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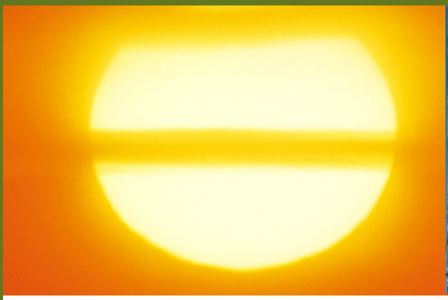
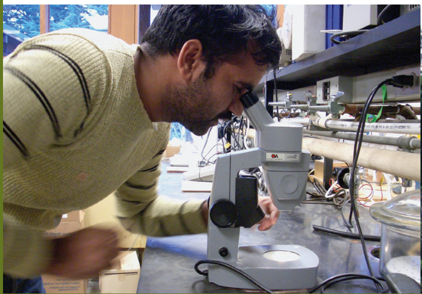



Energy: Environmentally Acceptable Choices for Washington State




Summary of the Proceedings of the Sixth Annual Symposium

Held as Part of the 2013 Annual Meeting of the

Washington State Academy of Sciences

September 12, 2013, Museum of Flight, Seattle, WA

Spring 2014

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Proceedings Released
Winter 2014

About the Washington State Academy of Sciences (WSAS)

WSAS is an organization of Washington state's leading scientists and engineers dedicated to serving the state with scientific counsel. Formed as a working academy, not an honorary society, the academy is modeled on the National Research Council. Its mission is two-fold:

- To provide expert scientific and engineering analysis to inform public policymaking in Washington state; and
- To increase the role and visibility of science in the state.

Governor Christine Gregoire authorized legislation establishing WSAS in 2005. Its 12-member Founding Board of Directors was recommended by the presidents of Washington State University and the University of Washington, and was duly appointed by the governor. In April 2007, WSAS was constituted by the Secretary of State as a private, independent 501(c)(3).

Progress in 2013

The Academy welcomed 25 new members, continued outreach to K-12 students and teachers, and completed two published studies at the request of the state of Washington. *Root Diseases of Douglas Firs* is a study requested by the Washington State Department of Natural Resources. *I-522 Mandatory Labeling of Foods with Ingredients from Genetically Modified Plants and Animals* is a white paper charged by the state Legislature to produce an evidence-based analysis addressing the underlying science of the labeling that would be mandated by Initiative 522. Michael Kern, director of the William D. Ruckelshaus Center, was invited as a Symposium guest speaker to address opportunities for the Academy to work together with the Center for the state of Washington. The Center's mission is to foster collaborative public policy in the state and the Pacific Northwest.

Symposium materials

Source material for the Sixth Annual Symposium may be found on the WSAS website, including:

- Speakers' slides;
- Video of the invited speakers' presentations;
- Symposium handouts; and
- Symposium photographs.

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Welcome to the proceedings of our sixth annual symposium, ***Energy: Environmentally Acceptable Choices for Washington State***. We are increasingly dependent on energy in our daily lives — from living room lighting, to transportation, to products manufactured in huge plants. The heat is on, with climate change and the growing evidence of its negative impacts in our state. Washington has legislation in place to obtain 15 percent of our electricity from new renewable energy resources by 2020. Governor Inslee has made addressing climate change and reducing greenhouse gases a top priority. As the state's energy mix continues to evolve, the speakers share their expertise of where we stand and how we might best move forward.

Robert C. Bates
Executive director

L. C. Singhal
President

JAY INSLEE
Governor

STATE OF WASHINGTON
OFFICE OF THE GOVERNOR
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Greetings from the Governor

September 12, 2013

I am pleased to extend warm greetings to all of those attending the Sixth Annual Washington State Academy of Sciences (WSAS) Symposium: Energy & Environmentally Acceptable Choices for Washington State.

I'd like to take this opportunity to thank WSAS for its commitment to informing public policymaking through expert scientific, non-partisan analysis and to increasing the role of science in Washington State. Your work is critically important, and, as you gather to discuss energy at this year's Symposium, I'd like to share my vision for clean energy in our state.

As many of you know, I've made addressing climate change and reducing greenhouse gases a top priority of my administration. Climate change isn't merely an academic argument; it's real and it's already negatively impacting our state. In order to successfully tackle this escalating threat, we will need both energy efficiency and clean, renewable energy. Through clean energy we will reduce harmful air emissions, increase our energy independence and promote job creation. In fact, job creation rates in Washington's clean energy economy are already well above those in other sectors – and clean energy jobs provide good, family wages. A study conducted by the West Coast States concluded that with a continued strong focus on clean energy, jobs in these industries could see a 200 percent growth in the period from 2010 to 2020.

This past legislative session, we made progress toward a clean energy future. As part of my Working Washington jobs agenda, we established a new Clean Energy Fund, which will invest $40 million in clean energy technologies. In addition, I'm pleased to report that we extended our state tax incentives for producing renewable energy to support wind, solar and other renewable sources. We also extended our tax incentives for solar manufacturing and enacted policy improvements for businesses that produce energy from geothermal sources and organic waste. We will also fund the creation of a Clean Energy Institute at the University of Washington, which will focus on research and development of technologies that advance storage of electricity and solar power.

By the end of this year, the Climate Legislative and Executive Workgroup will recommend a state program of actions and policies to reduce greenhouse gas emissions, in order to achieve the state's emission targets enacted in 2008. I am chairing this bipartisan effort, and together we will determine how the state will tackle carbon pollution, avoid or minimize the worst impacts of climate change, and capture the economic opportunities of a clean energy future.

Innovation is key to increasing the use of clean energy and will form the foundation of sustainable growth for renewable energy here in Washington State and around the world. Washington is known for its culture of innovation and is ideally positioned to grow as a center for renewable energy transformation. We can and will lead on this issue, and in the process we will strengthen our economy and protect our state's natural resources for future generations.

Thank you for coming, and please accept my best wishes for a productive meeting.

Very truly yours,

Jay Inslee
Governor

Executive Summary

What are "environmentally acceptable energy choices" for Washington? Traditionally the state has been blessed with clean hydro power, but growth for that resource is tapped out. Renewables like wind and solar are adding to the mix, yet not as dependable for powering the grid. New and innovative applications of existing technology are opening the way to an abundance of natural gas. Coal is being phased out. Ocean energy offers vast potential but currently produces not one electron of power. The state is still dependent on petroleum, mainly for transportation. Power grid controls are unstable amid the influx of new electricity sources.

From voltaic shingles on a home to wind turbines twice the size of a jumbo jet's wingspan to seven miles of drilling 8,000 feet below the earth's surface, Washington is in the midst of an energy revolution. Scientists engaged in innovative research and product development affirm that it's an exciting time.

Taking the soft path to energy

Governor Inslee has requested a carbon-free electricity system in Washington in 20 years. Dr. Howard Schwartz introduced one approach to nearing that goal — transforming from the hard path of centralized industrial energy production to what's called the soft path of drastically reduced consumption of electricity through huge improvements in energy efficiency and renewable energy. The Northwest's hydro base makes that easier, and the Northwest Power and Conservation Council has helped the region lead in conservation. A carbon-free system is possible if a number of assumptions come to pass. None of the assumptions is unrealistic, and much is underway.

Hydro, renewables, and the grid

Because of its hydro resources, Washington has remained an energy-rich system. New renewable resources, mainly wind, bring a significant amount of additional energy. Kieran Connolly explained how these variable resources require a "dance of water" to control the system in a predictable way to manage for flood control, fish passage, and customers' electrical needs. In addition, climate change adds more uncertainty. Power suppliers seek to add this positive new mix of resources while finding ways to adapt into a system capable of handling it all into the future.

Influx of natural gas

Shale gas has turned everything in the energy industry on its head. In the past six years, hydraulic fracturing, or fracking, has moved natural gas from a resource that was scarce to one that is abundant. Dan Kirschner's presentation includes a video that depicts the technical process in detail, from deep horizontal drilling to the firing of perforated guns and infusion of high-pressure water. Research is under way to address concerns such as contamination of drinking water, water consumption, water recycling, and air emissions. It's predicted that shale will account for 60 percent of U.S. natural gas production by 2035.

The world is embracing nuclear. Will Washington?

Nuclear power is experiencing a renaissance, particularly in Asia, where 29 plants are being built in China and six in India. Dr. Alan Waltar discussed the declining nuclear scene in the U.S. Only one nuclear plant operates in Washington. There is burgeoning interest in new reactors like the Traveling Wave Reactor and Small Module Reactor. Hanford, with its existing Nuclear Regulatory Commission-approved site, could be ideal for an SMR demonstration plant. Renewables like wind and solar won't be able to solve all of the state's electrical growth challenges. Washington offers much nuclear expertise and innovation.

A tide of ocean energy

Ocean waves, tides, and currents are consistent and predictable sources of clean, renewable energy. Dr. Charles Brandt discussed how offshore winds have the potential to produce over four times the entire U.S. electrical generating capacity. While products exist for wave energy, tidal power, and offshore wind energy, deep water presents new and unaddressed problems. The maritime system of ports and vessels isn't ready. There are no state or federal permitting systems for these technologies, and little data, so potential investors are wary. Washington currently has no ocean energy production, but a pilot-scale project with the Snohomish Public Utility District is in the works.

Modern power control systems are on the way

Today's electrical systems have become increasingly complex with the inclusion of renewables and their variability. Carl Imhoff revealed how Smart Grid technologies and high-performance computing are revolutionizing grid operations and planning. New synchrophasors help monitor the electrical system in real time, improving reliability and mitigation for outages. Recently, the Northwest took part in the largest Smart Grid demonstration in the country, involving innovations in energy storage, plug-in vehicles, grid-friendly appliances, and outage recovery. The bottom line points to a multitude of opportunities for extracting more value out of Washington's expertise, capacity, and intellectual horsepower.

Dr. Edmund Schweitzer III pointed out that electricity is hard to store, and the variability of renewables like wind make an unstable power control system "twitchier." Engineers need to develop newer and faster ways, like feedback control, to control the power system, which can be automated to analyze contingencies and build responses. He predicted a move to closed-loop systems that will directly measure the state of the power system, predict the evolution and take anticipatory control actions. Automation will result in feedback control that's simpler, better, more reliable, and a lot more robust. The theories and tools exist to do this today.

