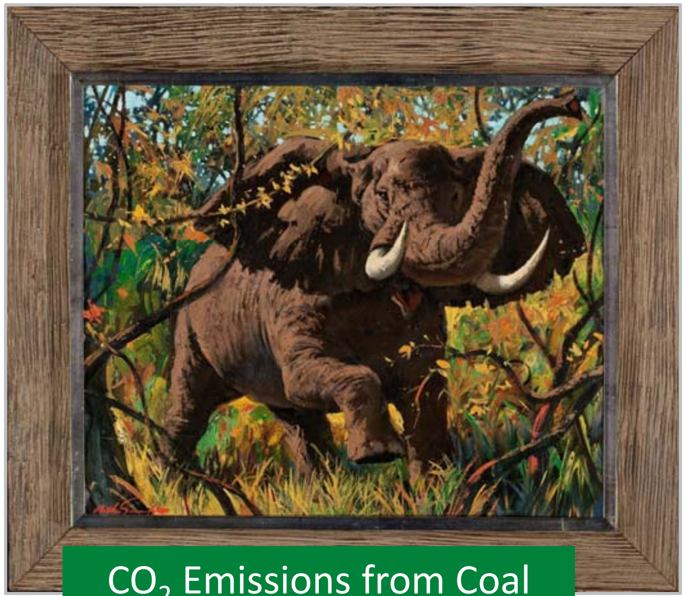
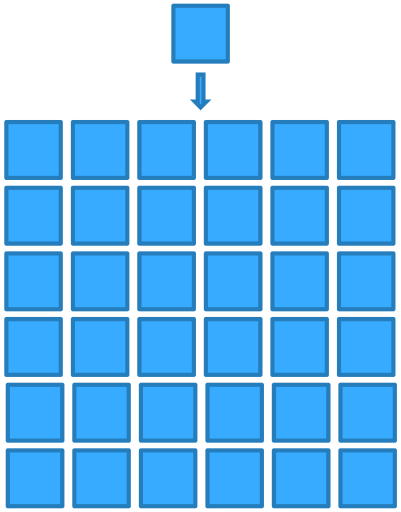
Driving Innovation ♦ Delivering Results



CO_2 Emissions from Coal
The Elephant in the Room

Modular Approach
Revolutionary Engineering



Revolutionary Materials
to support
Revolutionary Engineering

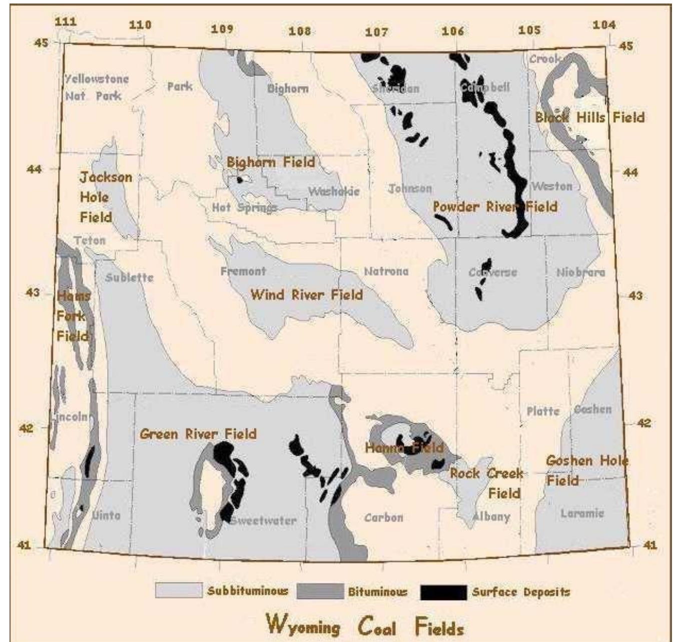
Coal Conversion Drivers
New DOE Focus and Ideas for Wyoming

