and thawing of ice is akin to the charging and discharging of a battery. A reduction in kWh is not expected except under conditions of high daytime temperature and optimally cool nights, which will allow for efficient freezing of water. A likely scenario is that the ice storage system will use slightly more energy given the added requirement of freezing water and conversion of ice back to water.

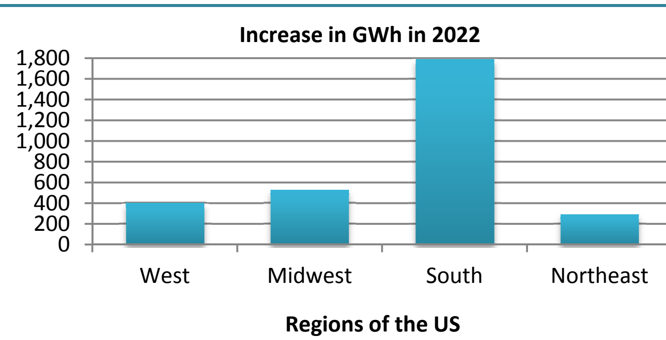
Coincident Peak Demand Savings: The main benefit of thermal energy storage is the shifting of cooling loads to the nighttime when outdoor temperatures are typically much cooler. An EPRI field demonstration of a full storage system showed a 45–60% reduction in coincident peak demand compared to standard unitary systems.

Customer Benefits

Customer Benefits and Acceptance: Building occupants should not observe any differences in the system's end product from traditional unitary systems; however, building owners may. Other benefits include that building owners can meet future cooling loads by adding ice storage capacity. This is beneficial because the entire system does not need to be removed to increase the total cooling capacity. Supplementing cooling load with thermal energy storage can also prolong service life of existing HVAC systems by reducing run time and full-load burden.

Adoption has been slow because the economics of this technology are not always beneficial for building owners. The exception occurs when the cost structure of their service territory causes them significant expense during peak operation times and rewards nighttime usage.





Economics

Current First Cost: The cost of ice energy storage is expected to vary depending on the installation and the size of the storage system. Where chillers are used to cool buildings, there may be additional cost savings because the chillers used in the thermal storage unit can be sized smaller than those used to cool the entire building. However, this may only be economical for new installs or major retrofits. EPRI estimates $150-250 in full, installed, capital cost per kWh/hr of storage – $525-$875 per ton/hr.

Total Resource Cost: The total resource cost (TRC) will vary largely depending on the rate structure in the customer's service territory. This technology is primarily intended for peak reduction savings and is even marketed to utilities by some manufacturers. Utilities may benefit from offering incentives with this product to help reduce peak demand.

Estimated Future First Cost in 5 Years: Retrofit/add-on may reduce in cost, but minimally. Cost is still a small percent of unit cost for a separate HVAC unit.

Future TRC: The TRC will continue to depend on the rate structure of the customer's service territory.

Technical

Technology Risk and Issues: The technology is not expected to have any outstanding technical risks. However, improper sizing of the attached unitary system will cause the ice storage system to be under-used, and full savings may not be realized.

Regional Applicability: Unitary thermal energy storage is not limited by regional constraints but is only useful in the north if a building requires cooling for the majority of the year. Because the system has a larger footprint than traditional unitary systems, designers must be more creative in placement of the systems when space is at a premium. Placement can vary: some designers have installed them in basements, on roofs, or in equipment rooms.

Supply Chain

Health of Manufacturing Sector: Several large manufacturers of heating, ventilating, and air conditioning (HVAC) equipment also produce thermal energy storage systems. Several smaller manufacturers also specialize in thermal energy storage.

Distribution Capability: Several existing distribution networks from HVAC equipment are being used for the distribution of thermal energy storage devices. One manufacturer markets its product to utilities for inclusion in distributed energy storage solutions.

Service Capability: Staff will need training to perform inspections and maintain the storage system.

Health and Environment

Human Impact: Indications are that human health impacts are minor and solvable because refrigerant systems, like any other system, must comply with applicable safety rules.

Environmental Impact: Potential increase in environmental impact compared to traditional technology because of an increase in refrigerant volume. Negative impacts are minimized or eliminated with proper installation.

Connectivity

Demand Response Readiness: Unitary thermal energy storage already reduces peak consumption without the need for a demand response signal. Additional demand response could be used by changing building temperature setpoints to reduce system load or using demand response in the attached unitary system.

Grid Impacts

Source of Power Quality Issues: The technology is no more likely to cause events than conventional heat pump systems. Proper design should reduce or eliminate power quality issues. Increasing the number of compressors on the grid, as would occur with increasing heat pump adoption, may increase the power system requirement for reactive power in order to prevent slow voltage recovery or voltage collapse after a voltage sag or outage when the compressors turn back on.

Susceptibility to Power Quality Issues: The technology has no unique power quality susceptibilities compared to standard heat pumps. Thermal storage technology controls may be susceptible; individual results will vary based on the quality of the product design.

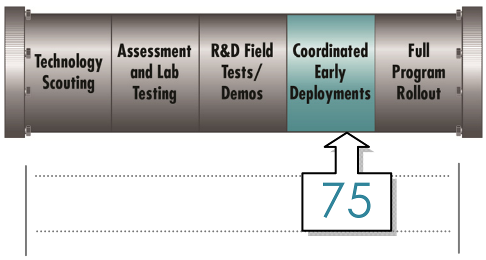
Requirements to Advance to Next Stage

Through several field demonstrations, the peak reduction potential of thermal energy storage has been verified. However, a greater understanding of the payback associated with thermal energy storage is needed for it to move into the program phase of the energy efficiency pipeline. A greater understanding of the requirements for payback will help utilities identify the most economically sensible locations for these units.

Variable Refrigerant Flow – Commercial

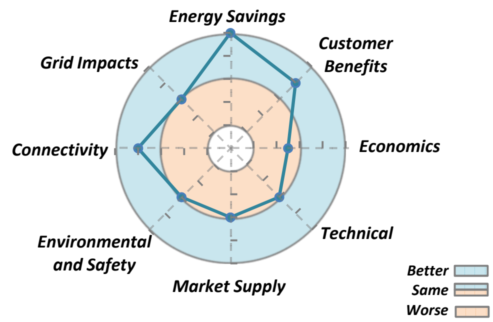
Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Commercial variable refrigerant flow heat pumps (VRF), a form of variable capacity heat pumps, operate as larger-capacity systems similar to mini-split heat pumps, but offer enhanced features, larger tonnage, refrigeration management, sophisticated controllability, and the capability to connect with multiple fan coil styles. Conditioned air is supplied directly to the space based on each room's set point. Each zone within a building has its own air-handling unit. The refrigerant is delivered to each air-handler by a network of refrigerant pipes.

VRF systems are similar to split systems as the compressor, heat exchanger, and controls are physically separated from the indoor units. VRF systems on the market are modular and scalable. Many units can be connected to operate as a single system.

There are two general types of VRF systems. Heat-pump systems operate with the system operating as a whole in either heating or cooling mode. Heat recovery systems allow different zones to operate in different modes. Heat is transferred to zones that require heat, and cooling is transferred to zones requiring cooling. However, the system as a whole will run in whichever mode has a greater demand.