Introduction

Symposium Moderator
Jud Virden
Associate Laboratory Director, Pacific Northwest National Laboratory's Energy and Environment Directorate

Synopsis

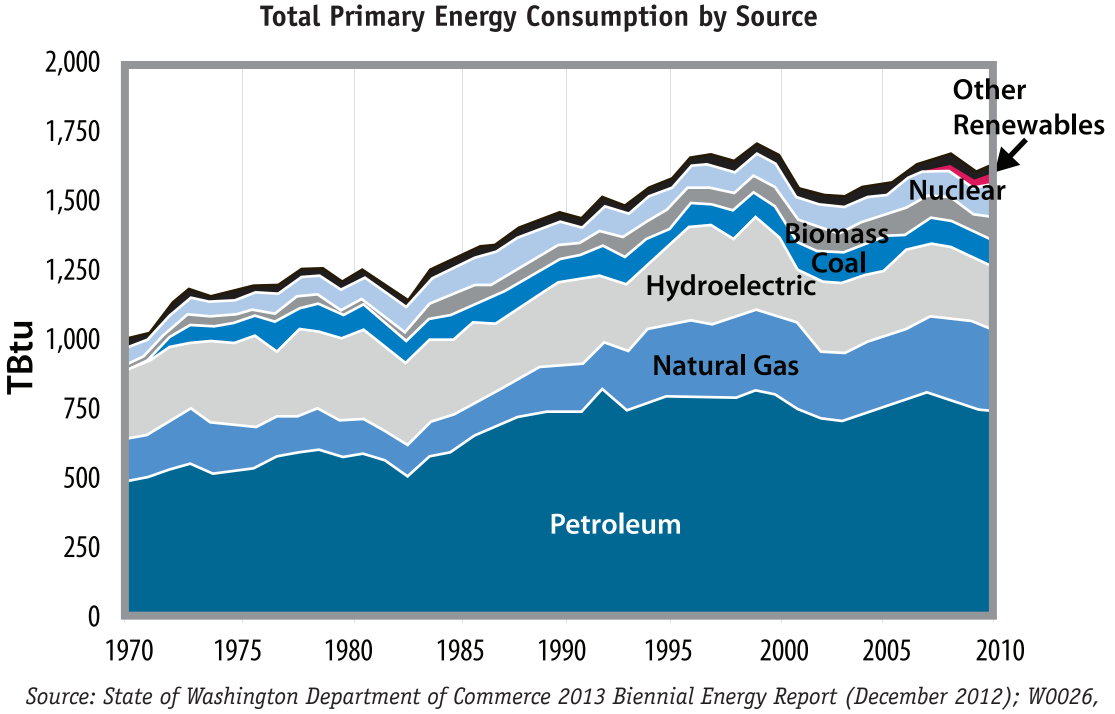
The outstanding panel here today touches on many of the different energy technologies in Washington state. A beginning point is the current look of energy in Washington and where it might be directing the state in the future.

Washington's abundant energy resources

In 2011, Washington was the nation's leading producer of electricity from hydroelectric sources, with 29 percent of the nation's net hydroelectric generation.

Although Washington is not a crude oil-producing state, it runs sixth in refining capacity. The state ranked sixth in generation of electricity from wind in 2011, and legislation is in place to obtain 15 percent of Washington's electricity from new renewable energy resources by 2020.

Figure 1. Petroleum, natural gas and hydro dominate as fuel source for Washington State



Source: State of Washington Department of Commerce 2013 Biennial Energy Report (December 2012); W0026, tab 2ch

Energy is a $20 billion industry in Washington. End users combined to spend that amount for residential, industrial, commercial, and transportation energy.

Hydro, energy costs, and carbon emissions

Hydropower dominates electricity end use in Washington, at over 73 percent, an achievement built on long-term investments over the past 60 years. While it is a stable source of electricity, it's also vulnerable to snow packs and climate change.

The largest growth in costs over the past 20 years has been the cost of petroleum. Energy prices in Washington are 4 to 17 percent higher than the national average.

The West is a leader in energy efficiency implementation. Yet Washington's carbon emissions have grown over the past 25 years, a trend to be examined in the context of greenhouse gas reduction limits over time.

Washington is in a unique position

The state has potential energy resources from water, wind, sunlight, natural gas, the nucleus of an atom, and the ocean. Washington is also going through a revolution in the grid system — how it's monitored, measured, and ultimately controlled.

"Electricity here, by far, has the lowest prices in the country."

Jud Virden

What does the state need going forward into the future? Low-cost energy and energy alternatives. Diversification beyond the hydro system, which is mainly tapped out. A robust energy infrastructure. That energy future needs to be defined within the context of 15 percent renewables by 2020, and all the cost-effective conservation that will be built into that.

The tools are in place, from research universities to the politicians, utilities, and industries. As Washington looks at environmentally acceptable energy choices, it's clear that the state is in a very good position.

Slides and a video for this talk are available at www.washacad.org.

Visions of the Future Northwest Electricity

Clean, Adequate, and Reliable

Howard Schwartz
Senior Energy Policy Analyst, Northwest Power and Conservation Council/Washington State Department of Commerce Energy Office

Synopsis

Governor Jay Inslee has asked for a 20-year plan that lays out a pathway to an electrical system that is 100 percent carbon-free, coal-free, and renewable. Is it possible to have a carbon-free electricity system in Washington?

The hard and soft energy paths

Almost 50 years ago, physicist and environmental scientist Amory Lovins described two energy paths for electricity. The hard path is a large industrial system based on the idea that electricity production and consumption would continue to increase rapidly. Electricity would come mainly from large-scale coal and nuclear plants. The soft path is based on drastically reduced consumption of electricity through huge improvements in energy efficiency and renewable energy. The result is smaller-scale distribution of loads and transmission. Both ideas are still alive. For the most part, the Northwest, and Washington especially, seem to have adopted an attempt to go down the soft energy path.

Washington's unique hydro base means most electricity is carbon-free

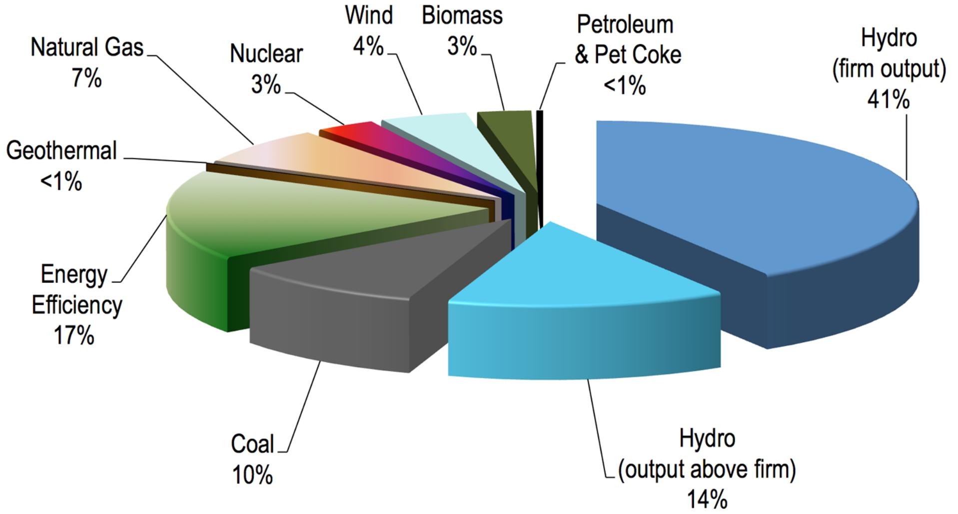
In the Northwest, there have been certain advantages that make it easier to be carbon-free. The large hydro base means the state already begins with most electricity already being generated by carbon-free technologies. In 2011, Washington was the leading producer of electricity from hydroelectric sources in the U.S. and thus the lowest carbon dioxide electricity system in the country. The state's carbon emissions are already very, very low.

"A clean and renewable energy electricity system is more possible in Washington and the Northwest than pretty much anywhere else."

Howard Schwartz

Figure 2. Northwest Power System: Energy Resources in an Average Hydro Year

Expected resource generation and efficiency savings based on simulated operation



Source: Northwest Power and Conservation Council

Over the last 50 years, though, Washington's generation mix has changed. It used to be all hydro, but gradually that was not enough to meet loads. Coal, nuclear and natural gas were added, and over the last few years, a lot of wind energy was as well. But the biggest amount of added resource has been through conservation measures — efficiencies both in homes (such as insulation) and hydro plants.

The Northwest Power and Conservation Council leads in conservation

The Council, the only regional power planning agency in the country, was created in 1980 as a compact among Washington, Oregon, Montana, and Idaho.

Each governor appoints two members. Its job is to develop a Northwest power plan, and a fish and wildlife program, and to provide for public outreach and accountability.

"The integration of renewable resources is a very effective way to meet the customer demand."

Howard Schwartz

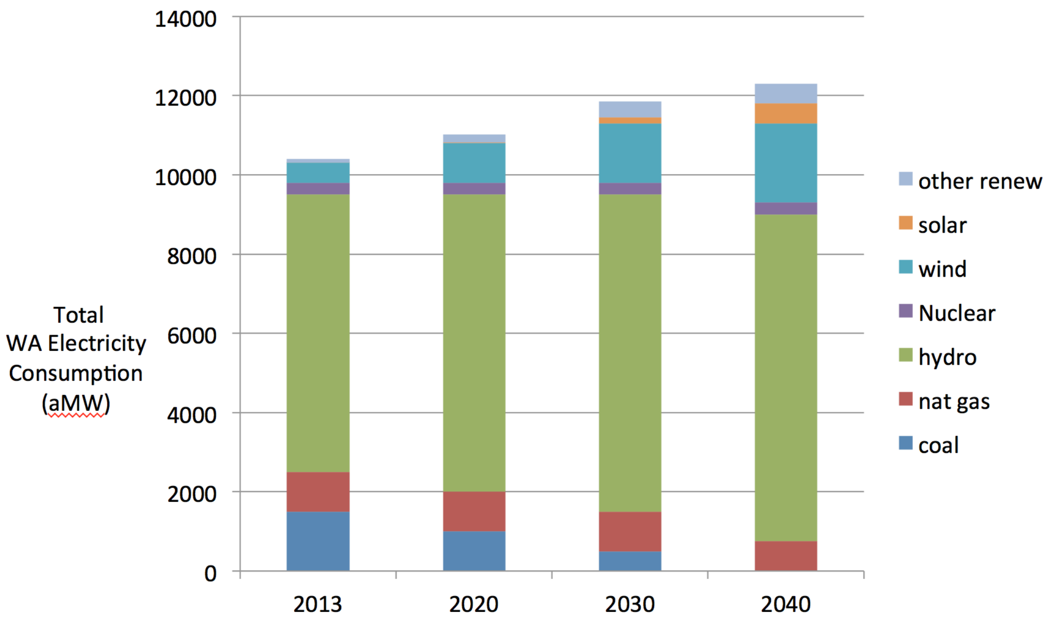
Each Power Plan has a 20-year horizon, updated every five years. It looks at electricity demand, price, and forecast, and identifies the least-cost, least-risk resources and technologies. The Sixth Northwest Power Plan was adopted in 2010. It anticipated that 85 percent of growth in demand would be met with conservation and the remainder from renewable energy.

