PSERC

U.S. Energy Infrastructure Investment: Long-Term Strategic Planning to Inform Policy Development

White Paper

Power Systems Engineering Research Center

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Power Systems Engineering Research Center

The Power Systems Engineering Research Center (PSERC) is a multi-university Center conducting research on challenges facing the electric power industry and educating the next generation of power engineers.

Our core purpose:

- Empowering minds to engineer the future electric energy system

What's important to us:

- Pursuing, discovering and transferring knowledge
- Producing highly qualified and trained engineers
- Collaborating in all we do

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Power Systems Engineering Research Center

Letter from the Director

March 2009

Planning practices in the electric power industry have evolved over time as changes occurred in technology, customer needs, analytical techniques, and public objectives. For decades, planning remained utility-specific. Inter-area transmission lines were viewed as only providing access to additional generation resources for operational reliability purposes. The principal focus was on building enough central station generation to meet six and seven percent demand growth rates. Demand growth was relatively predictable so forecasting could almost be done by putting a ruler on logarithmic graph paper and extending a line from past usage to predict future usage.

Contributors to this paper posit that existing energy planning tools, models, and procedures are inadequate, requiring the development of new planning capabilities. They describe sixteen issues that motivate the need for new planning capabilities using advanced system methods. Today's planning environment is very different than the past. Environmental impacts motivate the creation of long-term, national plans for infrastructure investment. Transportation systems and electric energy systems are becoming increasingly interdependent. Technology change is occurring rapidly. Customers are asking for even higher levels of reliability and power quality for sensitive processes and equipment, while they also want ways to improve their energy use efficiency and to offer their loads as system resources. Advances in analytical techniques and computational capability are enabling highly sophisticated analyses. Public policies have created competitive markets where investment decisions are made by many stakeholders. Public policies are also evolving in response to major challenges facing our nation's critical infrastructure.

Industry, government and universities need to be discussing how energy planning should be done in this new environment characterized by high levels of uncertainty about the future. We hope that this white paper helps to stimulate those discussions.

Sincerely,

Vijay Vittal
Director

Acknowledgements and Disclaimer

This white paper is intended to promote discussion of the need for new tools, models and procedures for energy planning. The white paper was prepared by the Power Systems Engineering Research Center (PSERC) in an industry-university collaborative effort. Its contents do not necessarily reflect the views of any of the organizations who are PSERC members, including those organizations of major contributors to the white paper.

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U.S. Energy Infrastructure Investment: Long-Term Strategic Planning to Inform Policy Development

Introduction

With passage of the American Recovery and Reinvestment Act of 2009 signed by President Obama, the U.S. Department of Energy has been given additional resources to advance the development of technologies that will provide a low-carbon supply of energy and will transfer much of the nation's transportation energy supply to the electric energy system. These changes will necessarily play out over decades as new technologies mature and existing ones are retired, with corresponding infrastructure investment lying in the multi-trillion dollar range.

Yet, how are we to decide what technologies to build, how much of each, where, and when? With stakes this high, we must recognize the temporal interplay between investments: the *sequence* of choices we make for infrastructure investment *matters* in our quest to reduce carbon emissions while maintaining resilient systems, and providing low-cost energy and transportation services to power our economy. There is a critical need for new flexible and comprehensive modeling capabilities to identify the right investments and the sequence in which they must be made to obtain strategies that efficiently meet our national objectives.

The energy planning problem facing the U.S. today is of a distinctly different nature than energy planning problems of the past due to the number of different infrastructures involved (see Fig. 1), the geographical scope (see Fig. 2), among other issues. As a consequence, existing tools, models, and procedures are inadequate, requiring development of new planning capabilities. In this white paper, we describe 16 issues that motivate the need for those new capabilities. The strategy to develop those capabilities should follow a rigorous research plan coupled closely with efforts to provide immediate planning results using existing planning tools because near-term policy development decisions must be made within the next one or two years.

Planning Needs

The U.S. is about to embark on what will eventually be a multi-trillion dollar investment effort to curtail carbon emissions from the electric power production system, and from the commodity and passenger transportation systems. However, there are major impediments to identifying what to invest in, when, and where. We do not have the planning tools, models, and procedures necessary to systematically develop and probe investment strategies for a 40 year time frame at the national level, and across the fuel, electric, and transportation industries. This formidable planning problem is amenable to analysis by advanced *system* methods, some of which are already available today but just have not been fully applied to this problem. We list 16 specific issues below that motivate this perspective.