Assessment Results

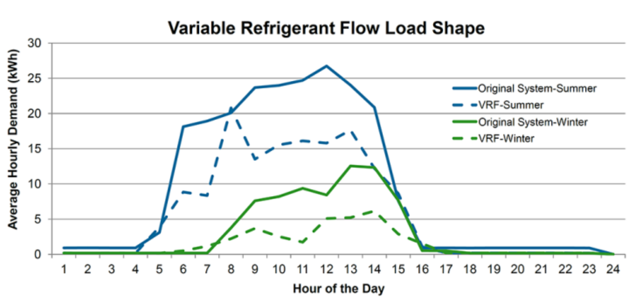
Energy Savings

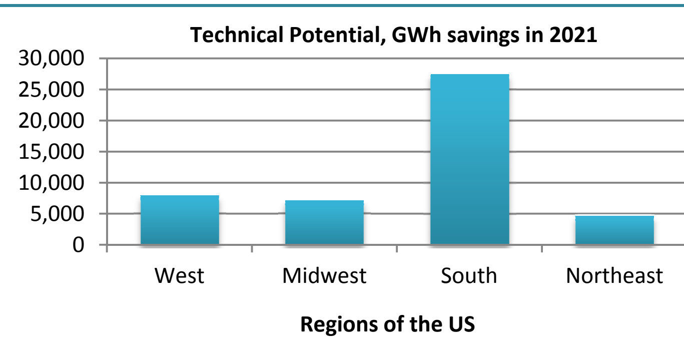
Energy Savings: The annual energy savings ranged from 20 – 45% at the four sites monitored during the EPRI Energy Efficiency Demonstration but varies depending on specifics of the installation.

Coincident Peak Demand Savings: Peak demand savings in the EPRI Energy Efficiency Demonstration were between 26 and 48% during peak operating times.

Customer Benefits

Customer Benefits and Acceptance: In the EE Demo, this technology exhibited more customer benefits than the replaced technologies. Zonal control of cooling, heating, and humidity provides increased comfort by providing the ability for different operating setpoints in different zones. Remote monitoring and diagnostic systems allows for real-time analysis, control, data collection, and data backup/transfer. During operation, unit runs relatively quietly. Survey results from the EPRI Energy Efficiency Demonstration show general satisfaction in terms of performance and the additional functionality.





Economics

Current First Cost: VRF can be the economic choice depending on the alternative. The incremental cost ranges from $0 to $0.25/sq. ft. for a total cost of $2 to 4/sq. ft. but is highly dependent on base system type.

Total Resource Cost: For a 24 ton VRF system that costs 12% more and resulted in 45% energy savings compared to the conventional system, TRC is 1.05.

Estimated Future First Cost in 5 Years: VRF installations require custom configurations tailored to fit each customer's needs. This implies that the price may decrease as market for VRF is developed, but isn't expected to do so rapidly.Future TRC: Future costs may reduce slightly but TRC is expected to remain the same at 1.05.

Technical

Technology Risk and Issues: No change in technology risks compared to baseline. Proper installation and design increases reliability and performance while minimizing risks or potential issues. Ductless feature of the system reduces ducting problems such as sealing issues and improper insulation that can cause heat loss. Custom installation is required.

Regional Applicability: Multiple region applicability. Technical potential and nature of technology suggests increased savings in warmer climates. Higher potential in the South, West, and Midwest climates.

Supply Chain

Health of Manufacturing Sector: Strong manufacturing sector. US market still being established, but recognized vendors and manufacturers offer units that have been proven in the field. Mature manufacturing sector in Japan and Europe. Daikin, Fujitsu, LG, Mitsubishi, Panasonic, Samsung, Toshiba Carrier and Trane all have products available in the US.

Distribution Capability: Moderate strength distribution sector. Since market is still being established, distribution capability is somewhat limited. Dedicated manufacturers strive to meet consumer needs.

Service Capability: Moderate strength service capability. Authorized factory representative needed for maintenance and roubleshooting. US knowledge and capability is limited, but expanding.

Health and Environment

Human Impact: Indication that human health impacts are minor and solvable. Refrigerant systems like any other must comply with applicable safety rules.

Environmental Impact: Potential increase in environmental impact compared to traditional technology. Refrigerant use occurs near occupied spaces since refrigerant lines are run to each indoor unit. Negative impacts are minimized or eliminated with proper installation.

Connectivity

Demand Response Readiness: VRF offers potential to perform as a demand response tool by turning off indoor units in certain spaces. This would allow the temperature and humidity to drift but may still remain comfortable due to spill over from other areas. The units could also be disabled for short periods of time in each zone to minimize overall impact. Units can be sequentially turned on to prevent demand spikes caused by starting power transients. Overall VRF system air conditioners have sophisticated controls which could be potentially controlled with demand response signals.

Grid Impacts

Source of Power Quality Issues: Technology no more likely to cause events than conventional heat pump systems. Proper design should reduce or eliminate power quality issues. Increasing the number of compressors on the grid, as would occur with increasing heat pump adoption, may increase the impact of slow voltage recovery which can reduce system voltage. This could occur after a voltage sag or outage when the heat pump compressors turn back on.

Susceptibility to Power Quality Issues: The technology has no unique power quality susceptibilities compared to standard heat pumps. Controls associated with heat pump technologies may be susceptible, and individual results will vary based on the quality of the product design.

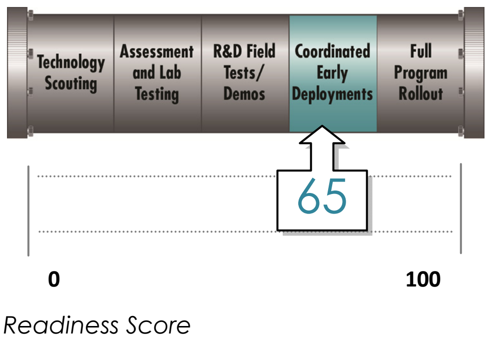
Requirements to Advance to Next Stage

The variable refrigerant flow demonstration showed that VRF has potential for significant energy savings. This is a good reason alone to move toward including VRF in utility energy efficiency programs. However, there remain questions as to what are the energy savings in different settings and how to quantify them, related to difficulties in determining baseline energy usage. Beyond understanding the energy savings, there are expected market adoption barriers with a little-known technology. While work continues in developing modeling capabilities to better quantify energy savings, early deployment projects under the EPRI collaborative project Coordinated Early Deployments for Efficient End-Use Technologies are recommended to gain experience with the market and increase the opportunity for success in utility energy efficiency programs.

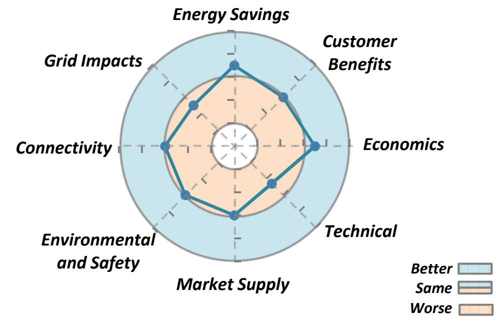
Voltage Optimization – Residential

Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

Energy Efficiency Technology Pipeline



Compared to Existing Technologies



Technical Description

Voltage optimization, also known as conservation voltage reduction, is the reduction of voltage on a distribution line to reduce the energy and peak demand usage in delivery and in the use of energy and demand on the customer side of the meter. While the original concept of conservation voltage reduction was a temporary measure for peak demand reduction, the concept described here is for continued operation at a lower voltage for ongoing energy savings. This can be accomplished using equipment on the distribution system such as load tap changing transformers and voltage regulators to control voltage and smart meters to measure voltage.