Jenny Tennant
DOE Technology Manager
Coal Gasification and Fuels Production

October 7, 2015

DOE has…

- ✓ Supercomputer and scientist-programmers
- ✓ Experienced coal conversion experts
- ✓ Reactor designers
- ✓ R&D partnerships with industry and academia
- ✓ Techno-economic systems analysts
- ✓ Economists, with expertise in coal



Wyoming has…

- ✓ **Produces more coal than any other state**
  - >40% more than all of Appalachia
- ✓ **In 2014, 388 million short tons in 2014**
  - Slight decline since 2008 high
- ✓ **Low cost coal**

DOE wants…

Can't do this by tweaking 1800's to 1940's technologies

Must think about coal conversion in different terms

✓ Reduce coal's environmental impact

AND

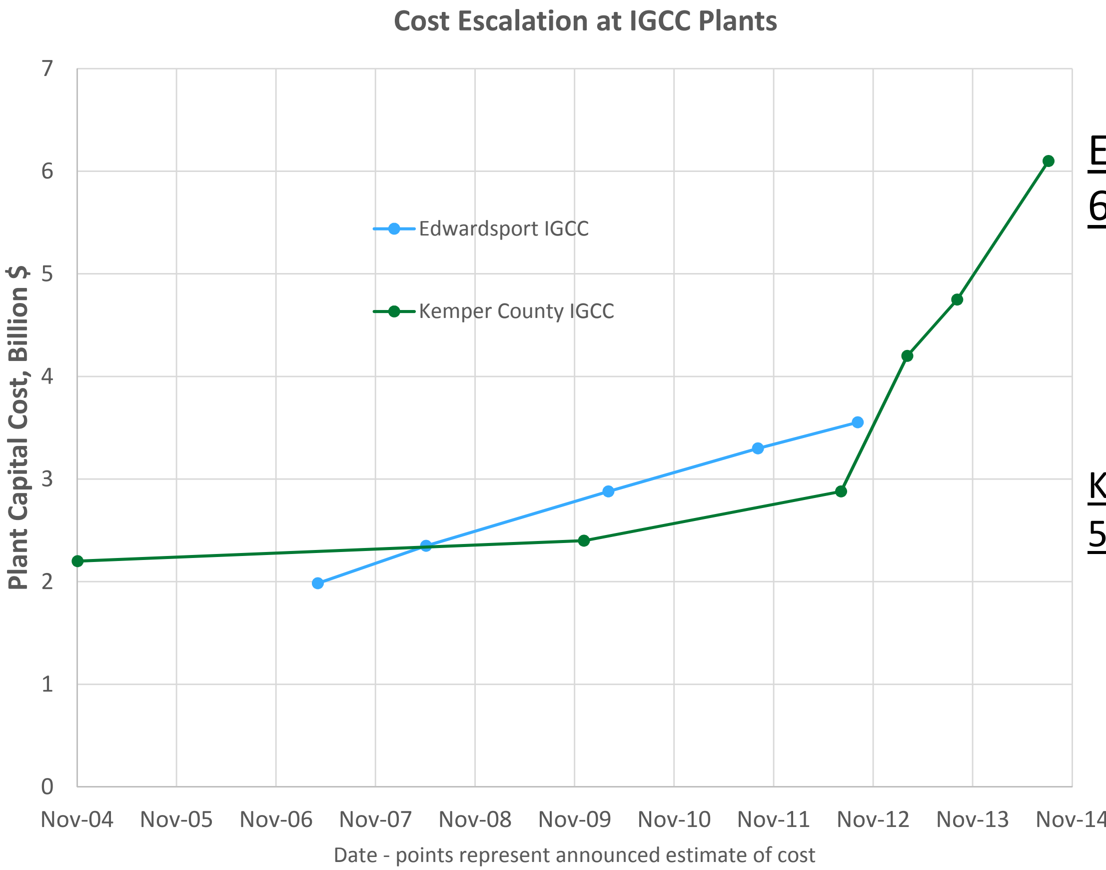
✓ Use coal to support the U.S. economy

Wyoming wants…

✓ Long-term coal based jobs
✓ Coal value to state maximized

NETL

Edwardsport IGCC and Kemper County IGCC Plant Capital Costs



<u>Edwardsport IGCC – 618 MW (no carbon capture)</u>

Initial Cost Estimate - $1,985M ($3,200 per kW)