Governor Inslee came to the Council on July 9th, 2013, and asked that the Seventh Northwest Power Plan, due in 2015, accelerate the transition from coal power by identifying the steepest reasonable date-certain path for an electrical system that is 100 percent carbon-free and renewable for the Northwest. The Council will examine whether this can be done in an adequate, reliable, economic, and efficient manner.

Is a carbon-free electricity system possible in Washington. Yes—IF

To forecast possible generation scenarios, the Western Electricity Coordinating Council, funded under a grant from the U.S. Department of Energy, developed four possible generation solutions in order to examine transmission planning options. One scenario that might fill Governor Inslee's request is Scenario 2: Low Carbon, Clean Energy, High Economic Growth.

Figure 3. A Speculative Path to a Carbon Free Washington Electricity System



Source: Howard Schwartz Extrapolations from WA Fuel Mix Reports, Dept. of Commerce

Scenario 2 involves a mix of resources based on a number of assumptions:

- A high carbon (policy-driven) cost that forces out coal and limits natural gas;
- Solar costs continue to fall rapidly;
- Wind costs continue to decline;
- Renewable integration issues (such as storage and Smart Grid) are solvable;
- Natural gas generation to fill gaps;
- More hydro is available in Washington;
- Load growth is small due to conservation and efficiency; and
- Adequate transmission is available.

None of these is unrealistic, and much is already underway

Smart Grid applications are already being deployed that will bring greater efficiencies. For example, transmission operations can be monitored by synchrophasors; meters can be automatically read, compiling time-of-day usage data; substations are more automated; distribution systems' outages detected; and remote-control of end-uses for demand-response is almost a reality.

In addition, many small improvements may add up to make a significant difference. For example, virtually every hydro project in the state has either replaced turbines, rewound generators or improved fish passage so they can spill less and generate more. There is some hydro potential in irrigation canals, new projects and improved technology. Bonneville Power Administration has been experimenting with a number of efficiency techniques for both increasing and reducing loads that are nearly ready for operation.

Will the Power Council be able to honor Governor Inslee's request? The large hydro base of Northwest electricity generation makes a carbon-free electricity system a possibility. Can the rest of Washington's resource mix be carbon-free and renewable? The answer is yes, if all the assumptions in Scenario 2 are realized, and if the costs are manageable, and if there is a sustained political commitment.

Slides and a video for this talk are available at www.washacad.org.

The Role of Hydropower in Serving Pacific Northwest Power Needs

Kieran Connolly
Regional Power Manager, Bonneville Power Administration

Synopsis

Because of hydropower, the Northwest has been a capacity-rich system for a long time. But since the 1990s, loads have grown and the system's operation has changed to meet biological obligations to help migrating salmon. Is there now enough peaking capacity, flexibility, and energy so that the system is not out of balance?

Hydropower offers sustained peaking capacity

When water comes rolling down the hill, it can't all be captured, but hydropower can generate as much electricity as possible. To keep residential lights on tomorrow, the system has to let go the water today at a certain place so that in 18 hours it's behind the next dam. Other regions, with their reliance on thermal (gas, coal, or nuclear) generation, look at single-hour peaking capacity, i.e., the maximum power system capability during the peak hour of demand. Bonneville's hydro system looks at sustained peaking capacity, the maximum average power system capability during a number of heavy load hours for one or more days. This looks at capacity over consecutive days during an extreme weather event, or meeting expected peaks loads over a month.

Flexibility provides the ability to meet loads

The question here is, how nimble is this system? If the net load becomes greater or less than an expected, can the system react? Can energy move up or down on very little notice? The electric system does not like to be out of balance. Too much energy on the grid, or not enough, can cause rolling blackouts and system collapse. One of the blessings of the hydro system is the ability to move in a hurry and unexpectedly, which has allowed the system to integrate new resources.

Still an energy-rich system

Because of the region's hydro resources, the system has remained energy-rich. New resources have come online, mainly wind, bringing a significant amount of additional energy. A majority of the wind in the Pacific Northwest has integrated into the Bonneville Power Administration system. This region has one of the highest penetrations of wind relative to load anywhere in the world.

Figure 4. Each Type of Resource Can Provide Unique Mix of Energy, Capacity and Flexibility

Resource Type	Provides Energy	Can be Dispatched	Provides Add'l Peaking Capacity	Provides Flexibility
Hydro	Yes	Yes	Yes	Yes
Coal	Yes	Yes	Not normally	Not normally
Natural Gas	Yes	Yes	Yes	Not normally
Nuclear	Yes	Yes	No	No
Wind	Yes	No	No	No
Solar	Yes	No	No	No
Storage (e.g., battery)	No	Yes	Yes	Yes
Energy Efficiency	Yes	No	No	No
Demand Response	No	Yes	Yes	Yes

"This whole dance of water"

Now the system is moving forward into a world of expectation of an ever-growing resource mix. The Northwest's hydropower comes from an interconnected system of dams, combined with a very large hydro system to the north — B.C. Hydro and the Peace River. With the addition of variable resources, there's this whole dance of water that has to go on in terms of planning, operation, and transmission systems. The flows need to be managed for flood control, meet required loads for fish, and have sufficient generation to always keep the lights on. How does this mix dance together? The better the dance, the more that can be accomplished.

Growing need for flexibility

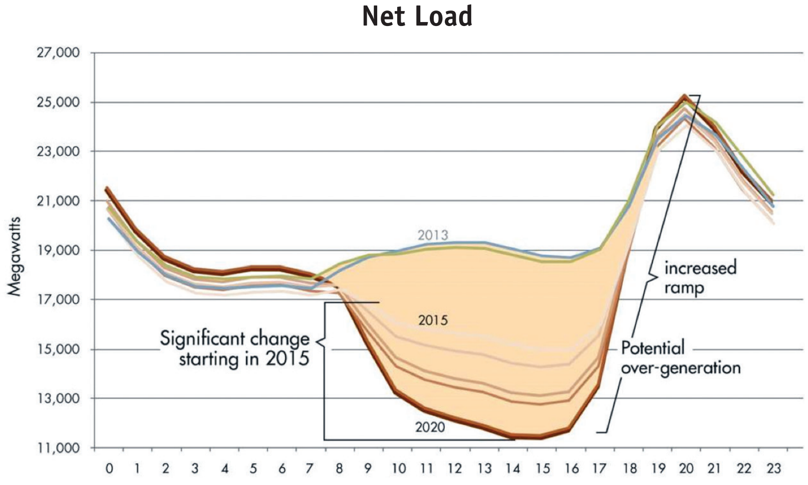
"As we see the change in electricity supply, we need to think about peaking capacity and flexibility."

Kieran Connolly

The typical load today looks like a one-hump camel. Industry and residential customers tend to use a lot of electricity in the morning and evening, and if it's summertime, in the middle of the day. The period of least use is at night, and for most of the year during the day. But when significant amounts of solar are brought into the picture, that occurs in the middle of the day, not coinciding with the standard electricity usage. The system is going to have to accommodate that, and these additions may be greatly accelerated in the future.

California in particular is looking at large gains in solar power, and as the saying goes, if California sneezes, the Northwest will catch a cold, so it's important to pay attention.

Figure 5. **Growing Need for Flexibility Starting 2015**



Source: Bonneville Power Administration; California Independent System Operator

Understanding climate change

What will climate change do to the loads and the volatile fuel supply? It's something to worry about. BPA has collaborated on a study with the University of Washington, taking global models and scaling them down to the Columbia River system. The results are inconclusive. It could be wetter, or it could be drier. Some expected results include higher winter flows and lower summer flows, with peak runoff shifting to earlier in the spring, and more winter precipitation falling as rain rather than snow.

Currently, except for September and October, Bonneville shows a surplus in terms of supply. However, projections for 2016 show a significant deficit, from 500 to 1,500 megawatts, in the majority of months. Excess power is now sold to other users, but in the future the system will have to seek other sources of supply to meet those loads.

While climate change adds more uncertainty to the picture, scientists and engineers are exploring ways to adapt. That new mix of resources, with all their positive attributes, needs to be built into a system capable of handling it all into the future.

Slides and a video for this talk are available at www.washacad.org.

Natural Gas: Realizing the Potential

Dan Kirschner
Executive Director, Northwest Gas Association

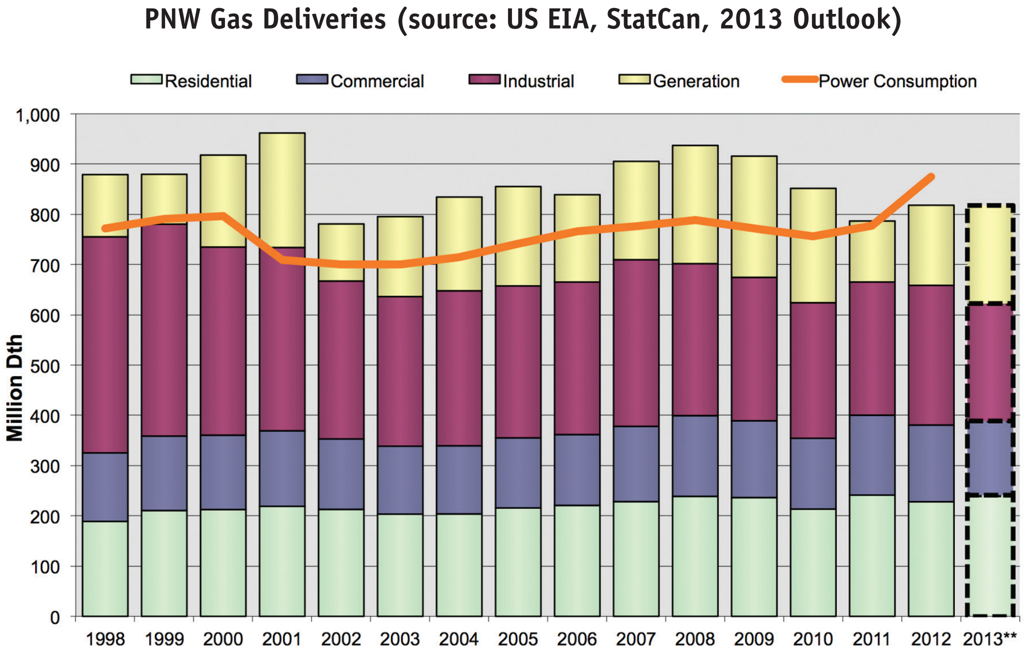
Synopsis

Shale gas has turned everything in the energy industry on its head. In the past six years, there have been tremendous technological advances in retrieving natural gas and oil from shale. New and improved applications of existing production technologies have moved natural gas from a resource that was scarce to one that is abundant. Like any industrial process, producing hydrocarbons from shale is not without risks, which are being examined by researchers and addressed by producers.