Most states require the utilities to supply voltage at the meter to within the American National Standards Institute (ANSI) standard of plus or minus 5% of the nominal service voltage. Operating between 114 and 120 volts is within this range and can enable energy savings for the end user.

The potential savings will vary from site to site because of the type of distribution line as well as the length of lines. Reducing the line voltage so that the end of line voltage is the minimal allowable voltage is an option but other events on the grid must be taken into account to avoid line voltage drop at the meter to below allowable limits.

On the end use side of the meter, energy savings varies among different equipment and devices because each behaves differently as voltage is reduced. For example, plasma TVs were found to actually require more power while purely resistive loads, such as incandescent lamps, were found to require less power.

Assessment Results

Energy Savings

Energy Savings: EPRI analysis estimates median savings of 2-3%. However, actual savings will vary depending on circuit characteristics. While the savings percentage seems low, the technical potential for energy savings is high.

Coincident Peak Demand Savings: Voltage optimization provides peak demand savings estimated to be similar to energy savings.

Customer Benefits

Customer Benefits and Acceptance: The use of voltage optimization may be easy on customers since action is taken by utilities without customer action. Energy savings achieved without a need for change in consumer behavior implies acceptance and persistence, although acceptance has not yet been proven.

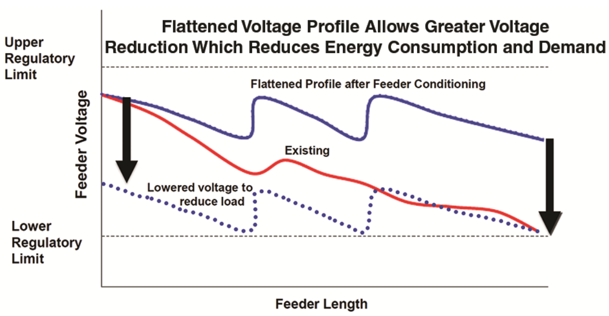
Economics

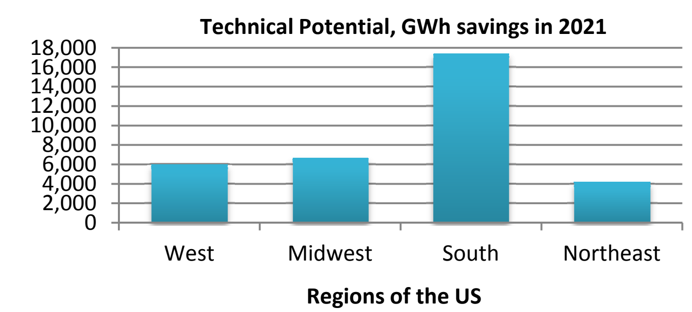
Current First Cost: Voltage optimization equipment range from $0.008 to $0.04 per kWh saved.

Total Resource Cost: TRC will vary depending on design considerations as well as savings potential on feeder. TRC is expected to be favorable overall. Example TRC calculations ranged from 1 to over 4.

Estimated Future First Cost in 5 Years: Cost is expected to decrease within next 5 years, although speed of decrease is not certain.

Future TRC: TRC may increase in the future.





Technical

Technology Risk and Issues: No significant change from current practices. Proper application and feeder selection limits technology-specific issues. Additional issues have not yet been discovered. Operation of some appliances may change such as HVAC or water heaters, which may run longer but may not consume more energy in aggregate.

Regional Applicability: National applicability in general terms, but there is a possibility of feeder-based and equipment-based applicability issues. Technical applicability is dependent on feeder characteristics, consumer end-use equipment, and customer type. Benefits depend on end-customer equipment which can vary due to climate and region. Proper feeder selection increases savings potential.

Supply Chain

Health of Manufacturing Sector: Very strong manufacturing sector with several easily recognized vendors.

Distribution Capability: Distribution capability is in place to meet demand for voltage optimization technologies.

Service Capability: Service capability is in place but staff may need additional training.

Health and Environment

Human Impact: No indication of risks to human health.

Environmental Impact: No indication of environmental impacts.

Connectivity

Demand Response Readiness: When voltage optimization becomes normal operation, then there is little additional peak demand reduction remaining to call upon.

Grid Impacts

Source of Power Quality Issues: Voltage optimization is believed to cause increased sensitivity to power quality issues due to the lower system voltage. However, this has not been observed in EPRI field testing.

Susceptibility to Power Quality Issues: The voltage optimization system would not be susceptible to power quality events but may intensify the effects of existing events. However, this has not been observed in EPRI field testing.

Requirements to Advance to Next Stage

Voltage optimization is a grid strategy that utilities are using or considering for use to reduce distribution delivery system peak demand and energy consumption. To reduce risk of unknown impacts on end users, additional lab and field research is underway to determine the impacts of reduced voltage on today's residential end uses. The next step would be field demonstrations to confirm that end-use customers will see energy consumption reductions and not detrimental effects of voltage optimization.

6
FULL PROGRAM ROLLOUT STAGE TECHNOLOGIES

The required criteria for this stage include the required criteria for the previous stages, plus the following:

- Energy savings are refined or deemed.
- There is a line of sight to acceptable Total Resource Cost test and payback period.
- There has been positive consumer adoption experience.
- There has been positive progress with the supply chain.

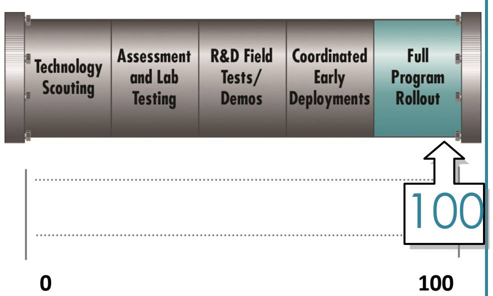
The technologies assessed in this stage are:

- 2X High-Efficiency Incandescent Lamps – Residential
- Server Power Supplies – Data Center
- Reduced Consumption Halogen – Residential
- LED Street and Area Lighting – Commercial
- LED Lamp – Residential

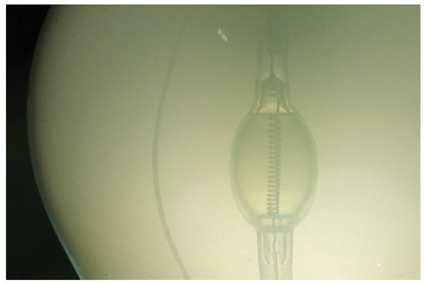
2X High-Efficiency Incandescent Lamps – Residential

Readness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**

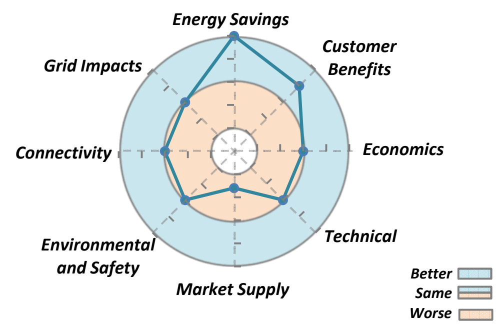
Energy Efficiency Technology Pipeline



Readiness Score



Compared to Existing Technologies



Technical Description

By 2014, production of 100, 75, 60, and 40 watt incandescent lamps will have been discontinued due to new lighting standards under the Energy Independence and Security Act of 2007. Many lamp manufacturers have been pressed to look into second generation incandescent lamps. The concerns of mercury in CFLs, the extra expense for dimmability, and the increased cost per lamp overall create a stage for incandescent manufacturers to reclaim the market.