Final Cost - $3,554M ($5,700 per kW)

<u>Kemper County IGCC – 582 MW (65% carbon capture)</u>

Initial Cost Estimate - $2,200M ($3,800 per kW)

Final Cost Estimate - $6,100M ($10,500 per kW)

Coal is being Crushed Between CO_2 Emissions and Low Prices for Oil and Natural Gas

To Transportation Fuel

Without CO_2 capture and storage

A 50,000 barrel per day plant will emit 2.3 times more CO_2 in the atmosphere every day than conventional oil refining

A 50,000 barrel per day plant will be economically competitive when oil is $120 per barrel

We need to think about coal conversion in different terms

NETL Ongoing Efforts:

Survey of U.S. coal conversion needs

Survey of U.S. coals and high value products from past R&D

Systems Analysis geared up to focus on optimizing systems that will focus on most compelling needs

Existing Coal R&D

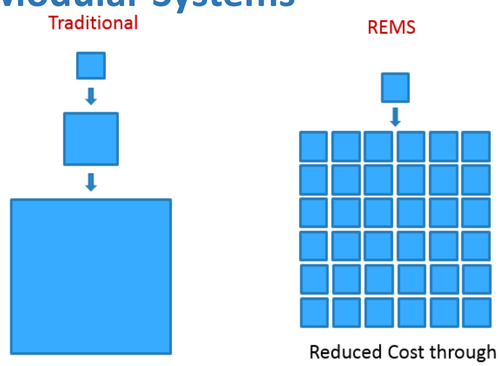
- At least 3 companies engaged in active R&D
- Several larger-scale targeted technologies will apply even better to smaller systems
- Actively seeking other ongoing R&D work and potential collaborations
- New NETL initiative: Radically Engineered Modular Systems (REMS)

NETL Supercomputer

and expertise on coal kinetics and reactor behavior

Like personal computing, modeling gas-particulate reactions is becoming increasingly powerful

Modular Systems



Less expensive products the bigger the plant gets

- Funding difficulties
- Biomass use infeasible

Reduced Cost through Advanced Manufacturing

- Any size for any application
- Repeated designs mean faster replacements and less plant down-time
- More plant flexibility: feed and products

Advanced Manufacturing

- Reduced reactor and plant capital costs
- Decreased plant down time
- Increased product value

By 2020 hope to build prototype REMS mine mouth economically viable pilot-scale plant

- ✓ Use coal prep plant fines as a feedstock
- ✓ Go after highest value products

By 2030 Achieve a coal conversion revolution by manipulating coal at the particulate level. Expand reach to bigger markets.

NETL

Don Collins told me think BIG

But the new focus is small, modular, unique conversion applications

- Aim for bigger later
- *Doesn't help you now*

- Aim for long-term environmental regulation targets versus present day interim targets
  - Target Ultimate Goal – Sustainable Energy Systems and Industries
  - Recycle CO_2 for products needed for sustainable societies
- Energy-Water Efficiency, Conservation-Recycle Strategies
  - Utilize water in low rank coals
  - Devise integrated multi-plant schemes that avoid/minimize plant temperature ramping damage/degradation costs and inefficiencies
  - Maximize operating at peak efficiency/peak profitability
- Maximize product value-density vs. shipping impacts
  - Achieves lowest energy, water, emission LCA level per unit of economic good (GDP)

Remaining presentation focused on this part

From Don's keynote presentation at the NETL Coal Conversion Workshop this past August

Big Enough Near-Term Markets

- **Raw coal exports**
  - not part of any NETL program
- **Large Scale Power**
  - can't compete with natural gas and CO_2 emission control would add cost
- **Large Scale Transportation Fuels**
  - can't compete with oil in price or CO_2 emissions
- **Next biggest chemicals market: Fertilizer**
  - approximately a 12 million ton per year market

…CRU has revised down its forecast of marginal export costs for key Chinese producers, lowering expectations for pricing in 2015 and 2016

http://www.crugroup.com/market-analysis/products/UreaMarketOutlook

What about anticipating upward trends?

