TECHNOLOGY INNOVATION:
AN INVESTMENT IN BPA's FUTURE

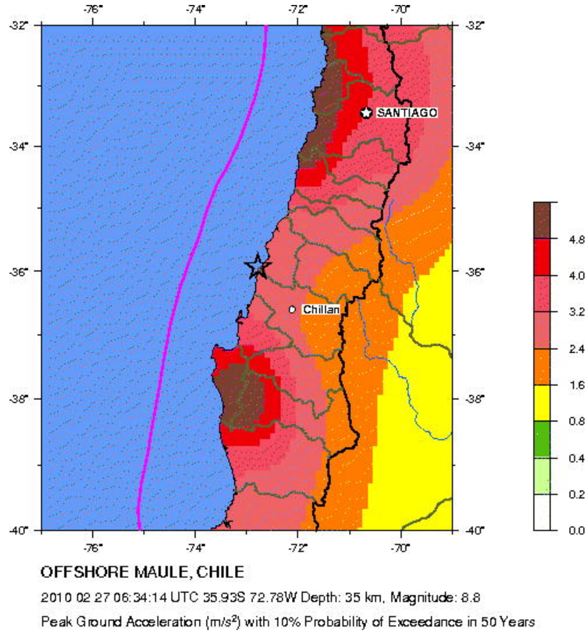
Introduction

New technology can help the industry adapt to challenges and deliver more cost-effective results. Research and Development (R&D) is an investment in BPA's future. Executives at the Bonneville Power Administration (BPA) determined in 2004 that they could better serve its customers and contribute to the long term economic health of the Pacific Northwest by pursuing valuable new technology. BPA created a new organization, the Technology Innovation (TI) Office, to focus and manage its technology initiatives. "We are seeking a shared innovation agenda" said Terry Oliver, BPA's Chief Technology Innovation Officer. "We want to build linkages to others in the industry to achieve it." The TI office guides the way BPA researches, develops, demonstrates and deploys new technology. Its successes are already saving BPA and its customers millions of dollars a year, while also fostering a more reliable and resilient power system:

- **Seismic safeguards make the power system more resistant to earthquake damage.**
- **New system monitoring devices and communication help BPA operate the power system more efficiently and reliably.**
- **A newly developed shunt boosts the capacity of power lines without much more expensive line replacement.**
- **Energy efficient ductless heat pumps save thousands of homeowners electricity and costs.**

Protecting the power system from large earthquakes

BPA is developing and installing new technology and examining case studies that will help the power system better withstand a major earthquake. Parts of Oregon and

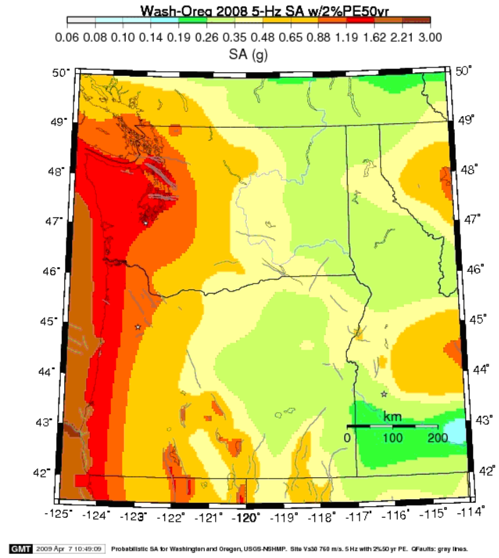


Seismic risk in Chile

Washington west of the Cascades face a 20% chance of a subduction zone earthquake in the next 40 years like the one that struck Chile this year.

The Seattle area faces an 80% chance of a major earthquake in the next 40 years. Such quakes could cripple the region and power failures would only compound the crisis. Dr. Leon Kempner leads BPA's seismic research. The American Society of Civil Engineers has recognized his work in improving the seismic performance of high-voltage transmission facilities by giving him the Charles Martin Duke Lifeline Earthquake Engineering Award, 2009. Dr. Kempner recently visited Chile and assessed how Chile's power transmission system, which is similar to BPA's, performed during the 8.8 magnitude quake there. BPA research has resulted in revisions of IEEE 693 standards, Recommended Practice for Seismic Design of Substations, and investigations in retrofitting existing field equipment with damping and base isolation devices.

BPA is working with researchers at Portland State University (PSU) to examine the way earthquakes affect high voltage equipment. Mike Riley is the BPA project manager that managed the R&D project developing instrument transformer damping devices being test at PSU. The project uses a shake table at PSU to test effects of an earthquake on a 115 kV instrument transformer.