The 2X high-efficiency incandescent lamp has emerged to potentially fill this gap. It uses a precision filament to deliver the same light output at half the power while preserving color temperature, shape, and dimmability. The lamp is able to do this by centering the filament within an ellipse which recaptures infrared light. A narrow neck is used in the ellipse to minimize loss of visible light through the end of the tube. The gas fill of the ellipse has also been changed. These modifications allow the temperature of the filament to be raised, and produce light, with less power required.

Assessment Results

Energy Savings

Energy Savings: EPRI lab testing shows a 50% reduction in power consumed without impact to lumen output.

Coincident Peak Demand Savings: A 50% reduction is expected when compared to traditional incandescent lamps.

Customer Benefits

Customer Benefits and Acceptance: Some additional benefits compared to conventional incandescent lamps. There is a lower temperature of operation because of the reduced amount of electrical energy converted to heat. The lifespan is also advertised as longer than conventional incandescent lamps.

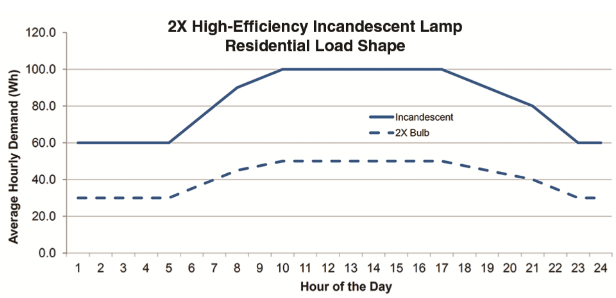
Economics

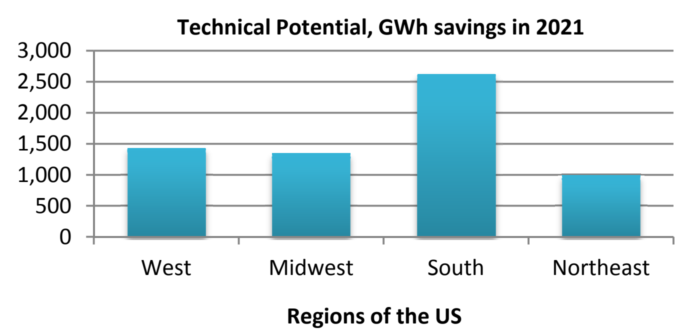
Current First Cost: The 2X incandescent is expected to be 300% or more in price than conventional incandescent lamps. The 2X incandescent is available through the manufacturer and is sold at $3.50 per lamp.

Total Resource Cost: TRC is expected to be greater than 3.

Estimated Future First Cost in 5 Years: It is assumed that the price will continue to be 150% or more than the cost of conventional incandescent lamps. There is not enough evidence to determine whether the technology will come down in price. An increased number of lamps manufactured could reduce the cost but since the product is not widely available it is difficult to predict market penetration.

Future TRC: There is not enough data to determine whether the cost will decrease, so a TRC of greater than 3 is assumed.





Technical

Technology Risk and Issues: No change from current practices. Technology performed at or above performance standards already in place for standard incandescent lamps. Since the 2012 release, the technology behind the 2x incandescent has also been applied to different lamp bases other than Edison base, including the multifaceted reflector format.

Regional Applicability: There are no regional impacts on technology, thus the technology is nationally applicable.

Supply Chain

Health of Manufacturing Sector: Because only one large manufacturer is developing this technology, manufacturing health is considered moderate.

Distribution Capability: Distribution is performed directly through the manufacturer's website. However, another company has branded their MR-16 base version of the 2x-incandescent as their own. This manufacturer has a very well developed distribution network.

Service Capability: No additional service is required of 2X incandescent lamps when compared to standard incandescent lamps. Any able-bodied person could perform a lamp change and no modification to fixtures must be made for 2X incandescent lamps.

Health and Environment

Human Impact: The human health impacts of 2X incandescent lamps do not differ from standard incandescent lamps. Operating temperature of lamps are lower because of reduced power consumption so burn/fire risk is reduced but not eliminated.

Environmental Impact: No change in environmental impacts when compared to standard incandescent lamps. The lack of mercury in incandescent lamps is an environmentally beneficial difference compared to CFLs.

Connectivity

Demand Response Readiness: No change in demand response capability compared to standard incandescent lamps. Incandescent lamps can be dimmed or turned off systematically if controls are developed but the majority of residential lighting loads occur at night during off peak hours.

Grid Impacts

Source of Power Quality Issues: Similar to standard incandescent lamps, there is no evidence of the technology causing system power quality issues.

Susceptibility to Power Quality Issues: There is no evidence of the technology reacting to system power quality issues any differently than standard incandescent lamps.

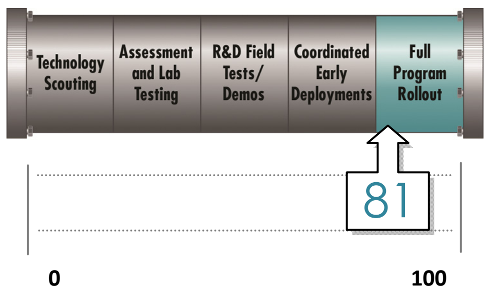
Requirements to Advance to Next Stage

The technology is now available but manufacturing is ramping up. Once manufacturing increases, it is expected to be ready for utility energy efficiency programs. However, its adoption may occur without outside intervention due to competitive cost of the technology when compared with CFLs and the benefits of its incandescent-like behavior.

Server Power Supplies – Data Center

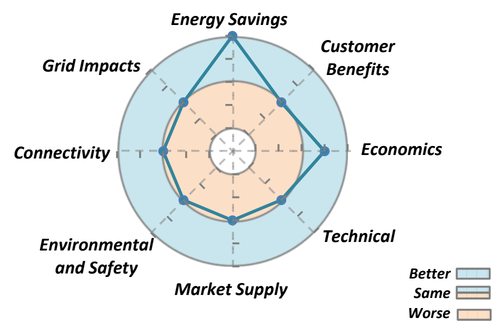
Readiness Brief – Energy Utilization, Power Delivery & Utilization 2013

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

Larger data centers (mid-tier and enterprise-class), which make up no more than 1% of U.S. data centers, are already energy efficient. However, the remaining 99% have significant room for improvement in energy efficiency. Small data centers are found in most commercial buildings, including office buildings, hospitals, universities, city halls, and supermarkets. One of the largest financial costs for data center operators is providing power to the servers. At the heart of this is the power supply, which converts alternating current (ac) power from utilities to direct current (dc) power used in computer, server, and data center devices.

Power supply efficiency continues to improve, but the average is still estimated at 86.6%—which is below the 93% that is available on the market today. *80 PLUS* is a voluntary certification program to promote efficient energy use in computer power supply units. An 80 PLUS certified device must have more than 80% electrical efficiency at 20%, 50%, and 100% loading and a power factor of 0.9 or greater at 100% loading. However, above-80% efficiency certified products are labeled with various tiers from *80 PLUS* (80% efficient) to *80 PLUS Titanium* (>90%) efficient.

Computer power supplies are a poster child for energy efficiency because efficiency can be increased without any variation in the final output of the product. 80 PLUS certified power supplies provide the same amount of power to devices but consume a smaller amount of power than less efficient models.