Natural gas use is residential, commercial, industrial, and for power generation

Six natural gas utilities in Idaho, Oregon, Washington, and British Columbia compose the Northwest Gas Association. Together, they serve 3.5 million customers — residential, commercial, industrial, and power generation. Today, the Northwest uses about as much energy via natural gas as through electricity.

Figure 6. Recent Gas Demand



*** 2012-2013 Forecast*
Source: Northwest Gas Association

Horizontal drilling combined with hydraulic fracturing opens up natural shale gas resources

Hydraulic fracturing has been around for 60 years, horizontal drilling for 50 years. The real breakthrough in the past six years is the combination of techniques and precision that were unknown before.

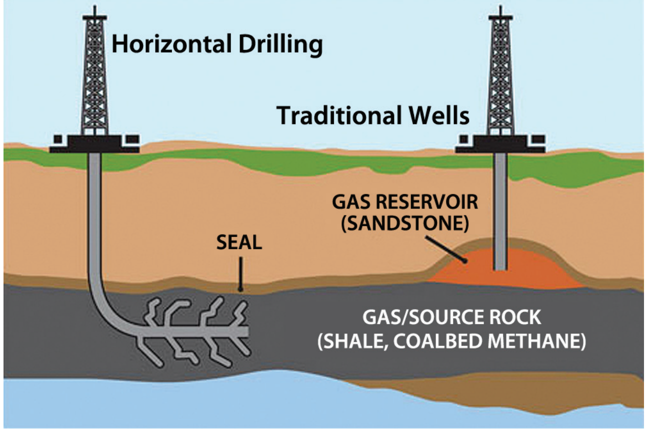
"The natural gas production from shale is remarkable and provides a lot of opportunities."

Dan Kirschner

Shale rock is 35- to 50-million-year-old mud from river or lake beds, swamps or coastal areas that contained lots of organic material, which has since decomposed into hydrocarbons. Conventional drilling involves accessing hydrocarbons by drilling vertically into a porous rock formation like sandstone and letting the hydrocarbons bubble up. Horizontal drilling goes deeper and continues laterally for some length, accessing the hydrocarbons at their source. With conventional drilling, one well pad can access a limited area, but horizontal drilling, with its length and 360-degree radius, opens up a very large production zone from one well pad.

After drilling, the second step is hydraulic fracturing. Water, sand, and a few chemicals are pumped through the well bore into the formation at very high pressures, creating fissures (fractures) in the shale. The sand holds the fissures open, allowing the hydrocarbons to move through otherwise impermeable rock.

Figure 7. Conventional vs. Horizontal Drilling



Source: Northwest Gas Association ; www.dteenergy.com.

Shale surges as source in North America's natural gas production

Natural gas has gone from scarcity to abundance. Overall production of natural gas in the U.S. increased almost 15 percent between 2001 and 2011, and more than 20 percent over the past five years. In 2001, almost no natural gas was being produced from shale formations. By 2011, 30 percent of the natural gas produced in the U.S. came from shale, and that share is expected to increase to 60 percent by 2035. In addition, shale production is much less susceptible to weather-related disruptions like hurricanes. For example, in 2005, one-fifth of U.S. natural gas production came from the Gulf of Mexico, and 98 percent of that production was shut down because of hurricanes Katrina and Rita. In 2011, the Gulf accounted for about 6 percent of all U.S. natural gas production.

Four primary concerns with fracking: Water. Water. Water. Air.

1. Drinking water. Hydraulic fracturing bores down 8,000 feet or more before proceeding horizontally. Private and municipal wells are drilled to less than 1,000 feet. The well bore is encased in cement, so drinking water is isolated. Chemicals and lubricants that are used are listed in a public registry available at FracFocus.org. More than a million wells have been drilled using fracking, with few very instances of contamination of drinking water.

2. Water consumption. Three to five million gallons of water per frack sounds like a lot of water, and it is. But put in the context of other uses, it typically makes up less than one percent of all water use in a producing region.

3. Water recycling. Water used in and produced by fracking is brackish. It is often recycled and reused in the production process. When no longer useful, the water must be disposed of through treatment, by evaporation from surface ponds, or injected deep underground. These disposal processes are regulated by the Safe Drinking Water Act and the Clean Water Act.

4. Air emissions. Surface activity involves diesel trucks and drilling rigs. There are questions about whether any hydrocarbons are released into the air during the production process, through pipelines and processing stations, or through distribution systems. Because the technology is so new, there are not field data to document air emissions. Research projects are in the early stages, including one led by Washington State University to estimate emissions from distribution systems.

5. Earthquake hazard. Recently confirmed reports indicate that disposal wells may trigger tremors induced by large seismic events elsewhere, a new concern that is being researched.

> *"The increase in shale has been dramatic. From zero percent of U.S. natural gas production in 2001 to an anticipated 60 percent by 2035."*
>
> Dan Kirschner

The economies of natural gas

Natural gas is the most economic option for generating electricity, and it's the most viable option for backing up hydropower and renewables. Compared to oil, natural gas is currently one-sixth the cost, which creates opportunities for transportation, most notably for long haul trucks and as a marine fuel. Natural gas is used as a feedstock fuel in manufacturing for a range of products from frozen French fries to safety-glass laminates. It's estimated that lowered feedstock costs could result in savings of $11 billion by 2025, with a million additional manufacturing jobs created.

While natural gas could be liquefied into LNG, shipped, and sold overseas, the profit is small, and there is a highly competitive global market. Policy makers and others are encouraged to focus on how to use this North American resource in North America.

Slides and a video for this talk are available at www.washacad.org.

The Role of Washington State in Developing Advanced Nuclear Energy Options

Alan E. Waltar
Past President, American Nuclear Society

Synopsis

After Washington's "whoops"* debacle, and more recently the meltdown of Japan's Fukushima reactor, this might not seem like the best time to talk about building nuclear plants. On the other hand, nuclear plants are in use and under construction around the globe, and Washington has a lot to offer in expertise and innovation.

The global nuclear scene is growing; in the U.S., it's declining

Nuclear power is experiencing a renaissance around the world. China is building 29 plants. India has 17 with six more under construction. The United Kingdom and Sweden are turning back to nuclear, Finland is building a new plant, and Russia is planning to double its nuclear capacity by 2020.

"Some of the newest nuclear reactor technology holds great potential for Washington state."

Alan E. Waltar

The U.S. began with nuclear power in 1955 and currently has about 100 plants, but some are beginning to close. We have lost capability, key professionals have retired while few are coming into the industry, and construction costs are high. The Northwest has one nuclear plant, located at Hanford, Washington.

Current energy options aren't enough. It's time to think about something else.

The state has vast amounts of hydro, but with anticipated substantial increases in electricity demand, hydro is pretty much tapped out. Coal is being phased out and natural gas is a concern for climate change. Can renewables like wind and solar solve all electrical growth challenges? Absolutely not. The latest nuclear technologies have much to offer.

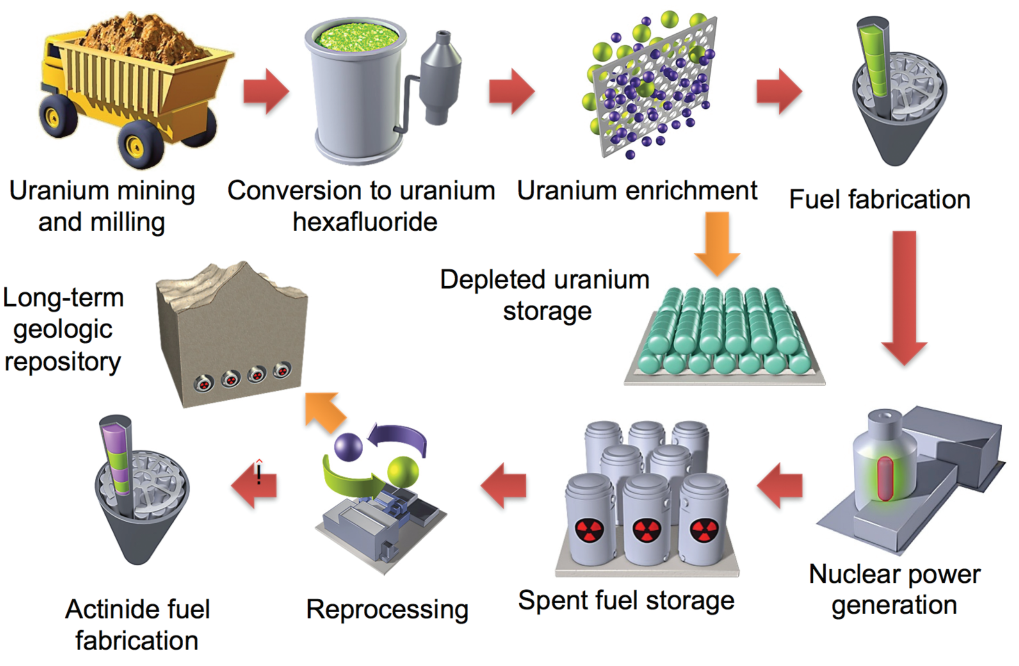
One thing to consider is the cost of electricity to consumers. In Washington, consumers pay 3 cents a kilowatt hour. In Germany, where renewables have been championed for over a decade, the average cost is now 32 cents a kilowatt hour. Even in Finland, where its $15 billion nuclear plant is the most expensive ever built, the cost of electricity is still only 7 cents a kilowatt hour.

The Traveling Wave Reactor makes fuel from depleted uranium

About 95 percent of the material contained in the assemblies discharged from a nuclear reactor still contains useful fuel. The TWR is a new class of nuclear reactor, developed from a concept that's been around since the 1950s. It takes what has been called waste and turns it into energy. The current nuclear fuel cycle is complex, and the TWR simplifies it considerably. The TWR can operate for an extended period of time using only depleted uranium. Washington state's TerraPower, with Bill Gates as chairman, is moving into the arena with its Traveling Wave Reactor Generation IV.