Pacific Northwest seismic risk

Equipment Pedestal anchor-dampener

If the equipment performs as expected, BPA could use it to help buttress the power system against the shaking that occurs during major quakes.

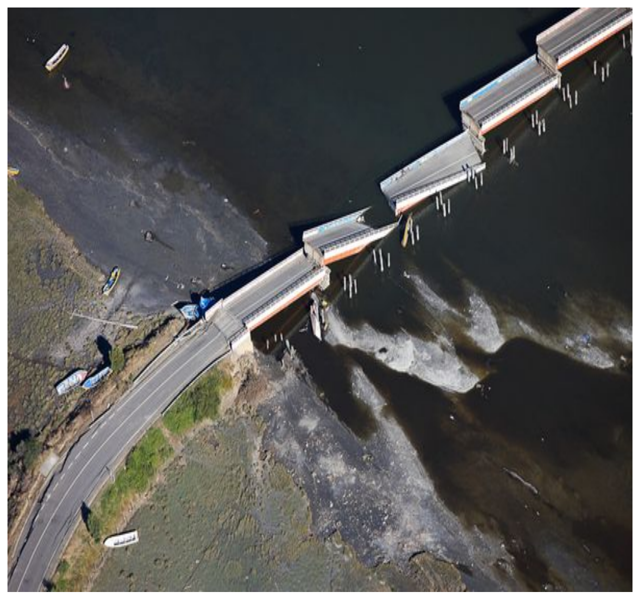
The research and updates will help protect new equipment from earthquakes. Dr. Kempner is also a member and co-chair of the IEEE 693 Seismic Design of Substations Working Group. The working group revises the recommended practices and methods for verifying seismic withstand capability. Examples of equipment the IEEE 693 standard revisions cover are composite insulators for voltage and current instrument transformers, and power transformer bushings.

Most of BPA's high voltage infrastructure was installed in the 1960's and is vulnerable to earthquakes. Critical equipment like power transformers are at risk from earthquakes. Over the last 10 years approximately 200 units have been anchored with about 100 left un-anchored west of the Cascades. A large number of transformers east of the Cascades remain unanchored.

Dr. Kempner returned from a visit to Chile just after the recent earthquake with some key lessons. "We have to see what failed during the earthquake. But more importantly we have to see what didn't fail. That gives us valuable information we can use to adjust our earthquake vulnerability assessments and determine where we need improvements," said Kempner. BPA learned that a prepared power system can perform well in a subduction zone earthquake. High-voltage equipment suffered less earthquake damage than low voltage equipment.

Low voltage distribution and High voltage substation damage in Chile

Damage to roads and highways hindered Chile’s response to damaged facilities. BPA now stores spare equipment like bushings in an immediate occupancy/operational facility designed to withstand earthquakes, where occupants can leave for safety reasons but then return for necessary work. The BPA power system is better prepared to continue functioning in the aftermath of a large earthquake thanks to R&D managed by Dr. Kempner.