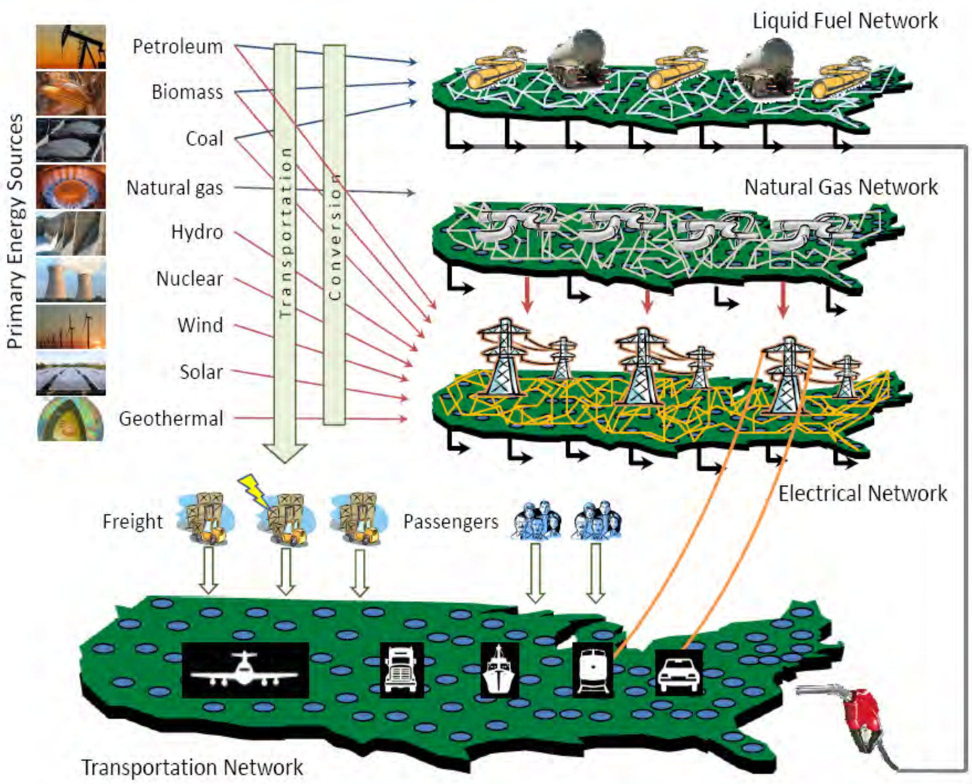

Fig. 1: Cross-Infrastructure Interdependencies

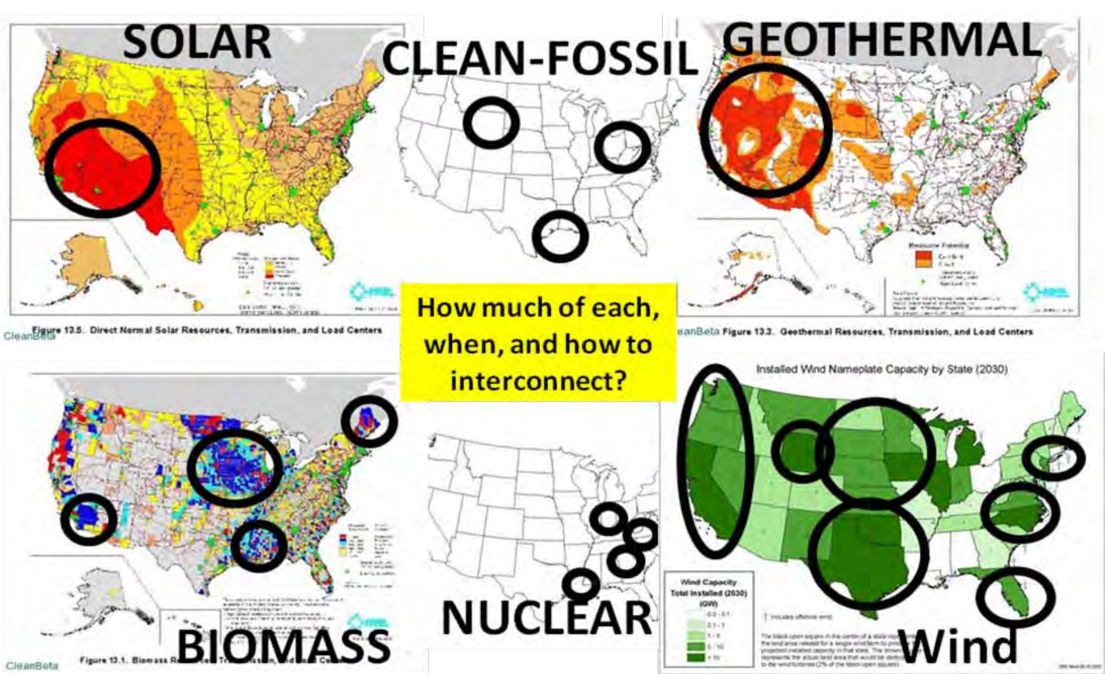

Fig. 2: Geographical Scope

1. **Cross-industry**: Traditional single-industry planning cannot account for cross-industry interdependencies (e.g., electric system connections to electric or hybrid electric vehicles used in transportation systems) or of "parallel" energy transport modes (e.g., in rail, liquid pipelines, gas pipelines, and electric transmission). This issue will grow in importance as the electric and transportation systems become more strongly coupled via plug-in electric and hybrid electric transportation systems. Although U.S. DOE national laboratories have considered interdependent vulnerabilities in multiple infrastructures (e.g., communications, power grid, gas pipelines shown at www.dis.anl.gov/exp/ia/index.html), the principles underlying this on-going work have yet to be implemented in planning tools.

2. **Geographical scope**: Investment planning at the local and regional levels may miss strategic opportunities available from interregional bulk energy transport (e.g., is the Southeast U.S. better supplied by local nuclear, Midwestern wind, or western geothermal?).

3. **Planning horizon**: Current investment planning based on what is most attractive in a given 5, 10 or 20 year period is insufficient. Elements of the related infrastructure (such as gas wells, pipelines, power plants, transmission, carbon sequestration technologies, and transportation fleets) may have economic lifetimes of 20-50 years. For example, some existing equipment is still in operation even though it is 70 years old.

4. **Modeling uncertainties**: Developing investment plans for 40 year decision horizons requires extensive uncertainty modeling. This modeling is needed to account for such uncertainties as the effects of climate change (including extreme weather, and changes in hydro and wind availability), and the uncertainties of technological change addressed in (5) below. This will drive the need for exploring different planning objectives. For example, rather than just minimizing cost, decision-makers may need to minimize measures of regret (i.e., the increased cost of choosing an alternative plan) or seek flexible solutions that are robust to the uncertainties. There is a need to understand the performance of infrastructure investment strategies under both the worst and best outcomes.