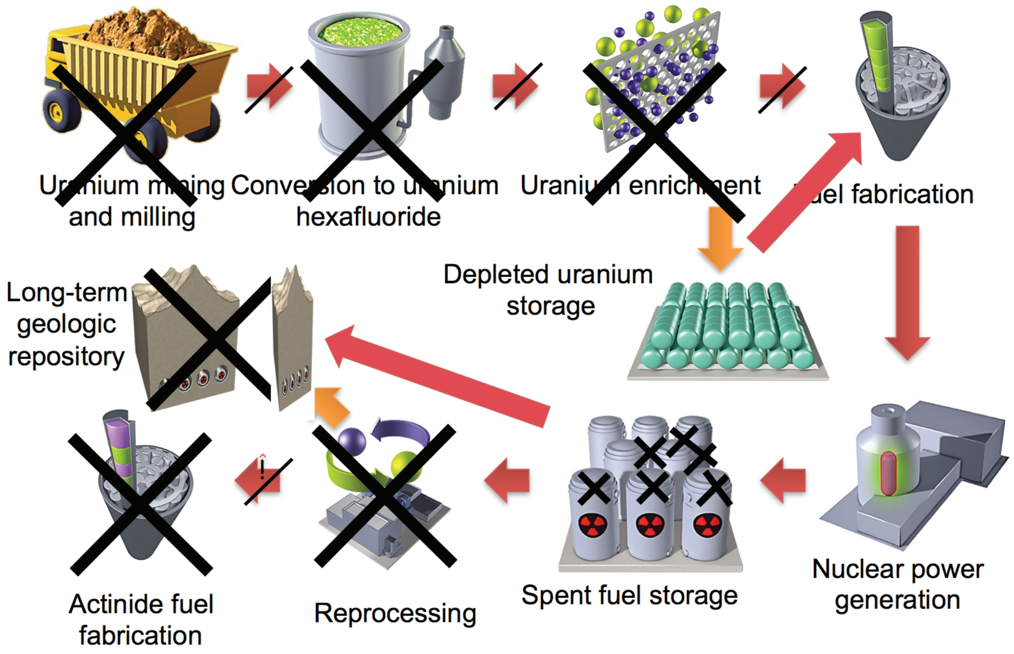
However, the technology has some key challenges. It requires very high burnups, so that the fuel in the reactor has to operate for long time. It's cooled with sodium instead of water. Sophisticated fuel shuffling is required, and to support breeding, the reactor has to be physically large.

Figure 8a. Current Nuclear Fuel Cycle TWR Simplified Fuel Cycle



Source: Doug Adkisson, TerraPower Corp.

Figure 8b. **TWR Simplified Fuel Cycle**

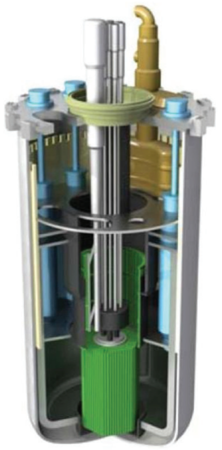


Source: Doug Adkisson, TerraPower Corp.

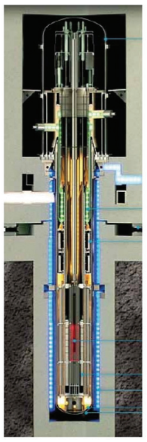
Interest in Small Modular Reactors — because they're small

There is a burgeoning interest in SMRs, and Washington state has the potential to take a leadership role. Over a billion people — one-third of the world's population — have never seen a light bulb. As global energy demand increases, SMRs have a lot of appeal: a much smaller plant; smaller upfront costs; reduced capital costs; shorter construction time; considerably safer; lower water use; and able to be developed incrementally. In places where there is not the electrical infrastructure to handle large nuclear reactors, SMRs can play an important role. Around the world, different designs are being explored, cooled by water, gas, or liquid metal.

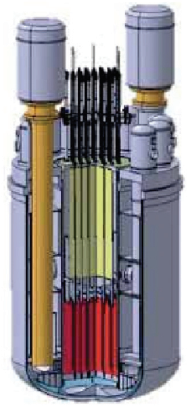
Figure 9. **Fast Spectrum Reactor Designs (Liquid Metal Cooled)**
Able to provide improved fuel cycles



PRISM (General Electric)
300 MWe



4S (Toshiba, Japan)
10 MWe



SVBR-100 (AKME Engineering, Russian Federation)
300 MWe

In the U.S., many of the coal-powered plants are more than 50 years old. SMRs' grid stability is a close match to these traditional power sources. The federal Department of Energy is interested in the small reactor program and would like a fleet of these in the U.S.

"Hanford is an ideal location for a demonstration Small Modular Reactor."

Alan E. Waltar

SMRs face economic and licensing challenges. There are economies of scale that potentially inhibit smaller plants, and it's unclear whether this modular approach can warrant the necessary upfront investment. The United States Nuclear Regulatory Commission is considered the gold standard globally, but that scrutiny makes it extremely difficult to get licensed, which in turn makes it difficult to find a buyer.

Hanford has an NRC-approved site the right size for a 100-megawatt SMR. Existing infrastructure means a savings of about $50 million. There's a qualified work force, and support from the Senate, the House, and Governor Inslee.

Washington state could be a leader in the renaissance of nuclear power

The interest in nuclear power, and specifically Small Modular Reactors, is growing rapidly throughout the world. If the U.S. intends to remain a leader in nuclear power, the nation needs to become aggressive in developing and constructing SMRs. Washington has the innovation, the brain power, and the potential to site a demonstration plant at Hanford, and to play a major role in shaping the national and international nuclear enterprise.

Slides and a video for this talk are available at www.washacad.org.

* "Whoops" is named for "WPPSS." The Washington Public Power Supply System over-committed to nuclear power and defaulted on $2.25 billion in bonds for its cancelled projects, the largest municipal bond default in U.S. history.

Opportunities and Challenges: Sustainable Ocean Energy Development in Washington

Charles A. Brandt
Director, Marine Sciences Laboratory, Pacific Northwest National Laboratory

Synopsis

Ocean waves, tides, and currents are better behaved than other renewable energy resources. They're consistent and predictable. It's estimated that offshore winds alone can produce over four times the entire U.S. generating capacity. Yet how much electricity is Washington state now producing from the ocean? None. Why is that, and what does the future look like?

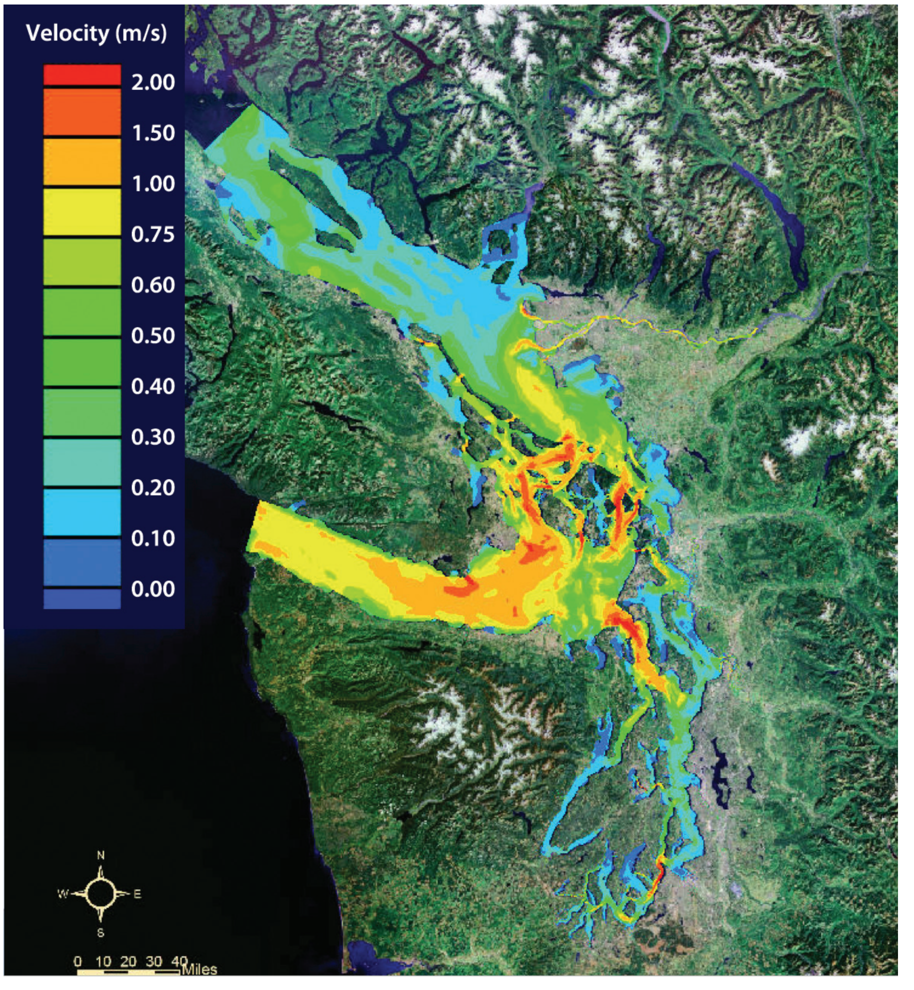
The ocean provides vast energy opportunities

The ocean is a large renewable energy source, where potential greatly exceeds demand. Tides and currents are constant, not dependent on the sun or the day's weather. California, Oregon, and Washington produce a combined 376 terrawatt hours annually. Total recoverable energy from ocean waves alone could provide 250 terrawatt hours per year. The ocean is near the customer base. The U.S. is a coastal nation, with 52 percent of the population living in coastal counties. Twenty-eight coastal counties consume 78 percent of the nation's electricity, which simplifies transmission. Ancillary benefits include solving transmission limitations across the Cascades, and between Washington and California during summer congestion.

"Offshore winds can produce over four times the entire U.S. electrical generating capacity."

Charles A. Brandt

Figure 10. **Tidal Power**



Georgia Tech (2011) Assessment of Energy Production Potential from Tidal Streams in the United States; PNNL (2007) Development of Hydrodynamic Model of Puget Sound and Northwest Straits

Wave Energy

Ocean waves contain tremendous recoverable energy potential. Consistent and predictable, wave energy is especially effective for remote coastal communities. Products to capture wave energy mainly sit on the surface of the water. Although most are from Europe, the U.S. has several technologies, including Ocean Power Technologies, and one in development by Oregon State University that has no surface expression.

Tidal Power

Within the Salish Sea (Puget Sound, Georgia Basin and Strait, and the Strait of Juan de Fuca), the tide moves 24 hours a day. Unlike solar power, it doesn't matter whether or not the sun is shining; it's 100 percent predictable. In this model the Northwest National Laboratory developed of the Salish Sea, everything in green is commercially viable tidal power.