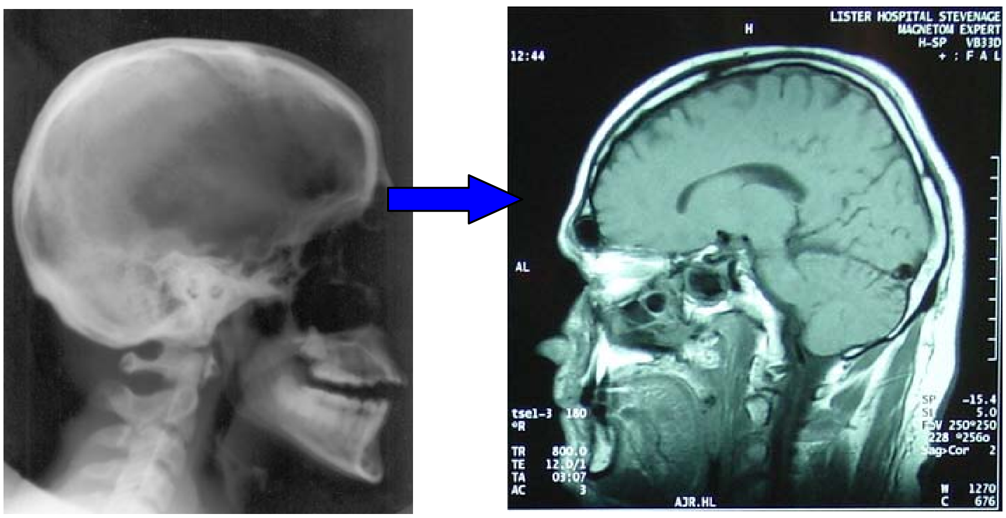


Transportation infrastructure damage in Chile

Collaboration between BPA and our research partners has improved our understanding of high voltage vulnerabilities and potential retrofit options. BPA’s research results have also help revise the IEEE 693 standard. Assessment of the Chilean earthquake helped BPA understand why things did and didn’t fail. BPA’s critical buildings and infrastructure are being strengthened to address current earthquake hazards. The research is helping BPA to build more seismic protections into critical equipment like power transformers that have two years of lead time to manufacture and deliver.

Promoting rapid grid communications

BPA is at the forefront of the development and large scale deployment of synchro-phasors, cutting-edge devices that give system operators instant snapshots of what’s happening in the grid. This makes the grid more resilient, reliable and responsive. The name “Synchro-phasor” sounds like something that you’d hear at a star trek convention and evokes the vision of a ray gun. But it’s an unparalleled tool for managing power systems. **“It’s like going from an X-ray to a MRI of the Grid,”** says CEO Terry Boston, PJM Interconnection-*NASPI System Benefits and Fact Sheet*.



X-ray versus MRI images.

Phasor measurement units

Synchro-phasors, or Phasor Measurement Units (PMUs), are synchronized measurement systems that measure the stress on a power system. PMUs take three-phase voltage and current waveforms and calculate their amplitude and phase, known as “phasors”.

Various phasor measurement units, also known as synchro-phasors

PMUs are geographically distributed throughout BPA's system and networked together using a fiber optic telecommunications system. The PMUs stream the data continuously from a substation to a BPA control center at rate of 30 or 60 packets a second! Synchro-phasor technology enables a variety of applications that improve:

- Grid stability and resilience;
- Helps avoid outages;
- Managing congestion; and
- Improving decisions on capital investment by better system analysis and grid modeling.

BPA was an early adopter of synchro-phasors and installed the first prototypes developed at Virginia Tech in 1986. BPA also pioneered the first Phasor Data Collectors (PDCs) and data stream protocols in the 1990's.

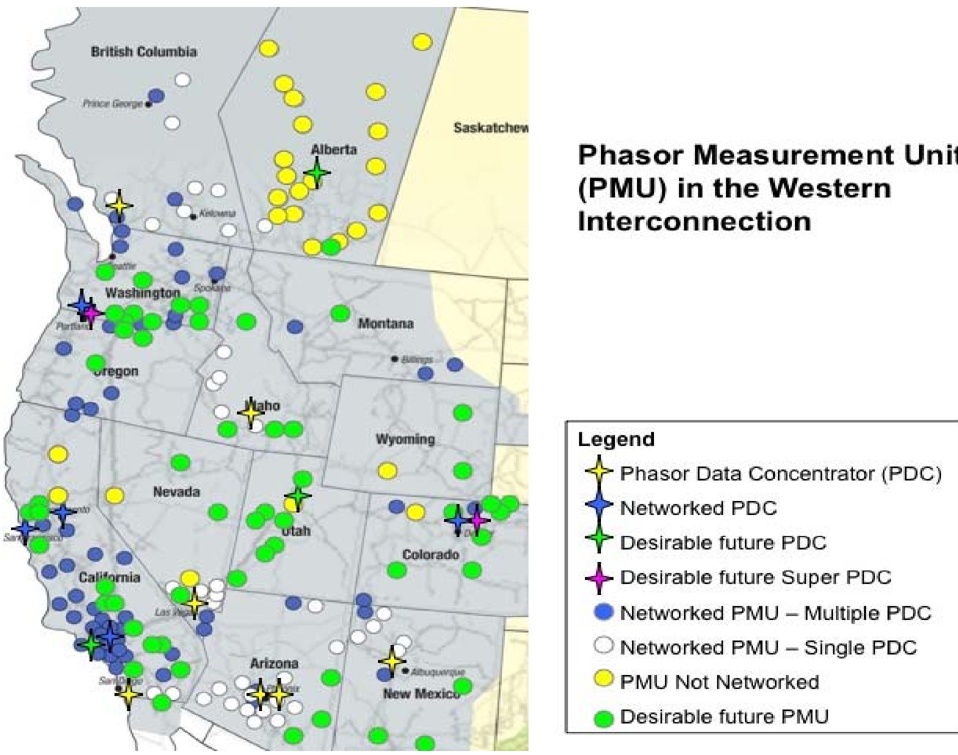
Currently the BPA has 25 PMUs on its territory and also exchanges the data with other entities such as Southern California Edison, Pacific Gas and Electric, Western Area Power Administration and California ISO. BPA uses synchro-phasor data for analysis of system behavior during system tests, for real-time trending, for post mortem forensics and for validation of power system models.