Assessment Results

Energy Savings

Energy Savings: Energy savings for 80 PLUS power supplies in data centers are driven by a reduction in energy consumed within the power supplies. Increased efficiency in the electronics, leads to reduced cooling load because less energy in the power supply is converted into heat. The energy savings associated with 80 PLUS server power supplies are estimated to be up to 20% of the total data center energy consumption depending on the efficiencies of current power supplies and the type and efficiency of the cooling system. Larger savings are expected at a lower loading utilization because this is where efficiencies are the lowest.

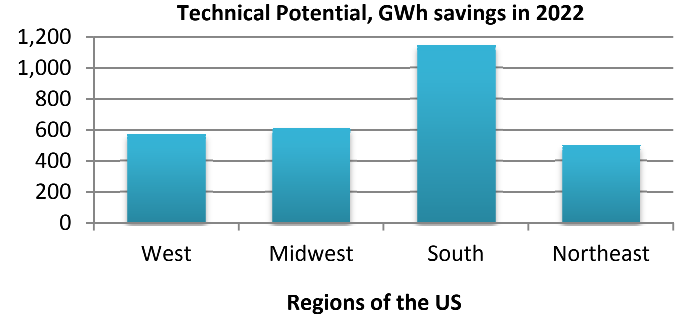
Coincident Peak Demand Savings: Load does not largely vary at data centers because the computers require only about 20% less energy when idle. Because of this, the load shape is flat—so any savings realized will occur at all hours. However, variation in outside temperature may have an impact on cooling load.

Customer Benefits

Customer Benefits and Acceptance: Consequential benefits of 80 PLUS certified power supplies include reduced circuit stresses from lower currents and operating temperatures that can lead to improved reliability. In addition, the reduced need for cooling load decreases the size and/or speed of cooling fans on the power supply, which may reduce fan noise.

Compliance Level	Loading				Power Factor
	10%	*20%*	*50%*	*100%*	
80 Plus Bronze		81%	85%	81%	0.90 @ 50%
80 Plus Silver		85%	89%	85%	0.90 @ 50%
80 Plus Gold		88%	92%	88%	0.90 @ 50%
80 Plus Platinum		90%	94%	91%	0.95 @ 50%
80 Plus Titanium	90%	94%	96%	91%	>0.95 @ 50%

Technical Potential, GWh savings in 2022



Acceptance has been positive; there are no performance differences between 80 PLUS certified power supplies and less efficient power supplies. However, the pricing is higher than the lower efficiency models because the high-efficiency models are sold as premium products.

Economics

Current First Cost: The incremental cost from a non-80 PLUS rated power supply to an 80 PLUS rated power supply ranges from $5 to $20 per power supply, but incremental costs are almost always less than 10%. Power supply prices average around $200 per unit, depending on wattage rating and manufacturer. Even though the first cost of the 80 PLUS power supplies tend to be higher, the operational cost is less compared to existing power supplies over its lifetime.

Total Resource Cost: It is difficult to determine the total resource cost (TRC) of 80 PLUS server power supplies because of the variety in ratings of existing systems. However, because of the low incremental cost and higher energy savings, the TRC is always expected to be favorable if current power supplies are replaced by efficient power supplies during regularly scheduled replacements.

Estimated Future First Cost in 5 Years: Incremental costs are expected to continue to decrease as efficiency becomes less of a premium feature.

Future TRC: TRC is expected to remain favorable in 5 years. However, increased penetration of 80 PLUS power supplies may lower the expected savings as the baseline becomes more efficient.

Technical

Technology Risk and Issues: There is no increased risk compared to non-80 PLUS power supplies. 80 PLUS certified power supplies provide the same amount of power to devices but require less power than less efficient models.

Regional Applicability: There are no regional constraints because the technology is unaffected by any regional differences. Energy savings related to reduced cooling load may be impacted by weather and seasonal variations, but power supply performance is not affected.

Supply Chain

Health of Manufacturing Sector: Very strong manufacturing sector. Industry leaders and smaller manufacturers produce 80 PLUS certified power supplies. More than 50 manufacturers currently have 80 PLUS certified server power supplies.

Distribution Capability: Distribution capability is already in place for this technology through distributors that sell non-80 PLUS power supplies and other server equipment.

Service Capability: Data center staff trained to replace power supplies should be able to service 80 PLUS power supplies. No additional training is needed for 80 PLUS certified power supplies.

Health and Environment

Human Impact: There are no known human health impacts.

Environmental Impact: There are no known environmental health impacts.

Connectivity

Demand Response Readiness: Data centers will not provide demand response capability. Reduced load is not possible based on demand response signals because it could cause downtime or insufficient bandwidth. The energy demand of the data center servers does not vary largely based on the workload, so the demand is relatively steady-state throughout the day.

Grid Impacts

Source of Power Quality Issues: The technology is not expected to be the source of power quality issues.

Susceptibility to Power Quality Issues: The technology is susceptible; however, because of high reliability and uptime requirements, susceptibility has been addressed in the design.

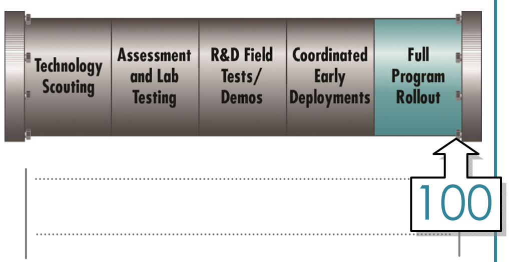
Requirements to Advance to Next Stage

80 PLUS power supplies provide the same end product as less efficient power supplies but use less power and have a reduced amount of heat production. For these reasons, 80 PLUS power supplies are expected to be naturally adopted by larger data center operators over time. Adoption will be through server replacements because servers typically have more efficient power supplies. However, research under the Coordinated Early Deployments project found that smaller data centers do not replace servers on a schedule and utility intervention is likely to be critical to adoption.

Reduced Consumption Halogen – Residential

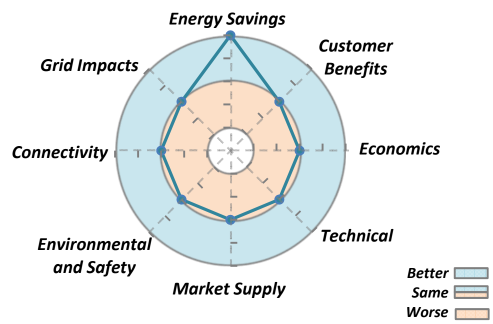
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

By 2014, production of 100-, 75-, 60-, and 40-watt (W) general service incandescent lamps will have been discontinued per new lighting standards under the Energy Independence and Security Act (EISA) of 2007. Some lamp manufacturers have been pressed to look into alternatives to traditional incandescent lamps, due to concerns about mercury in compact fluorescent lights (CFLs) and the extra expense of dimmability in CFLs.

The reduced consumption halogen lamp is a type of incandescent lamp that meets the EISA mandate and delivers improved efficiency compared to traditional incandescent lamps. These lamps offer similar properties but are able to produce more visible light per unit of energy and have a longer lifetime. The key to this technology is the ability to reach much higher operating temperatures, at which the filament is able to emit more light than a similar lamp operating at a lower operating temperature. The higher operating temperature also allows for the lamp to go through a recycling process in which tungsten that has evaporated off the filament is re-deposited on the filament. This process allows the filament to last longer than a standard incandescent filament.

Assessment Results

Energy Savings

Energy Savings: EPRI's lab analysis of reduced consumption halogen lamps demonstrated average savings of 28%.