Figure 11. Ocean Renewable Energy Resources

Tidal Power
Clean Current™

Offshore Wind Energy
Principle Power™, Seattle, WA.

Wave Energy
Wave Dragon™, Denmark

It's estimated that this area alone has the potential to produce two gigawatts of power, or six percent of the current generating capacity in the whole state of Washington. As with wave energy, there are a number of commercial products already available.

Offshore winds

In addition to the potential to provide four times the U.S. energy-generating capacity, offshore there are fewer competing uses, and fewer bats and birds. It's a large resource, and a number of technologies are currently available, but mainly for shallow water, less than 30 meters (98 feet).

What's holding ocean energy back?

Deep water presents new and unaddressed problems that hinder investment. At 60 meters (196 feet), what's needed are floating platforms. The latest technology prototypes are 15 megawatt turbines that sweep a 220 meter (721 feet) diameter, over twice the wingspan of the largest jumbo jet. It is an enormous mass that will need to be manufactured in a port and shipped out to sea.

The maritime system is not ready. Specialized vessels and ports will be needed. There is no state or federal experience permitting these technologies, so there's no established information base to enable approval by regulatory agencies. That, coupled with their high cost, hinders investment.

"There is no state or federal regulatory experience in permitting these and the maritime system is not ready."

Charles A. Brandt

There's also a lack of data for wind speeds more than a few hundred meters off the coast. Estimated energy resources are based entirely on extrapolated data, which may be correct but not sufficient to convince an investment banker.

Most of the technology is European-derived, so one might assume they have a great deal of data. However, it remains proprietary to the companies and is not shared.

Additional research is needed to resolve uncertainties like the interaction between whales and devices spinning beneath the surface, mooring cables and other devices, as well as effects electromagnetic fields might have on marine animals. Current research includes wind data collection via LIDAR buoys. The Department of Energy is creating a research facility in Chesapeake Bay to study wind characterization technologies and has established an ocean energy database that links to projects and research literature from around the world.

Snohomish PUD and Coos Bay projects are in the works

Snohomish Public Utility District in Admiralty Inlet is on schedule to deploy a pilot-scale tidal power turbine operation within the next couple of years. Coos Bay, Oregon, is working on development for a 30-megawatt facility that will initially have five 6-megawatt wind-power turbines designed and manufactured by Principle Power of Seattle.

Ocean energy: Washington-produced power, Washington-produced capability

Despite the many challenges, ocean energy provides a great deal of opportunities for the state of Washington. The region has the potential to produce power for energy customers in Washington and the western U.S. On a global scale, Washington's talent and capabilities can generate Washington-produced technology for the state and global energy production.

Slides and a video for this talk are available at www.washacad.org.

Modernized Grid for a Clean Energy Future

Carl H. Imhoff
Manager, Electric Infrastructure Research, Pacific Northwest National Laboratory's Energy and Environment Directorate

Synopsis

For almost 100 years, power engineers have been dedicated to these principles: Keep it affordable, keep it reliable, keep it safe. In the past, they accomplished this, maintaining the electric grid network, without the ability to see the power system in real time. Electrical systems have become increasingly complex with the inclusion of renewables and their variability. Now there is a revolution of the grid and how it operates, all the way from the home system to large generators and bulk transmission.

Advanced grid modeling is a game-changer

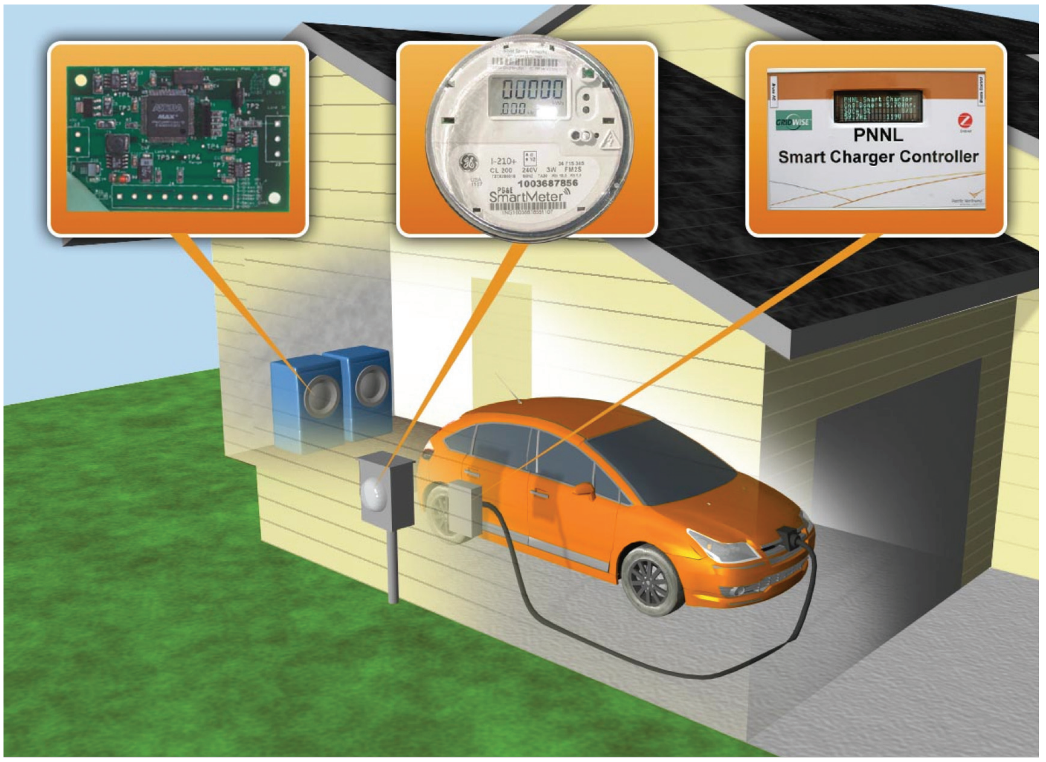
Very few consumers know what goes on behind the wall plug. It's really a very complex system. Some people have heard about smart meters, but the Smart Grid goes way beyond that. Communications is becoming essential to power systems today. Smart Grid technologies produce much more real time transparency in terms of the load. High-performance computing is revolutionizing grid operations and planning. It incorporates new business models and methods to accommodate the uncertainty of renewables.

"With Smart Grid technologies, high-performance computing is revolutionizing grid operations and planning."

Carl H. Imhoff

One example is the synchrophasor. The Northwest has played a leadership role in the development of this high-resolution monitoring device. Basically, it measures voltage and phasing 30 to 60 times a second. It helps monitor the health of the electrical system in real time, improving reliability and mitigation for outages. Through the North American SynchroPhasor Initiative, more than a thousand of these devices will be operational in 2014, which will dramatically transform how to see and monitor electrical systems in real time. The synchrophasor provides more than 200 times more data, more than 200 times faster, and with greater accuracy.

Figure 12. **Smart Meters, 2-way Communications Offers New Opportunities with Greater Complexity**



Washington and the national clean energy agenda

In the U.S. today, there are more than 3,500 operating utilities, ranging from small co-ops to large municipal utilities. They are divided into four electrical "machines," or areas, which cover vast regions. Within the machines is a very complex collage of reliability management, asset ownership, state and local regulations, environmental concerns, and more.

Overarching all those utilities is the federal Clean Energy policy from the current administration. It sets a goal of 80 percent clean electricity by 2035 coming from renewable, nuclear, clean coal, and natural gas. Further, it outlines a 20 percent improvement in building efficiency by 2020 and an 83 percent reduction in greenhouse gases by 2050.

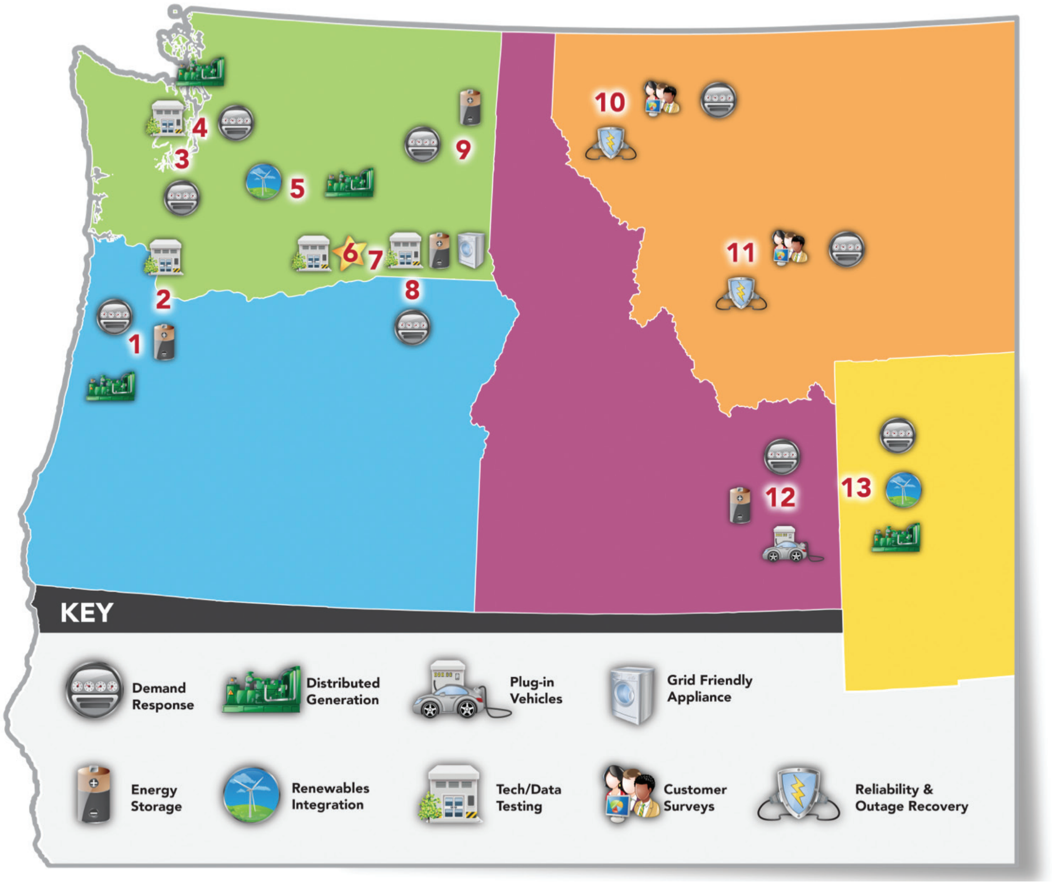
Washington is the quiet clean energy champion in the U.S. The state already has a very low carbon footprint due to hydropower and has done a good job of integrating a high penetration of wind energy. However, the hydro system is over-subscribed. If the next 20 years bring more rain and less snow, the tapped-out storage system will require other alternatives.