However, the existing BPA synchro-phasor network is not reliable or secure to be used in real-time critical operations. The objective of the current synchro-phasor project is to upgrade and rebuild the existing PMU network so that it can support real-time applications such as wide-area situational awareness and response-based controls.

BPA has also joined the Western Electricity Coordinating Council (WECC) to participate in a West-wide synchro-phasor network, the project named WISP - Western Interconnect Synchro-phasor Program. Other large partners include Pacific Gas and Electric, Southern California Edison, PacifiCorp, Idaho Power, Nevada Energy, Salt River Project and California ISO. This is very ambitious three-year project to build a synchro-phasor network coverage over the large portion of the Western Interconnection and to deploy a wide-area situational awareness and control applications. The project is supported by DOE through the American Recovery and Reinvestment Act.

BPA deliverables under WISP include:

- Networking 70 PMUs together using a fiber optic communications infrastructure (see OMET),
- Remedial Action Scheme (RAS) upgrades,
- Situational awareness tools,
- System disturbance analysis and modeling, and
- Integration into WECC’s synchro-phasor Wide Area Network (WAN).



Current and planned phasor measurement units in the West

These improvements together will make the power system more reliable. BPA Technology Innovation Office is currently funding several projects that are directly linked to WISP objectives. Inter-area Oscillation Damping project looks at the ways to use wide-area synchro-phasor data to detect large unstable oscillations before they become a problem. Real-time monitoring gives operators the situational awareness information needed for smart decision making and control. Voltage Stability Control project looks at using synchro-phasors for better voltage control at wind power plants to support agency's objective of reliable wind integration.

Leveraging synchro-phasor technology projects will bring value to BPA from real time system modeling, large scale outage avoidance, reliable renewable integration, and better decisions on capital investment.

OMET Fiber Optic Telecommunications Network

The rapid development of renewable energy projects is adding a major new variable to the operation of power systems. Since the output of renewable energy such as wind power varies, power system operators must track and respond to changes to keep generation and loads in constant balance. They need access to real-time information to do this. State and Federal renewable energy portfolios, climate change, and national security requirements and new technologies are driving the changes. BPA requires:

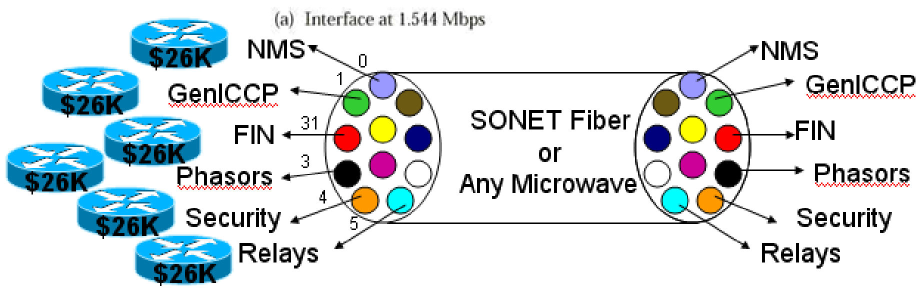
- Reliable secure telecommunications with significantly more bandwidth;
- Higher operating speed that supports multiple networks; and
- The ability to integrate new technologies.

BPA has supported tests of the Operational Multi-gigabit Ethernet Transport (OMET) system to help deliver on these requirements. The synchro-phasor project network was originally designed to use the Synchronous Optical Networking (SONET) platform but the OMET platform has been recommended as a better replacement alternative. The BPA Energy Efficiency (EE) and Transmission technology roadmaps have several technologies that will impact BPA's fiber optic telecommunications system. The EE and transmission technology roadmaps include:

- Demand response;
- Smart appliances;
- Grid integration technologies.
- Wide area control and measurement, and
- Real time analysis for dispatch and operations.