- Rural U.S. and Developing Country Power Needs
- Carbon Fiber (co-product and stored carbon)

Rural and Developing World Power Needs

- **Possible approach we're considering for a REMS:**
  - Modular, high methane catalytic gasifier to make syngas…
    - Coal and biomass feed to gasifier
    - Perhaps solid carbon extraction as part of process
  - To feed fuel cell to produce power
- **Perhaps to a direct current micro-grid**
  - DC has many benefits (see more information after the presentation)
  - Greatly simplifies solar use as part of the system
- **U.S. Market may be Small (but important); World Market could be Huge**

U.S. Bill Passed this Summer:
Energy Policy Modernization Act of 2015

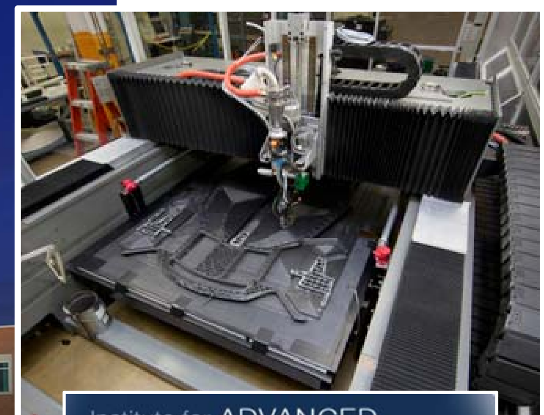
Senator Murkowski handout includes

Hybrid Micro-Grid Systems – Promotes hybrid micro-grid technologies, including the integration of renewable resources in rural communities that currently depend on diesel for electricity generation, and promotes the kind of research being conducted at the University of Alaska's Center for Energy and Power in Fairbanks.

Carbon Fiber House – Oak Ridge

Permanent carbon storage?