The Smart Grid supports the clean energy agenda

Today the power system is being asked to do new things, such as to deliver renewable energy and integrate grid storage and flexibility into the power system.

It brings an entirely new dimension of complexity than the system of the past. In Washington, the biggest lever for reducing carbon emissions is to further electrify transportation.

Figure 13. **Pacific Northwest SC Demonstration Project**



The Pacific Northwest Smart Grid demo helps to explore new methods and technologies for integrating renewables. Pacific Northwest National Laboratory recently hosted the largest Smart Grid demonstration in the nation. Eleven utilities took part, along with vendors and universities. The $178 million, five-year project studied 60,000 metered customers in five states to look for ways to quantify costs and benefits, develop standards and communications protocol, and facilitate the integration of wind and other renewables. The Smart Grid was tested at a wide scale and included innovations such as energy storage, plug-in vehicles, grid-friendly appliances, and outage recovery.

The Pacific Northwest's clean energy expertise is a basis for opportunity

The Northwest Power Planning Council's plan in 1980 began a legacy of energy efficiency that is second to none. The Northwest has expanded on its long history in energy efficiency with renewable power, and remains in the forefront of several decades of innovation in power systems and new technologies.

Washington has progressed with statewide leadership through senators and modernization legislation. With its excellent universities, laboratories, and world-class vendors, the state has a superb foundation of expertise, capacity, and intellectual horsepower. Washington has the opportunity to extract more value from those resources, and many assets to leverage. It's an exciting time.

Slides and a video for this talk are available at www.washacad.org.

"The bottom line is that there are a lot of opportunities to extract more value out of Washington's expertise, capacity, and intellectual horsepower."

Carl H. Imhoff

After-dinner address

Distributed Control, Protection, and Automation of Modern Electric Power Systems

Edmund O. Schweitzer III
President, Schweitzer Engineering Laboratories, Inc.

Synopsis

This industry delivers energy at the speed of light. Electricity is a fantastic commodity. It's safe, reliable, versatile, economical, and gets cleaner every day. In the Seattle area, people pay 3 cents a kilowatt hour; nationally the average is about 12 cents. Society in general has become entirely dependent on electric power. What is the future for the control and protection of modern electric power systems?

An unstable system made "twitchier"

Electricity is hard to store. Batteries are expensive, and once they give out, it's over. Legacy power systems like hydro, coal, and nuclear had a lot of margin. Today, because of the variability of renewables, there is less margin. Currently, control for the power system is centralized in control centers, with control by operators, with rather slow data gathering.

Despite an increasing dependence on electricity, today there is a lot less control over many of the desired energy sources, like wind and solar. Newer, faster, more robust ways, like feedback control, are needed to control the power system.

"We need to look for newer, faster, more robust ways, like feedback control, to control the power system."

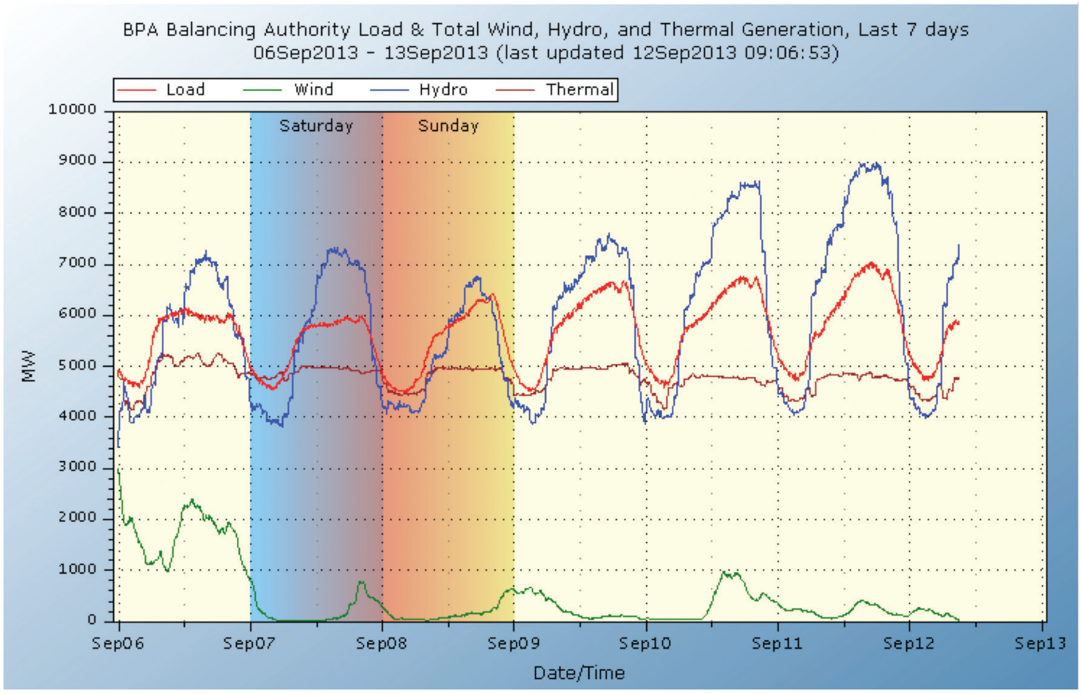
Edmund O. Schweitzer III

The system is inherently unstable to begin with, and now the system is becoming what might be called "twitchier." Instead of a traditional generation like hydro, in a central spot with a big rotating mass, now there's energy stored in photovoltaic cells and wind farms in a multitude of places, resulting in capacitors where less energy is stored. This lower net storage means faster power swings.

System automation for area-wide control

How can the system utilize this trajectory instead of just react to it? This graph shows how wind can drop from a little over 3,000 megawatts to zero in a very short time. Because dams can modulate the flow of the rivers, hydro can be used to fill in when the wind slows or stops. It's possible to have a penetration of 100 percent of energy from intermittent sources, as long as for every megawatt of a source like wind there is a megawatt from a traditional source.

Figure 14: 2013 Hydro Picks Up When Wind Stops



The kinds of loads that exist today, with such things as electric power chargers and data centers, are really "stiff" loads that make the system more brittle and increase the risk of voltage collapse. When they can't deliver as much energy as customers want, the result is what's called a brownout.

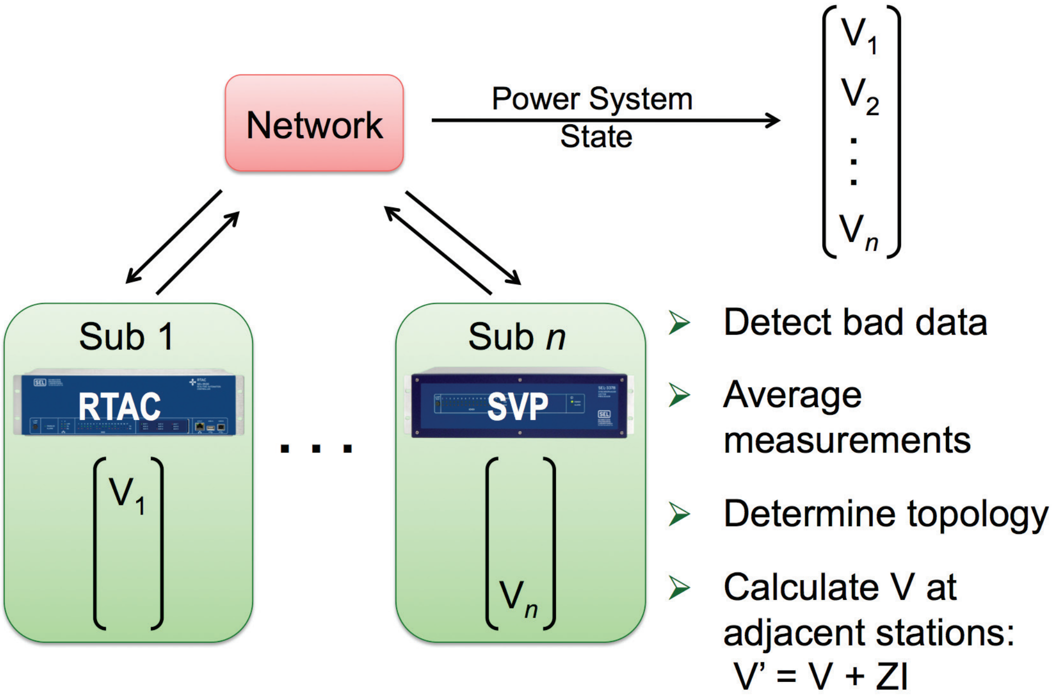
The system needs to be automated for wide-area control. The aim is to create models and analyze the contingencies for various operating conditions, and then build systems to respond to those contingencies in ways that are based on the operating conditions at that moment. However, the problem with predicting contingencies is that with something like a 49-line system and looking at K outages, the result can be 120,000 contingencies to plan for. In addition, it's hard, and getting harder, to even know all the contingencies and operating conditions.

The system needs to be better than this. The systems need to be operated, controlled, and protected better. Automation control must be distributed. With distribution feeders as buses, automation would offer a looped feed and pilot protection, with virtually no loss of service. It would accept all types of generation anywhere, and match the load to the source.

Direct State Measurement moves the system to a more predictable state

Ultimately, there will be a move to more and more closed-loop systems. Instead of predicting contingencies, closed-loop systems will directly measure the state of the power system, predict the evolution, and take anticipatory control actions.

Figure 15. Directly Measure the State



The state of the power system is a vector of the complex voltages at every node, measured at the same time. The state can be estimated either by using a state estimator or directly measuring the state with synchrophasors.

With direct state measurement, the state is directly measured in each region and shared. When an asset is lost, control action begins to take place — the system starts to move from its present state to a predictable new one.

A distributed control system integrates protection through operations in two ways. Under normal conditions, it guides the system to the maximally efficient operating point. In case of an event, it drives the system to equilibrium along the minimum cost path.

Moving forward with distributed automation

Changes in loads, sources, and expectations mean that the systems may require automated controls. General solutions are too complicated for remedial action schemes. With automation, feedback control will be simpler, better, more reliable, and a lot more robust. The theories and tools exist to do this today.

"The idea is to predict and respond before instability."

Edmund O. Schweitzer III

Distributed automation is going to be the future for electric power: moving energy at the speed of light from all kinds of sources — whether a wind turbine farm, a fuel cell in the basement, or voltaic shingles on the roof — or something that no one has thought of yet.