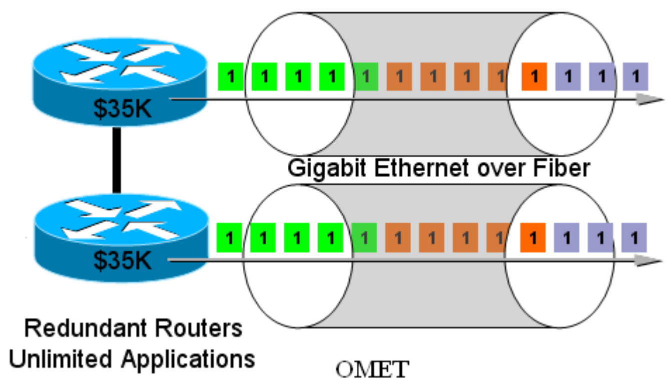
The OMET project is a field demonstration that was launched September 1, 2007 and is scheduled for completion by September 30, 2010. BPA project manager Joe Andres has demonstrated that commercially available OMET routers improve BPA's fiber optic telecommunications system for data transfer. The OMET project installed a small 4 substation network ring that helped overcome challenges including:

- System configuration;
- Deployment;
- Integration with BPA legacy equipment like radios; and
- Cost effective bandwidth expansion.



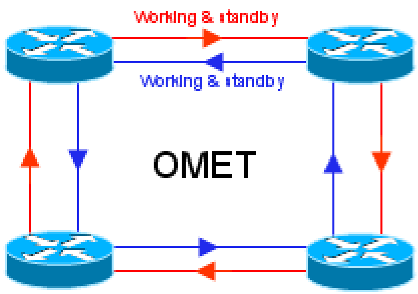
SONET configuration

SONET multiplexes or time shares the different applications through a fiber. SONET does not fully utilize the bandwidth or capacity of the fiber optic system when dedicated channels are idle. This limited bandwidth results in slower data transfer across the network.



OMET configuration

OMET uses the entire bandwidth of the cable and transfers much more data across the network faster than SONET.



4 PMU substation network ring

BPA currently uses the SONET fiber optic telecommunications system to support the synchro-phasor network. The major differences between SONET and OMET are in the cost and capabilities of the routers they each use, how routers are physically connected, and the speed working traffic crosses the networks.

SONET and OMET both use routers at each end of a fiber optic cable. SONET requires two routers for each single operational network. OMET requires two smart routers that are expandable supporting multiple networks within a single router. OMET is faster than SONET and will enable real-time Synchro-phasor technology and many new network applications for situational awareness, system disturbance, modeling RAS and integration into WECC's WAN. New applications are realized on OMET by simply changing a few software command lines. OMET will simplify deployment, avoid significant future operating expense and manpower requirements, and will prepare the network for growth.

New splice-shunt reduces BPA, customer costs

BPA engineer Len Custer developed a shunt technology that quickly and easily mitigates temperature problems in connectors on transmission lines, avoiding far more expensive line replacement projects. BPA's transmission system consists of 15,238 circuit miles of transmission lines. Transmission lines consist of many shorter pieces of conductor joined together end to end with compression connectors. Ends of a transmission line conductor can be joined together with a mid-span splice or at a dead-end tower with jumpers. The compression fitting slips over the cable end and is compressed onto the cable. The compression splice is a critical link in the cable system, which has a maximum operating temperature of 100 ^{0}C. This limits the power that can flow through the cable system. Until development of the high-temperature shunts the only way to get more capacity on a transmission line was to re-conductor or rebuild the line with new, expensive cable.

BPA crews install a dead-end high-temperature shunt above the Columbia River.

The high-temperature shunt is a set of pre-formed aluminum wires that wraps over mid-span splices or dead-end connectors.

Mid-span splice shunt.

TI research has determined that the shunt strengthens the cable and raises the maximum operating temperature of the compression fittings from 100 to greater than 200 ^{0}C. The cost of shunting is on average 30% of the cost to re-conductor a transmission line with newer cable. The high-temperature shunt enables more transmission capacity, power flow and load integration on existing transmission lines increasing BPA's revenue and minimizing rates.