Coincident Peak Demand Savings: Demand savings are expected to be similar to energy savings because lighting loads occur at all times of the day. In addition, incandescent lamps are resistive loads, so their power consumption varies only if dimmed.

Customer Benefits

Customer Benefits and Acceptance: The same as those of traditional incandescent lamps but with roughly double the lifetime. Compared to other incandescent replacements, reduced consumption halogen lamps do have some benefits. They turn on instantly (unlike CFLs) and have a color temperature of around 2700K—closer to incandescent lamps than CFLs or LEDs. Reduced consumption halogen lamps are also able to dim without advanced control and have minimal dimming induced flicker.

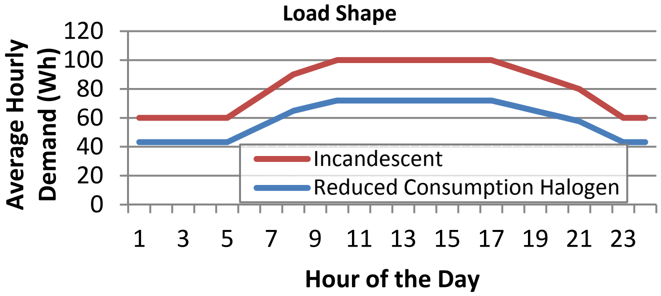
Economics

Current First Cost: The reduced consumption halogens cost 200% or more in price than conventional incandescent lamps. Typical incandescent lamps run less than $1; reduced consumption halogen lamps are approximately $1.50 to $1.75. This is significantly less than the majority of LED lamps and slightly less than many CFLs.

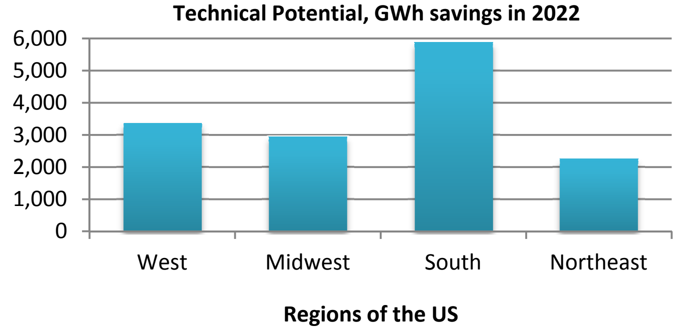
Total Resource Cost: TRC is expected to be around 7 to 9 depending on cost.

Estimated Future First Cost in 5 Years: Reduced consumption halogen lamps are expected to decrease in price to around a dollar in the next year.

Reduced Consumption Halogen Lamp Residential Load Shape



Technical Potential, GWh savings in 2022



Future TRC: If the price drops to around a dollar the TRC will grow. However, the TRC at current costs is already high.

Technical

Technology Risk and Issues: No significant change from current technology. The use of dimmers can reduce the life of reduced consumption halogen lamps if the reduced output causes the lamp temperature to drop below optimal operating temperature for long periods of time.

Regional Applicability: No regional constraints.

Supply Chain

Health of Manufacturing Sector: Manufacturing sector is strong. Several large lamp manufacturers produce reduced consumption halogen lamps.

Distribution Capability: The manufacturers that produce reduced consumption halogen lamps have strong existing distribution channels to big box stores and other distributors.

Service Capability: Service capability is in place. Service is no different from that for standard incandescent lamps.

Health and Environment

Human Impact: No change from current technology. Halogen lamps have a higher operating temperature but that is not a factor.

Environmental Impact: No change in environmental impacts compared to standard incandescent lamps. The lack of mercury in halogen lamps is an environmentally beneficial difference compared to CFLs.

Connectivity

Demand Response Readiness: No change in demand response capability compared to standard incandescent lamps. Halogen lamps can be dimmed or turned off systematically if controls are connected, but the majority of residential lighting loads occur at night during off-peak hours.

Grid Impacts

Source of Power Quality Issues: Similar to standard incandescent lamps, there is no evidence of the technology causing system power quality issues.

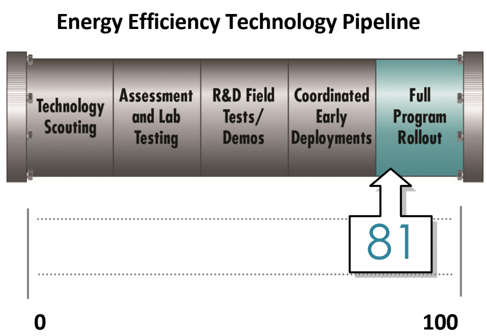
Susceptibility to Power Quality Issues: There is no evidence of the technology reacting to system power quality issues any differently than standard incandescent lamps.

Requirements to Advance to Next Stage

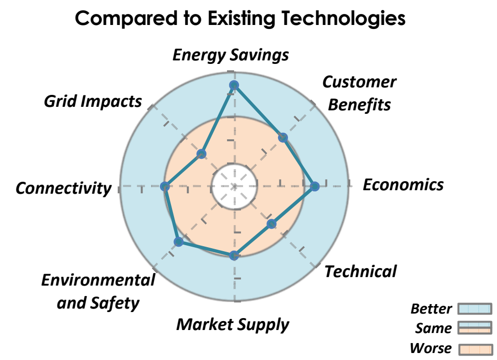
Reduced consumption halogen lamps offer the performance of incandescent lamps but with a longer life and reduced energy consumption. This combination in addition to a strong market sector and reasonable incremental pricing warrants this technology to be placed in the program stage of the pipeline. Reduced consumption halogen lamps may be adopted naturally by consumers with no utility intervention because of the low cost compared to other technologies allowed under the Energy Independence and Security Act of 2007.

LED Street and Area Lighting – Commercial

Readiness Brief – Energy Utilization, Power Delivery & Utilization **Updated: 2013**



Readiness Score



Technical Description

There is a move across the United States to replace existing street and area lights—normally mercury vapor, high-pressure sodium (HPS) or metal halide (MH) lamps—with new technology that costs less to operate. Light emitting diodes (LEDs) are at the forefront of this trend. Since LED street and area lighting technology is still relatively new to the market, utilities, municipalities, energy service providers, and lighting designers have expressed a keen interest in what the trade offs are between conventional and LED lighting. Cost is probably first among them, with the disadvantage of higher initial cost, but the potential advantage of lower operating costs.

LEDs, first produced in the 1950s, are solid-state lighting sources offering significant energy savings and efficacies that will exceed the energy savings of non-LED lighting technologies. LEDs are semiconductor diode devices that emit photons when voltage is applied across the devices. Their physical principles are fundamentally different from those of traditional lighting sources, such as incandescent, fluorescent, and high-intensity discharge (HID) lamps. For example, incandescent and fluorescent lamps use filaments with emissive coatings. HID lamps use electrodes immersed in specific gas mixtures. While all of the traditional lamps produce visible light, the production of that light does not involve the use of semiconductor materials.

LED street and area lighting technologies provide energy savings because they provide less overall light but at a color temperature that is easier for our eyes to pick up. Also, fixtures are able to focus light better than HID fixtures because of the low profile and the point source nature of LED lamps. A reduction in wasted light shining upwards and outside of the target area gives the potential for additional savings. The ability to direct the light only where it is needed as well as provide a better quality light allows for the use of lower wattage fixtures.