Slides for this talk are available at www.washacad.org.

K-12 Special Guests

American Junior Academy of Sciences Award Winners

The Washington Academy of Sciences has selected three high school science students who will travel with a mentor to represent Washington at the 2014 annual American Junior Academy of Sciences convention in Chicago, Illinois. This is the third year for the WSAS award program and sponsorship, made possible by member-donated funds. The students are chosen based on academic record, with a strong scientific merit and a strong interest in science or engineering and research. Parents and teachers were also present to witness their students receiving WSAS certificates and awards. Jim Krueger, WSAS K-12 Committee member, presented the awards and noted, “It was tough to choose because all the projects were absolutely fantastic.” He encouraged attendees to read the project presentation boards. “I think you’ll be impressed with the quality of science of these students.”

AJAS winners, Alisha Saxena, Meghal Sheth, and Thorsen Michael Wehr with WSAS President Subhash Singhal and Past President, Guy Palmer

Alisha Saxena commented, “It’s an amazing opportunity. When I was little, I played with circuit kits for fun. In the fifth grade, I learned programming and made a website. I started a non-profit called TakeKnowledge to encourage more girls to program. I also started an initiative in Africa to teach girls programming, and just won a $2,500 grant to improve and expand my program.”

"I'm grateful and really excited," noted Meghal Sheth. "This is one of my first research projects, and I'm looking forward to making connections with scientists who have been doing their research for 30 or 40 years. In March, I took third place overall in the Washington State Science and Engineering Fair. My grandfather is a doctor in India, and my career goal is to be a surgeon."

Thorsen Michael Weir commented, "It's a huge honor. I've been doing science fairs since I was in the seventh grade, when I generated electricity with magnets. I've been working on projects since then. I'm not sure where I'll go to college but will definitely study computers and physics."

AJAS finalists

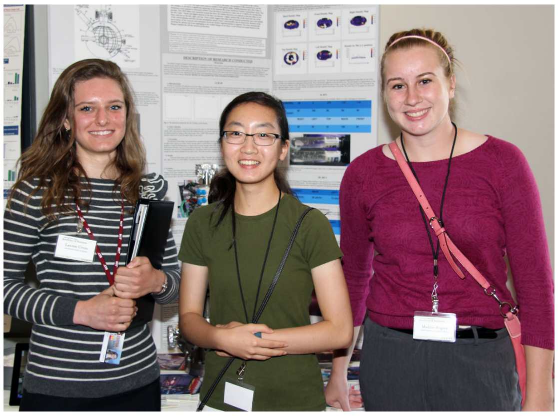
Quinn Brown, Isabelle Crary, Isaac Harper, Jacqueline Nguyen, Shruti Parikh, Sophie Shoemaker, Swetha Shutthanandan, Meera Srinivasan

Program sponsors

The Boeing Company, The Paul G. Allen Family Foundation, Pacific Northwest National Laboratory, and Schweitzer Engineering Laboratories.

Pictured left to right: Isaac Harper, Shruti Parikh, and Jacqueline Nguyen

Students with the Northwest Nuclear Consortium



Pictured left to right: Lauren Crom, Julia Kim, and Maddie Rogers

The Northwest Nuclear Consortium is the only nuclear engineering curriculum for public high school students in the U.S. with a working fusion reactor. The private program for high school students operates both as a school and a nuclear laboratory. Julia Kim, Lauren Crom, and Maddie Rogers represented the Consortium at the WSAS Symposium. Mentored by industry professionals, students participate in reactor/accelerator operations, conduct research, and pursue publication of their own white papers. NWNC research teams won the Gold Award at the WSU Imagine Tomorrow Science Fair (2012) and placed second in the world at Intel Science and Engineering Fair (2013).

Lauren Crom said, "I'm interested in astrophysics and engineering, so this is an ideal gateway for me to get my hands dirty with some exclusive science research." Maddie Rogers added, "I'm learning a lot about the scientific process. It's so much more like real life than the controlled experiments you get in a high school classroom." Julia Kim summarized, "We really want to advocate for nuclear energy. We want to tell the public that it's a viable resource with people actively working on it, and that the younger generation has potential and we should be more prepared."

Learn more at http://www.nwnc.us.com.

Students receive an educational tour of the Museum of Flight

WSAS Members readily engage in discussions with the young scientists regarding their research and presentations

Speaker bios

Dr. Charles A. Brandt is Director of the Marine Sciences Laboratory within Pacific Northwest National Laboratory. His division's work focuses on sustainable ocean energy, understanding and mitigating effects of population growth and climate change on coastal systems, and coastal security. Prior to his current position, he managed PNNL's business portfolio in environmental sustainability, served as a technical group manager, and was a senior staff scientist. Dr. Brandt is an evolutionary ecologist conducting research primarily in the area of contaminant transport and effects in aquatic and terrestrial biota. He serves as a peer reviewer for several international journals in the areas of mammalian field studies, oil and gas industry effects on the environment, and ecological risk assessment. Dr. Brandt is also an adjunct professor in the Zoology Department at Washington State University.

Kieran Connolly has been with the Bonneville Power Administration for over 20 years in various capacities, including logistics, finance, power marketing, and power operations. He has been heavily involved in the design and implementation of power products to support reliable system operations, including the California ISO design, wind integration services for the BPA Balancing Authority, and evaluation of Northwest regional transmission organizations. He has managed BPA's Generation Scheduling organization from 2007-2013. This organization handles the short term system planning and operation of the Federal Columbia River Power System in cooperation with the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation. Connolly's education includes a Bachelor of Science in Business Economics from Willamette University, graduate work at the University of Notre Dame, and an MBA from the University of Portland.

Carl H. Imhoff is the Manager of Electricity Infrastructure Research for Pacific Northwest National Laboratory's Energy and Environment Directorate. He is responsible for research and development programs on innovations in advanced power transmission reliability concepts, demand response, development of improved integration concepts for renewable energy generation technologies, policy and strategy for Smart Grid concepts, and cross-cutting grid analytic tools in visualization and high performance computing. During his 30 years at PNNL, Imhoff has conducted and managed a broad range of energy research. He has been actively involved in the North American SynchroPhasor Initiative, the GridWise Alliance, the Consortium for Electric Reliability Technology Solutions, and the Western Electricity Coordinating Council. He is a member of the Institute of Electrical and Electronics Engineers, and currently serves on the Consumer Advisory Council of the New York Independent System Operator.

Dan Kirschner has been the Executive Director of the Northwest Gas Association since 2002. An expert on natural gas matters in the Pacific Northwest, Kirschner works to foster understanding among opinion leaders and informed decision-making by governing officials on issues related to natural gas in the region. Kirschner adds an MBA to his policy and public affairs experience, giving him a unique perspective on the intersection of public policy and business imperatives. His duties with the NWGA include formulating and disseminating market intelligence, policy analysis on issues affecting the Northwest regional natural gas market, and communicating the industry's perspective on a variety of issues to an array of stakeholders.

Dr. Howard Schwartz is Senior Energy Policy Analyst for the Washington members of the Northwest Power and Conservation Council and for the Washington State Department of Commerce Energy Office. He has worked in executive, policy, and academic positions in the Northwest for over 30 years. Most recently, he has been engaged with the Sixth Northwest Power Plan, the Western Renewable Energy Zone project, the Western Climate Initiative, and implementation of the Washington Renewable Portfolio Standard. He is the Governor's representative to WECC/WGA transmission planning committees. Dr. Schwartz is also an Adjunct Professor at The Evergreen State College in Olympia and previously taught at the University of Montana. He has held a number of management positions at the Washington State Energy Office and served as administrator of Missoula County, Montana. He has a Ph.D. in Political Science from Stanford University.

Dr. Edmund O. Schweitzer III, is President of Schweitzer Engineering Laboratories, Inc. He founded SEL in 1982; it serves the electric power industry worldwide to protect feeders, motors, transformers, capacitor banks, transmission lines, and other power apparatus. He holds more than 35 patents pertaining to electric power system protection, metering, monitoring, and control. A member of the National Academy of Engineering, a Fellow of IEEE, and a founding member of the Washington State Academy of Sciences, he received IEEE's highest award, the Medal in Power Engineering, in 2012. He served on the faculties of Ohio University and Washington State University, and was awarded honorary doctorates from Mexico's the Universidad Autónoma de Nuevo León and the Universidad Autónoma de San Luis Potosí. He received Bachelor's and Master's degrees in electrical engineering from Purdue University, and a Ph.D. from Washington State University.

Dr. Jud Virden is Associate Laboratory Director for the Pacific Northwest National Laboratory's Energy and Environment Directorate. The EED staff delivers science and technology solutions in energy efficiency, nuclear energy, carbon reduction technologies, biomass conversion, energy storage, and real-time grid operations. Dr. Virden holds bachelor's and doctorate degrees in Chemical Engineering, both from the University of Washington. Dr. Virden sits on the Board of the American Council for an Energy Efficient Economy, Washington Clean Tech Alliance, and Oregon BEST. He also sits on the visiting committee for the University of Washington College of Engineering, and the advisory committees for the University of Michigan Energy Institute and the Joint Center for Energy Storage Research at Argonne National Laboratory.

Dr. Alan E. Waltar is Past President of the American Nuclear Society. He recently retired as Director of Nuclear Energy at the Pacific Northwest National Laboratory. Previously, he retired as Head of the Department of Nuclear Engineering at Texas A&M University, following a nearly 30-year career with Westinghouse Hanford Company. He has written more than 75 scientific articles, and authored or co-authored four books. Dr. Waltar was instrumental in the formation of the World Nuclear University Summer Institute and has served as a mentor, lecturer, and emcee for all eight Institutes to date, plus both WNU Radioisotopes Schools in Korea. He led two People-to-People Ambassadors Nuclear Delegations (China, 2007; India, 2009). Currently he serves as a consultant to governmental national and international nuclear organizations and private nuclear firms. He holds a Ph.D. in Engineering Science from the University of California, Berkeley.

Acknowledgments

The Washington State Academy of Sciences acknowledges with grateful thanks the financial support and sponsorship by The Boeing Company, The Paul G. Allen Family Foundation, Pacific Northwest National Laboratory, and Schweitzer Engineering Laboratories.

The success of the symposium reflects the work of the scientific organizing committee: Subhash Singhal, Pacific Northwest National Laboratory, Ronald Thom, Pacific Northwest National Laboratory, and Anjan Bose, Washington State University.

Special thanks also go to WSAS staff members Sherri Willoughby and Laurel le Noble for their invaluable administrative support and organizational and technical skills so critical to the success of this annual meeting and symposium, and this report.

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