5. **Technology selection**: Future technology change will come in the form of technologies expected to mature in the near or distant future (e.g., carbon capture and sequestration), and technologies not yet known. Of these, the planning function should have embedded intelligence to determine which technology to implement and which to forego.

6. **Planning authority**: Questions can be asked about who is vested with planning authority in a period of major uncertainties when investment decisions can affect multiple regions. For instance, the Federal Energy Regulatory Commission has given planning responsibilities to Regional Transmission Organizations (RTOs), a decision which recognized the need to perform regional planning for transmission. Interestingly, several RTOs have recently banded together to create the Joint Coordinated System Planning group to coordinate design of a transmission overlay for the eastern interconnection. It seems possible that a national transmission planning entity may be needed. If so, who would this be? To what extent would this entity be responsible for evaluating the risks and uncertainties in such planning? If a national transmission planning entity is not created, then how will the necessary multi-

regional planning decisions be made, particularly as the U.S. considers an extra-high voltage transmission overlay that will clearly affect transmission flows over very wide areas?

7. **Multiple objectives and valuation**: A low-carbon future can be sought to address climate change concerns, but it is still essential that decision-makers understand, value, and plan for tradeoffs between (1) reductions in carbon emissions, (2) other environmental impacts (e.g., land and water usage), (3) costs (investment and operational), and (4) long-term system reliability and resiliency. Policies are being proposed today for which these tradeoffs are not yet well understood. Energy system experts should perform rigorous analysis to estimate these tradeoffs and identify the most cost effective, flexible, and reliable pathways for the energy system and other linked systems to meet public policy goals.