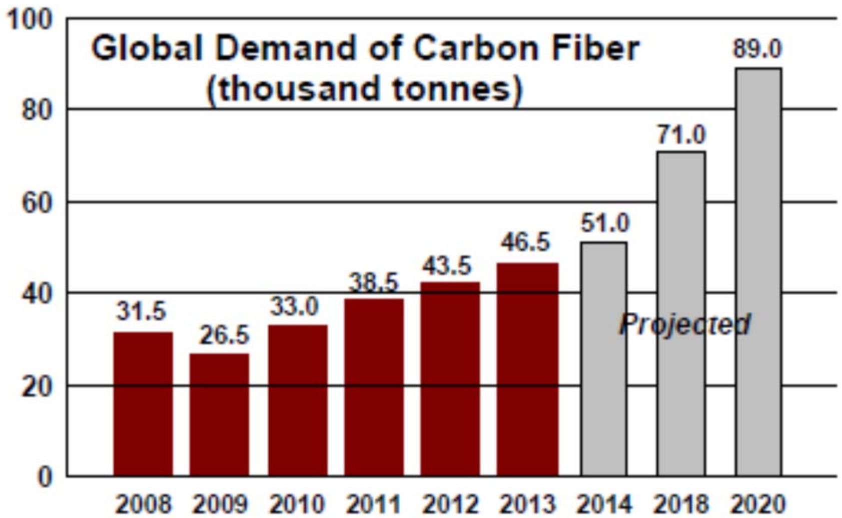
And Printed Utility Vehicle



Institute for ADVANCED
Composites Manufacturing
INNOVATION

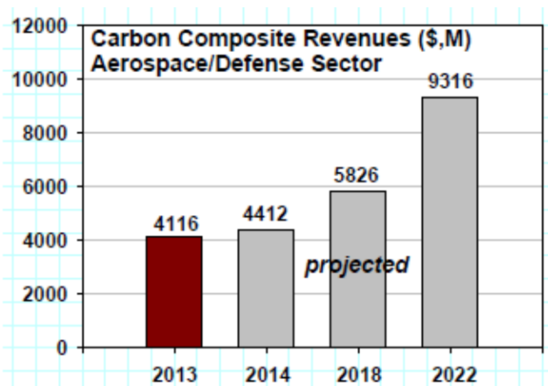
Happy Elephant

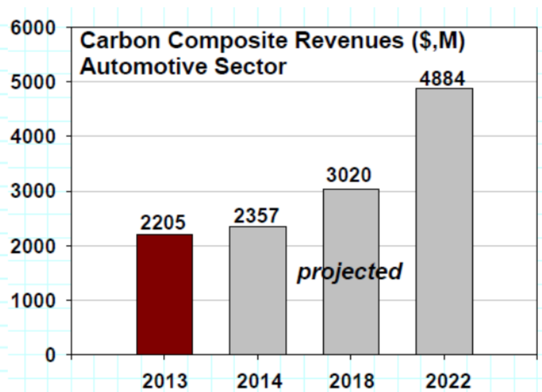
Carbon Fiber: Growing Demand

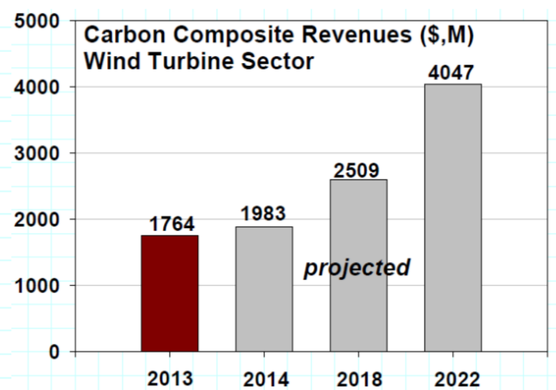


Demand for carbon fiber can be expected to reach 89,000 t by 2020 and generate revenues of $3.3B

Source: "Global carbon fiber market remains on the upward trend," Reinforced Plastics Nov/Dec, 2014 (0034-3617/14, Elsevier Ltd.)







Graphs after: "Global carbon fiber market remains on upward trend," Reinforced Plastics Nov/Dec 2014

Carbon Fiber:
Potential Market & Needs

Industry	Benefit	Applications	Drivers	Obstacles	Current Market	Potential Market
Automotive	Mass Reduction: 10% Mass Savings translates to 6-7% Fuel Reduction	Throughout Body and Chassis	Tensile Modulus; Tensile Strength	Cost: Need $5-7/lb; Fiber Format; Compatibility with automotive resins, Processing Technologies	< 1M lbs/yr	> 1B lbs/year
Wind Energy	Enables Longer Blade Designs and More Efficient Blade Designs	Blades and Turbine Components that must be mounted on top of the towers	Tensile Modulus; Tensile Strength to reduce blade deflection	Cost and Fiber Availability; Compression Strength; Fiber Format & Manufacturing Methods	1-10 M lbs/yr	100M - 1B lbs/yr
Oil & Gas	Deep Water Production Enabler	Pipes, Drill Shafts, Off-Shore Structures	Low Mass, High Strength, High Stiffness, Corrosion Resistant	Cost and Fiber Availability; Manufacturing Methods	< 1M lbs/yr	10 - 100M lbs/yr
Electrical Storage and Transmission	Reliability & Energy Storage	Low Mass, Zero CTE transmission cables; Flywheels for Energy Storage	Zero Coeficient of Thermal Expansion; Low Mass; High Strength	Cost; Cable Designs; High Volume Manufacturing Processes; Resin Compatibility	< 1M lbs/yr	10-100M lbs/yr
Pressure Vessels	Affordable Storage Vessels	Hydrogen Storage, Natural Gas Storage	High Strength; Light Weight	Cost; Consistent Mechanical Properties	< 1M lbs/yr	1-10B lbs/yr