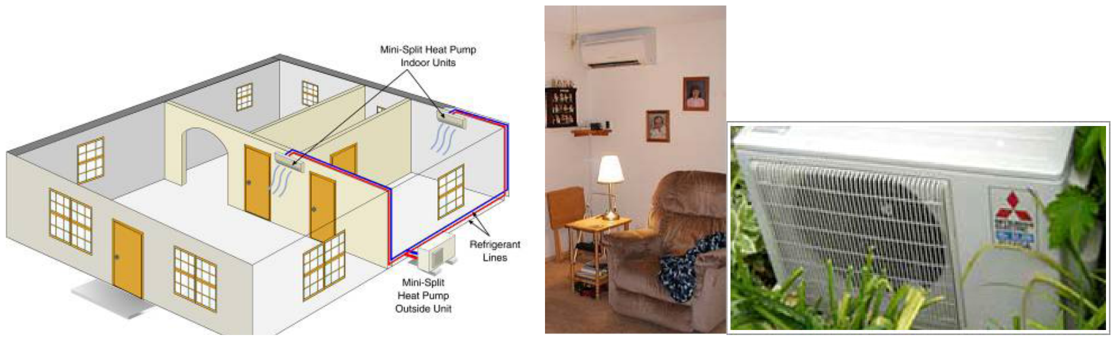
Shunting the compression fitting relieves transmission line constraints and can increase the cable transmission rating by 40%. These new shunts increase transmission line capacity making BPA's system more efficient. BPA increased transmission capacity on the 20 mile Ross-Lexington upgrade using the high-temperature shunts and saved BPA $4 million from an expensive line re-conductor. The savings were estimated by subtracting the project cost from the cost of a line re-conductor. In the future as part of the wood/steel asset management strategy BPA will be hardening existing compression fittings with shunts when transmission lines are serviced.

Energy Efficiency Ductless Heat Pump Demonstration

Ductless Heat Pumps (DHP) are a technology new to the Pacific Northwest with very promising potential for residential and small commercial applications. Also know as min-splits, DHPs variable refrigerant flow uses variable frequency driven motor technology to drive the compressor motor at the optimal speed for maximum efficiency at different outside air temperatures. DHPs are quiet and efficient using 30 to 50 percent less energy to heat homes than electric-resistance or forced-air systems. The Northwest Power Council has identified energy efficiency as the least cost method to meet most of the demand for electricity over the next 20 years. Ductless heat pumps are a prominent technology in the Council 6^{th} Power Plan, approved in early 2010. During 2009, a BPA-sponsored ductless heat pump pilot project, coordinated by the Northwest Energy Efficiency Alliance exceeded all goals, saving energy for many Northwest homeowners.

BPA has been a leader in examining the potential for this technology since 2004 when BPA began field testing Cold Climate Heat Pumps (CCHPs). Eight CCHPs were installed in 2004-2005 in Chiloquin Oregon, and Burley, Paul, Rigby and Ashton, Idaho. BPA concluded that the CCHP compressor technology was not reliable with a compressor failure on one unit and functional in-efficiency. The Ductless Heat Pump (DHP) technology emerged after assessing heat pump technology during the CCHP project.

In 2006, BPA undertook an effort to determine the potential savings of DHPs with the Monmouth TI project. To test the newer compressor technology in DHPs, the Monmouth TI project (2006-2008) individually metered applications to conduct an engineering analysis of 14 single family homes with electric resistance heat. The results from this engineering study provided enough confidence with the potential savings to propose a pilot to gather data on a larger regional scale.



Home Schematic Layout Drawing and Pictures of Inside and Outside Units

In 2008 DHP were identified by BPA's Energy Efficiency (EE) group as ready to test. The Electric Power Research Institute (EPRI) had been researching DHPs when BPA proposed to team up in a parallel effort. BPA collaborated with the EPRI on a program designed by EPRI to field test the DHP in a variety of utility service areas across the region. BPA's challenge was to install 1,500 units within a year with an overall regional goal of 2,500 units by the end of 2009. BPA collaborated with the Northwest Energy Efficiency Alliance (NEEA) to lead the regional DHP pilot program, the nation's largest DHP program. BPA handed off the fieldwork to NEEA, and as of June 2010, BPA and NEEA exceeded the overall regional goal installing more than 4,800 units and counting. The program is so successful that it is being expanded beyond the residential applications into small businesses and buildings in the region.

EPRI presented awards to several BPA and Snohomish County Public Utility District employees for their leadership and significant contributions to the Northwest for adoption and use of ductless heat pump technology. BPA's Lauren Gage, Sarah F. Moore and Mark Johnson from BPA Energy Efficiency, and Kevin Watier and Suzanne Frew from Snohomish PUD received the 2009 Power Delivery & Utilization Technology Transfer Awards.

EPRI Awards, from left to right: Ammi' Amarnath, Lauren Gauge, Sarah F. Moore, Mike Weedel, Mark Johnson, and Ronald Domitrovic.