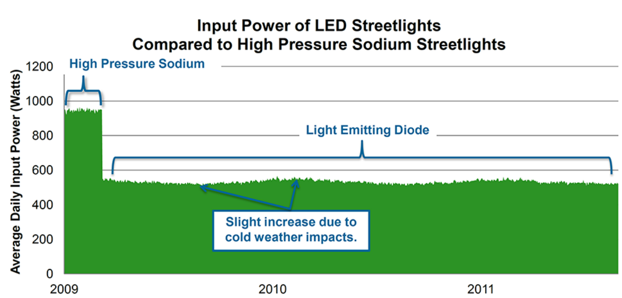
There are several important trade-offs to consider when adopting LED street and area lighting. The advantages may include energy savings, lower operating costs, durability, improved illumination which may lead to increased safety, and flexibility. On the disadvantages side are higher first costs, lower immunity to electrical disturbances, lower LED efficacy, varying fixture designs, three-wire installation, and general unsuitability for retrofit into conventional fixtures.

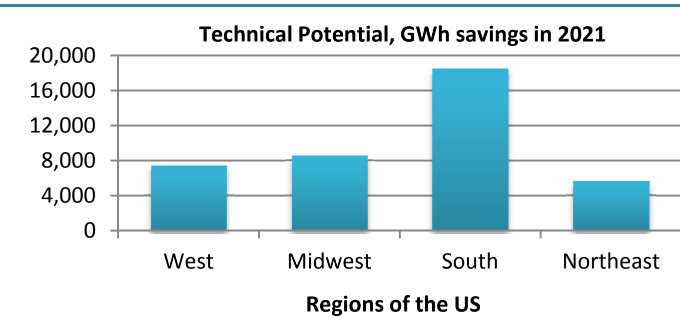
Assessment Results

Energy Savings

Energy Savings: EPRI Energy Efficiency Demonstration tests demonstrated energy savings ranging from 20% to over 70%. The variation was largely due to differences in design such as pole spacing, use of security cameras, adequacy of existing designs, and other design aspects. Average savings were 45%. Since the 2012 release, efficiencies have increased by 10-20% however the range of saving is still between 20% to over 70% due to differences in site design.

Coincident Peak Demand Savings: No indication of peak savings as fixtures do not operate during system peak usage times.





Customer Benefits

Customer Benefits and Acceptance: There appear to be more customer benefits over traditional technologies. Color rendering provides more visible light with decrease in required lumen output, directed illumination, increased productivity, reduced light pollution, and instant on/off capability. Color preference may not impact customer acceptance in commercial or industrial applications. Proper design is necessary to achieve benefits.

Economics

Current First Cost: Since the 2012 TRC release, LEDs have reduced in cost by 40-60%. LEDs now cost between 100 and 120% more than conventional high pressure sodium lights. For example, for a 400W equivalent, the LED fixture costs $400-600 vs. around $4009 for the high pressure sodium.

Total Resource Cost: The TRC will vary greatly depending on the site design and existing technology. However, due to the recent reduction in cost it is expected the TRC should be greater than one in most applications. However, proper site design must be followed to ensure energy savings are achieved.

Estimated Future First Cost in 5 Years: LED street and area lighting fixtures recently decreased in price. The cost is not expected to decrease by significantly more over the next five years.

Future TRC: TRC is expected to continue to look beneficial moving forward.

Technical

Technology Risk and Issues: Demonstrations have shown the viability of the technology to meet or exceed the performance of existing technologies. However, some risks remain. Life expectancy has not been proven, and driver failure can limit the useful life of fixtures. The manufacturability and reliability of the technology continues to evolve at a rapid pace. Individual LEDs have high durability and performance, and a single LED failure does not require immediate replacement due to the high number of LEDs in each fixture. Technical performance has been positive, but the design of driver outputs can cause blocks or bars of LEDs (portions of array) to experience possible early failure resulting in luminance below required minimum level. Pole spacing and fixture selection needs to be appropriate for the application. Fixture design may vary between manufacturers. Since the 2012 TRC release, more information has been gathered regarding the life of LED fixtures. Life expectancy is still estimated to be between 50 and 70,000 hours. However, there are still questions about how they performed after their estimated end of life and whether the lumens rapidly decrease or if it is a gradual process over a number of years.

Regional Applicability: National applicability. LED outdoor lighting has shown some reduction in energy savings during colder weather, but there are no application concerns related to weather or geographic region.

Supply Chain

Health of Manufacturing Sector: Strong manufacturing sector with recognized companies that offer a variety of fixture types, color rendering index, and shapes. Some major manufacturers include Cooper, GE, and Beta. However, increased variety points to over-diversification that can add difficulty for future replacements if suppliers leave the market. Large scale manufacturers can meet the demands of most customers with a variety of fixture and lamp types. Specialized companies exist that meet nontraditional and custom lighting needs. Declines in stimulus funding and financial support may mean future difficulties for manufacturers.

Distribution Capability: Distribution channels are in place. LED street and area lighting manufacturers distribute products through authorized dealers as well as distributors. Companies that distribute this technology also distribute other types of street and area lighting.

Service Capability: Service/maintenance may require fixture replacement rather than service of internal components including the driver or LED assembly. Service personnel would need additional training and equipment or fixtures would need to be sent to the manufacturers for repairs.

Health and Environment

Human Impact: Compared to high pressure sodium, LEDs provide improved lighting and create a more natural light which can increase visibility. This points to potential improvements to human safety. Research suggests blue lights negatively affect circadian rhythms/sleep patterns, but research is ongoing.

Environmental Impact: No environmental impacts, no disposal issues.

Connectivity

Demand Response Readiness: Street and outdoor lighting technologies should not operate during daylight hours, therefore peak reduction is not expected. Fixtures could be dimmed to reduce the amount of light in an area.

Grid Impacts

Source of Power Quality Issues: Demonstration results show that LED fixtures provided an increase in power factor compared to HID lighting technologies in the majority of cases. One installation required ferrite cores to be installed to prevent electromagnetic interference with neighborhood radios. Other research supports that some fixtures may present problems with harmonics.

Susceptibility to Power Quality Issues: LED street and area lighting has shown to be less immune to power quality events. The power electronics in LED fixtures are more susceptible to transients than current core and coil lighting technologies.

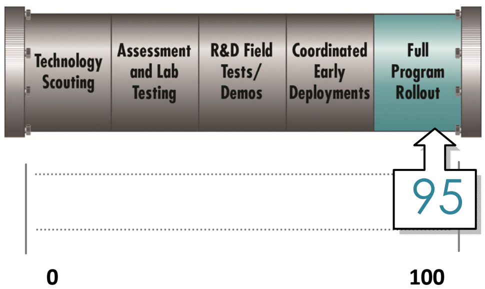
Requirements to Advance to Next Stage

EPRI assessed LED street and area lighting and found that the technology is ready for utility energy efficiency programs. The cost has reduced to an amount that is competitive with HID fixtures. However, the cost of the technology and the energy savings are a function of lighting design. Early deployments of LED lighting would help relate energy savings to lighting design and better prepare a utility for use in programs. The cost will have to be considered by each utility as it considers its energy efficiency program portfolio of measures.