250+ KSI, 25 MSI Fiber

550 - 750 KSI, 35 - 40 MSI Fiber

C.D. Warren, Low cost carbon fiber in the high volumes for 21st Century Industries, ORNL Sept 13, 2011

Carbon Fiber:
Potential Market & Needs

Industry	Benefit	Applications	Drivers	Obstacles	Current Market	Potential Market
Infrastructure	Bridge Design, Bridge Retrofit, Seismic Retrofit, Rapid Build, Hardening against Terrorist Threats	Retrofit and Repair of Aging Bridges and Columns; Pretensioning Cables; Pre-Manufactured Sections; Non-Corrosive Rebar	Tensile Strength & Stiffness; Non-Corrosive; Lightweight; Can be "Pre-Manufactured"	Cost; Fiber Availability; Design Methods; Design Standards; Product Form; Non-Epoxy Resin Compatibility	1-10M lbs/yr	1-100B lbs/yr
Non-Aerospace Defense	Lightweight Ground and Sea Systems; Improved Mobility and Deployability	Ship Structures; Support Equipment; Tanks; Helicopters	Low Mass; High Strength; High Stiffness	Cost; Fiber Availability; Fire Resistance; Design into Armor	1-10M lbs/yr	10-100M lbs/yr
Electronics	EMI Shielding	Consumer Electronics	Low Mass; Electrical Conductivity	Cost; Availability	1-10M lbs/yr	10-100M lbs/yr
Aerospace	Secondary Structures	Fairings; seat structures; luggage racks; galley equipment	High Modulus; Low Mass	Cost of lower performance grades; Non-Epoxy Resin Compatibility	1-10M lbs/yr	10-100M lbs/yr
Non-Traditional Energy Applications	Enabler for Geothermal and Ocean Thermal Energy Conversion	Structural Design Members; Thermal Management, Energy Storage	Tensile Strength & Stiffness; Non-Corrosive; Lightweight	Design Concepts; Manufacturing Methods; Fiber Cost; Fiber Availability	1-10M lbs/yr	10M-1B lbs/yr
Electrical Energy Storage	Key Storage Media	Li-Ion Batteries; Super-capacitors	Electrical and Chemical Properties	Design Concepts; Fiber Cost and Availability	1-5M lbs/yr	10-50M lbs/yr
Total					11-70M lbs/yr	3-114B lbs/yr

250+ KSI, 25 MSI Fiber

550 - 750 KSI, 35 - 40 MSI Fiber

DOE's interest is as a secondary product that stores excess carbon – WY can of course approach this with different goals

C.D. Warren, Low cost carbon fiber in the high volumes for 21st Century Industries, ORNL Sept 13, 2011

Back Up Information

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ELECTRIC POWER SYSTEMS LAB

12 Reasons Why DC May Replace AC for Future Power Infrastructure

Dr. Gregory Reed
Professor and Director, Center for Energy and Electric Power Systems Lab
Swanson School of Engineering – University of Pittsburgh

Introduction

Direct Current (DC) electric power is an emerging disruptive technological area that has the potential to stimulate economic growth, inspire innovation, increase research and development opportunities, create jobs, and simultaneously advance environmental sustainability.

DC technology and applications offer the promise of enhanced energy efficiency, improved power quality and reliability, and inherent alignment with renewable and clean energy development, as well as evolving end-use consumer needs.

The Power of Direct Current (DC)

DC power is beginning to evolve towards replacing AC as a worldwide standard for electricity delivery infrastructure, in many applications, based on the twelve (12) reasons listed below:

1. DC is inherently compatible with renewable sources of energy such as solar and wind.

These renewable sources generate power intermittently (when the sun shines or the wind blows), requiring storage (batteries) in some applications as part of the system in order to provide reliable supply, and also require a power conversion interface to the grid. Solar PV is inherently a DC energy supply, as are batteries, making DC a more naturally compatible interface. As an example, a current collaborative project among the University of Pittsburgh and Pitt-Ohio Express, Inc. – to install a DC-based renewable microgrid system including solar, wind, and energy storage technologies to serve a trucking distribution center's yard operations and lighting – is currently underway in Harmar PA, USA. The project is a first of its kind DC-based deployment and implementation of the associated technologies, with participation from various regional equipment suppliers and vendors.