8. **Measuring long-term reliability**: Reliability metrics for electric power system planning have traditionally depended on N-1 security evaluation or probabilistic unserved energy calculations. Are these appropriate for evaluating reliability over a 40 year period? Or should we measure national energy system resiliency in terms of response to extreme events (e.g., very severe weather or widespread loss of supply capability for an essential fuel)? To what extent should the planning function rely on operational solutions such as special protection schemes and self-healing designs? How can such solutions be valued against new or upgraded transmission and distribution infrastructure? What is the minimum level of reliability needed at the grid level vs. at the local level? The minimum level of reliability question is complicated by the observation that reliability at the grid level is a typical public good not amenable to market solutions whereas reliability at the local level is more of private good where individual customers have some choice over their reliability level by the investments or utility programs they choose. Finally, to make a decision about minimum reliability levels, it is necessary to quantify the risk of infrequent but large blackouts.

9. **Operational issues**: Traditional long-term planning tools may not account for operational impacts, such as variability in certain forms of renewable energy, the addition of significant new electric vehicle load, and control capabilities realized through smart-grid technologies. However, such impacts may impose needs for additional investment (e.g., in energy storage and demand response), or relieve needs for additional investment (e.g., through smart grid technologies) necessitating their inclusion within the planning assessment. Optimal operating solutions and costs must be determined for these new challenges.

10. **Cost allocation and recovery**: Cost recovery mechanisms associated with very large scale, interregional investments are not mature. Methods are needed for valuing benefits of new investments and identifying associated beneficiaries to facilitate acceptable infrastructure cost allocation. For example, the value of ramping capabilities of different generation technologies will be needed to use a planning method that could choose the right mix of generation for ramping.

11. **Financial adequacy**: With high penetration of renewable energy from variable sources such as wind and solar, the income streams for different participants in the electric delivery system will change substantially. In particular, the income streams of conventional generators

are likely to fall as their primary role changes from energy supply to system support and backup, while their importance to the system remains the same. New methods are needed to design an efficient set of financial incentives to ensure the financial viability of all participants needed to operate a reliable supply system. Different products need to be distinguished and financed through their own income streams. Electricity and carbon markets must be designed to ensure that all necessary products and participants are adequately compensated.

12. **Financial model**: The financial impacts of the economic downturn experienced worldwide over the last two years have dramatically changed short-term and mid-term plans in the energy sector. To what extent do we represent the potentiality of such crises (e.g., a major financial recession or depression, frozen credit markets, massive layoffs, etc.) in planning models?

13. **Computational methods**: New algorithmic and computational methods in computing are needed to address (1) the high dimensionality of a 40 year decision horizon, (2) the discrete nature of many investment decisions, and (3) high uncertainty. Such methods are only just beginning to emerge, and will require significant development and testing to enable their use with confidence.

14. **Selection of transmission technologies**: Transmission can be HVDC or HVAC, and there are choices of voltage level, conductor type (e.g., high-temperature low sag conductors, high surge-impedance loading conductors, and, eventually, high-temperature superconductors), and tower design. Making such choices for incremental transmission investment can be challenging; making such choices for an integrated national transmission backbone is unprecedented.

15. **Distribution planning**: The ability to economically produce and store electric energy using small-scale technologies suggests interconnection of distributed resources at the distribution level will become common. What is the cost to re-engineer distribution systems for two-way flow? What are the associated benefits? How do we judge the extent to which we want to use distributed generation and storage resources at the distribution level vs. from bulk facilities connected at the transmission level?

16. **Human resources**: Energy and transportation infrastructure planning has been and will continue to be an ongoing adaptive process. It will also be a complex process requiring the participation of highly skilled individuals. The human resources necessary to conduct the research and the continued national planning function must be carefully and intentionally cultivated, focusing not only on a large cadre of PhD-level students but also on the secondary and undergraduate educational systems that ultimately feed industry's human resource needs.

Moving Forward

Our nation's short and long-term energy planning methods and processes need to evolve to make a significant contribution to DOE's efforts to lead the nation in developing a low-carbon energy infrastructure portfolio. There needs be development, testing, and implementation of solutions that address the issues described above. This effort could include some or all of the following:

1. Scoping studies
2. Workshops
3. Inter-agency task forces in collaboration with industry and universities
4. Research projects funded by DOE and the National Science Foundation among others.

This effort should recognize that energy planning has to be from a system perspective. However, this does not mean that there will be only one energy planning methodology. There is diversity in planning needs and requirements in industry and government, so advances can be made without seeking to reach consensus on a "one" best method.