LED Lamp – Residential

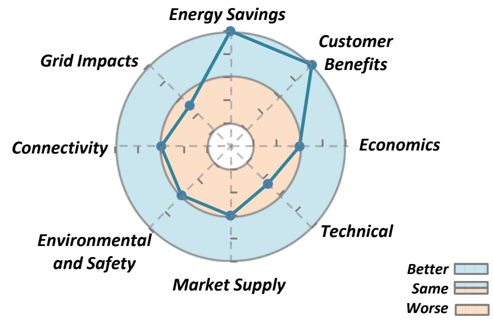
Readiness Brief – Energy Utilization, Power Delivery & Utilization **2013**

Energy Efficiency Technology Pipeline



Readiness Score

Compared to Existing Technologies



Technical Description

By 2014, production of 100-, 75-, 60-, and 40-watt (W) general service incandescent lamps will have been discontinued as a result of new lighting standards under the Energy Independence and Security Act (EISA) of 2007. Some lamp manufacturers have been pressed to look into second-generation incandescent lamps, due to concerns about mercury in compact fluorescent lights (CFLs) and the extra expense of dimmability in CFLs.

Light-emitting diode (LED) lamps provide consumers with another option for replacing standard incandescent lamps. LEDs are solid-state lighting sources that offer significant energy savings and efficacies. They are semiconductor diode devices that emit photons when voltage is applied across the device. Their physical principles are fundamentally different from those of traditional lighting sources, such as incandescent, fluorescent, and high-intensity discharge (HID) lamps. For example, incandescent and fluorescent lamps use filaments with emissive coatings. HID lamps use electrodes immersed in specific gas mixtures. Although traditional lamps produce visible light, the production of that light does not involve the use of semiconductor materials.

Because LEDs are point sources, the lamp or fixture must be designed to direct light to achieve the desired distribution. In addition, LEDs do not radiate heat in the same way that incandescent lamps do—so heat sinks must be used to remove generated heat. Because manufacturers differ in their approach to remove heat, the physical appearance and design of LED lamps vary among manufacturers.

The Department of Energy (DOE) expects that LEDs will represent 36% of the market by 2020 and 74% by 2030. However, as of 2012, LEDs represented less than 1% of the total installed 3.3 billion A-Type lamps in the market.

Assessment Results

Energy Savings

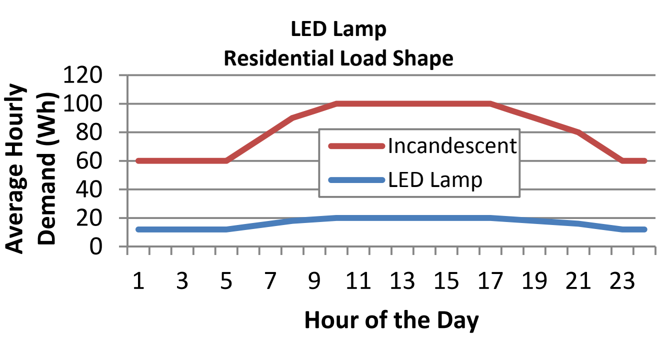
Energy Savings: EPRI lab testing confirms that LED replacements for 60-W incandescent bulbs can achieve savings up to 80%.

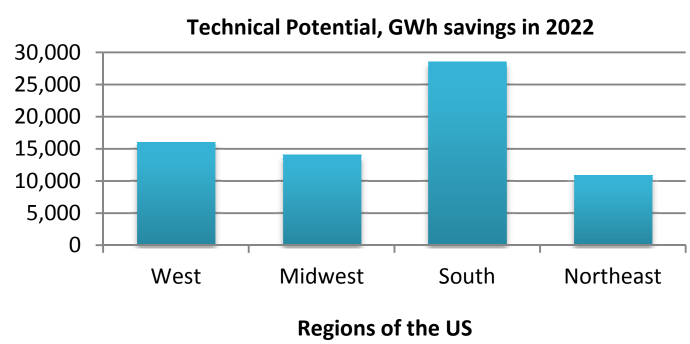
Coincident Peak Demand Savings: A reduction of up to 80% is expected when compared to traditional 60-W incandescent lamps.

Customer Benefits

Customer Benefits and Acceptance: LED lamps offer several benefits over other lightning technologies.

Unlike compact fluorescents, LEDs turn on instantly and flicker less, are impacted less by frequent on/off cycling, and contain no mercury. LED lamps operate at a temperature much lower than that of halogen fixtures, CFLs, and standard incandescent lamps. Most LEDs are also much more durable: because they are typically plastic and metal, there is no glass to break in many designs.





LEDs offer a much longer lifetime than other technologies. Traditional incandescent lamps claim lifespans of 1,000 to 1,500 hours and CFLs 6,000 to 8,000. Screw-based LEDs claim a lifespan of 25,000 hours. An LED can actually last much longer, up to 100,000 hours, but the lumen output of the lamp is likely to have decreased by 30% or more by the end of its lifetime. The lifespan of LED based products is largely determined by the driver and power supply life, not the life of the LED itself.

Economics

Current First Cost: LED lamps are priced at approximately ten times the cost of conventional incandescent lamps. Typical incandescent lamps run less than $1; LED lamps range from $10 to $30 for 60-W replacements. Cost varies by manufacturer. Because a major consideration for insuring a long

LED product life is heat, varying designs in heat removal exist for different applications—such as liquid cooling—and impact overall cost.

Total Resource Cost: EPRI's Technical Potential study estimates a TRC of 8.2 compared to incandescent lamps.

Estimated Future First Cost in 5 Years: The cost of LEDs is expected to continue to decrease. Some major manufacturers are already pricing LEDs at $10; other manufacturers can be expected to follow.

Future TRC: The future TRC is expected to increase with a reduction in price; however, an increase in penetration of energy-efficient lighting such as CFL may cause the baseline to change.

Technical

Technology Risk and Issues: Most LED lamps should not be installed in enclosed fixtures, such as lighting cans, because they prevent the heat sinks from removing heat. Some manufacturers offer lamps that radiate heat from the front of the lamp, but the majority radiate heat around the base. There is no increased risk with correct usage.

Over time, the color appearance can shift and lumen output decrease. However, traditional life span calculations have been adjusted to include lumen depreciation instead of the expected time until burnout.

Regional Applicability: No regional constraints.

Supply Chain

Health of Manufacturing Sector: The manufacturing sector is strong, with many major manufacturers.

Distribution Capability: Distribution capability is in place through online retailers and big box stores.

Service Capability: Service capability is in place; service is no different from that of standard incandescent lamps.

Health and Environment

Human Impact: No change from current technology.

Environmental Impact: No change in environmental impacts compared to standard incandescent lamps. The lack of mercury in LED lamps is an environmentally beneficial difference compared to CFLs.

Connectivity

***Demand Response Readiness*:** No change in demand response capability compared to standard incandescent lamps. LED lamps can be dimmed or turned off systematically if controls are connected, but the majority of residential lighting loads occur at night during off-peak hours.

Grid Impacts

Source of Power Quality Issues: Most LEDs pose little to no risk of power quality issues, but some designs have the potential of impacting other devices due to conducted (line) emissions. There is a risk that manufacturers may reduce components that mitigate power quality issues in order to lower prices, so this is an area which may need to be monitored as these products mature, but at this time LEDs shows little risk of power quality impacts.

Susceptibility to Power Quality Issues: The electronics contained within a LED lamp are more susceptible to power quality issues than incandescent lamps. Flicker has been observed in some LED designs.

Requirements to Advance to Next Stage

LED lamps are widely available for energy efficiency programs. Because cost is the largest barrier preventing adoption at this time, utility interventions will help move the market. However, as the cost decreases for LED lamps, there is an increased likelihood that consumers will adopt them without intervention purely based on the benefits and energy savings.

7
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