2. Modern electrical loads and electronic equipment operate on DC power.

Most of today's modern electrical and electronic loads – computers, datacenters and servers, lighting, home and office electronics, appliances, personal device apparatus, and other technologies require low voltage DC power to operate. Yet, we continue to supply all of this end-use equipment from a legacy AC system requiring inefficient and unnecessary conversions from AC to DC. There is a power loss of anywhere from 5% to 20% when AC power is converted to DC power. The increasing reliance on electronic equipment creates a greater need for DC power. Eliminating these conversion losses from AC to DC are becoming more important now and even more so in the future, and will motivate a shift to DC power requiring advances in new power conversion technologies.

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3. Energy storage integration is greatly enhanced.

Energy storage is required to improve the capacity utilization of renewable energy supplies. Most energy storage technologies are DC-based (primarily in the form of battery technologies), creating opportunities for improved integration efficiencies and reduced operating losses. This is also much more compatible in applications where storage and distributed renewable energy resources are applied.

4. DC power is significantly more energy efficient than AC power.

Today's DC motors and appliances have higher efficiency and power-to-size characteristics. Also at the end-use level, DC-based lighting (in the form of new LEDs) is as much as 75% more efficient than incandescent lighting. At the high voltage power grid level, the greater efficiency resulting from recent developments in DC converter technology, allows improvements in electricity delivery over long distances. Also, power electronics based DC to DC converters will become the new transformers of modern DC architecture, offering lower losses and greater efficiency for voltage transformation as compared to tradition AC transformer technology.

5. DC and Hybrid AC/DC micro-grids are being developed for resiliency and reliability.

Micro-grid applications can effectively integrate local and distributed power generation with the main power grid to effectively serve defined end-use loads; improve reliability, especially under disturbance event conditions; and create opportunities to buy and sell (net metering) power to minimize energy costs to the consumer. Micro-grid designs also increase grid resiliency and energy security.

6. DC is superior to AC for underground and submarine applications.

When considering underground and submarine power transmission and distribution applications, to improve resiliency and reliability, DC solutions become much less expensive than AC for both initial construction costs and longer term operation and maintenance. DC requires only two poles as compared to AC that requires three phases, resulting in less overall infrastructure to install. DC is the technology of choice today for off-shore wind integration.

7. The technology needed to gain the advantages of DC power in data centers, homes, and communities is making significant advances.

DC power is already in use at the "bottom of the pyramid' – such as in areas of rural China, India, and other developing nations – because existing national (AC) power grids do not reach remote areas. For example, four states in India are experimenting with providing DC power to homes. Also, the most significant new consumers of electric power today are the companies (Google, Apple, Visa, etc.) at the "apex of the pyramid," which operate computer data centers and server farms. They benefit from DC power because the electronics require DC power. New developments for DC applications are creating investment in local DC power generation in order to ensure 24/7 reliability with zero downtime, and improve the efficiency of supply.

8. Electric vehicle growth and adaptation

Electric vehicles use DC (battery) power and their batteries can be charged using DC power in a small fraction of the time needed for charging using AC supply. In Europe, smart villages that use DC power are being designed, and electric vehicles are envisaged as part of the storage system for renewable power. There are many potential ancillary markets for electric vehicle applications, in terms of charging and discharging, and new electric vehicle infrastructure provides a large growth potential for the electrical transportation sector, leading to reduced carbon emissions and other environmental benefits.

9. New technologies support clean, local, distributed generation of DC power.

Solar, wind, second-generation clean biomass, and innovative, low-cost fuel cell designs that use natural gas are ideal for green, local power generation. DC infrastructure will help to better improve the integration of such resources into the grid, and enhance their overall economic and environmental value proposition. DC also helps to better accommodate local and district energy type systems for the demonstration and deployment of these new and advancing resource technologies.

10. Many new long distance transmission lines in the U.S., China, India, and Europe are moving toward ultra-high voltage DC (HVDC).

In the U.S., the new transmission lines from major wind and solar farms in the mid-west and western states are being planned as HVDC, in addition to an emergence of HVDC merchant transmission projects throughout the county. There already are approximately 20 HVDC systems in operation in the U.S. and Canada. All of China's new high voltage transmission is planned as HVDC, with dozens of systems already in operation and over 20 new systems in planning stages. Europe is expanding and upgrading much of its transmission infrastructure with HVDC being a significant part of their strategic plans, including interconnection of nations and continents. HVDC transmission is cheaper than AC at a certain distance for power delivery, because of recently developed disruptive technologies involving power semi-conductors. Other esoteric technical reasons (such as elimination of the "skin effect" that arises with AC) and reduced losses through advanced power converter designs motivate the shift to DC transmission. Moreover, the investment for HVDC transmission is less because the gauges (thickness) of the wires can be smaller, and because one less wire is required (two poles for DC vs. three-phases for AC). Therefore, many of the major reasons why the world went with AC at the turn of the 20th century are no longer relevant. Perhaps most importantly, HVDC can carry 5 to 8 times the amount of power along a given transmission right of way as compared to high voltage AC systems. Also, HVDC as applied widely in a network design can lead to the elimination of wide-scale, cascading blackouts that AC networks are susceptible to, and also provide 'black start capability' for network energization. Today there are many strong economic reasons, reliability requirements, and sustainability related incentives to invest in DC infrastructure, technologies, and applications.

11. In China and Europe, new cities and villages are being envisioned that will be entirely DC powered.

In green-field applications, from resource integration and delivery infrastructure to end-use applications, complete DC system concepts and operation are being considered in many developing parts of the world. As we look to electrify more remote parts of the globe, there are many advantages to employing DC infrastructure. Some of the concepts provide a model for modernizing existing infrastructure in parts of the world like the U.S., where hardening power networks to created greater resiliency and self-sustainability have become important objectives.

12. DC offers opportunities for technology leadership, as well as economic development and job growth.

DC provides the potential of creating new markets for technologies, along with supporting equipment, devices, systems, and services, will support economic development and job growth. Everything from hardware and software development to modernization of standards and codes will be necessary for a future that incorporates higher penetrations of DC infrastructure.

Research, Development, and Deployment at Pitt

A significant effort is underway at the University of Pittsburgh's Electric Power Systems Laboratory to advance the state-of-the-art of DC technology research, development, demonstration, and deployed. Entitled DC-AMPS (Direct Current Architecture for Modern Power Systems) and funded through an opportunity grant by the Henry L. Hillman Foundation, the program was established in order to develop advanced DC technologies, systems, and infrastructure to lead the electric power industry evolution from AC to DC power, while also positioning the Pittsburgh region to become a global leader in DC power and microgrid applications. It will also work towards the acceleration of the emergence of hybrid AC/DC networks, operations, and microgrids – leading to complete DC infrastructure – to enhance modern power system efficiency; improved power quality, reliability, security and resiliency; and align technology integration with renewable and clean energy developments.

Other prior and on-going work at Pitt in the area of DC developments with the Electric Power Systems Lab is across the entire power sector – from HVDC to medium voltage DC to DC microgrids to end-use DC applications – has been largely supported by various industry partners including funded R&D programs from ABB, Siemens Energy, Mitsubishi Electric, Eaton Corp., and others, as well as from the U.S. Department of Energy and the Commonwealth of Pennsylvania. The Pitt-Ohio Express project, previously described, is an example of a true partnership that has benefited from a well-coordinated university-industry-community collaboration, demonstrating the advantages and benefits of the deployment of modern DC infrastructure. Many of the methods being developed through DC-AMPS are also being considered for larger scale District Energy systems that include new and innovative ways of integrating energy resources, grid systems, and end-users.