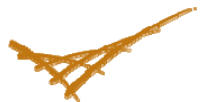


Predicting the Impact of Climate Change on US Power Grids and Its Wider Implications on National Security

*PC Wong (pak.wong@pnl.gov), LR Leung, N Lu, M Scott
K Baker, K Branch, B Bragg, J Correia, H Foote, W Jiang, L Kiesling, P
Mackey, M Paget, ZT Taylor, Y Xie, J Xu
SD Unwin, A Sanfilippo*

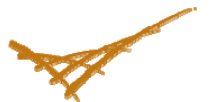


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Mission & Vision

- ▶ Develop a model and a system to interactively
 - Predict the impact of climate change on power grids and its wider implications on national security
- ▶ Suggest and examine plausible scenarios to
 - Compel policymakers to take proactive measures to address critical national issues
- ▶ Remove the dash between techno and social
 - Promote and advance interdisciplinary predictive analytic studies



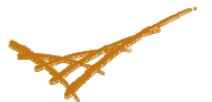
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Acronyms

Climate Power Grid Social Infrastructure

- ▶ **ACS (PUMS)** – American Community Survey Public Use Microdata Sample, <http://www.census.gov/acs/www/Products/PUMS/>
- ▶ **CBG** – Census Block Groups, <http://www.census.gov/geo/www/cob/bg2000.html>
- ▶ **CBECS** – Commercial Buildings Energy Consumption Survey, <http://www.eia.doe.gov/emeu/cbecs/>
- ▶ **CCSP** – US Climate Change Science Program, <http://www.climate-science.gov/>
- ▶ **DOE-2** – Building Energy Use and Cost Analysis Tool, <http://doe2.com/DOE2>
- ▶ **EIA** – Energy Information Administration, <http://www.eia.doe.gov/>
- ▶ **IPCC** – Intergovernmental Panel on Climate Change, <http://www.ipcc.ch>
- ▶ **NERC** – North American Electric Reliability Corporation, <http://nerc.com>
- ▶ **NGA** – National Geospatial-Intelligence Agency, <http://www.nga.mil/portal/site/nga01/>
- ▶ **PSLF** – Positive Sequence Load Flow software, http://www.gepower.com/prod_serv/products/utility_software/en/ge_pslf/index.htm
- ▶ **RECS** – Residential Energy Consumption Survey, <http://www.eia.doe.gov/emeu/recs>
- ▶ **WECC** – Western Electricity Coordinating Council, <http://www.wecc.biz/>



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Interdisciplinary Team

▶ Climate analytics

- L. Ruby Leung (lead), Jim Correia

▶ Power grid analytics

- Ning Lu (lead), Z. Todd Taylor, Jiang Wei, YuLong Xie

▶ Social analytics

- Mike Scott (lead), Kate Baker, Kristi Branch, Lynne Kiesling

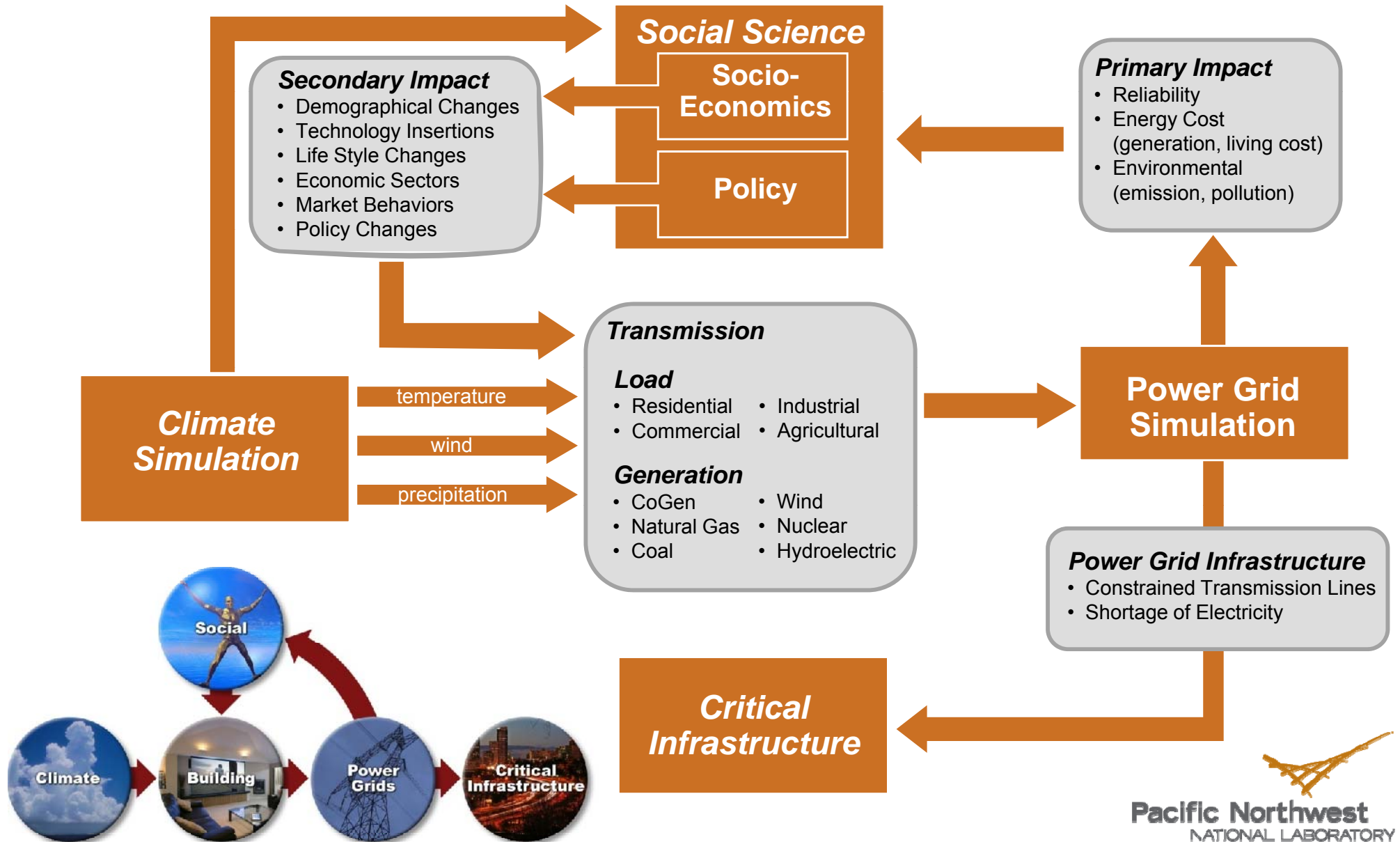
▶ Critical infrastructure analytics

- Pak Chung Wong (lead), Sally Xu, Patrick Mackey, Harlan Foote

▶ Visual analytics

- Pak Chung Wong (lead), Patrick Mackey, Bryce Bragg

Project Overview



Interdisciplinary Engineering Challenges

▶ In theory

- Investigation of all model components can be carried out concurrently

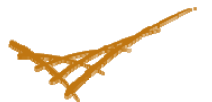
▶ In reality

- Model components accept input from each other (as well as external sources) → a chicken and egg problem

▶ R&D activities are coordinated in a gradual, sequential fashion

- Lead components provide just enough groundwork for the next component to take off before returning to the refinement stage to enrich the model
- Supporting components prepare model “templates” to anticipate and later plug in results from lead components

▶ A never-ending learning process for everyone involved



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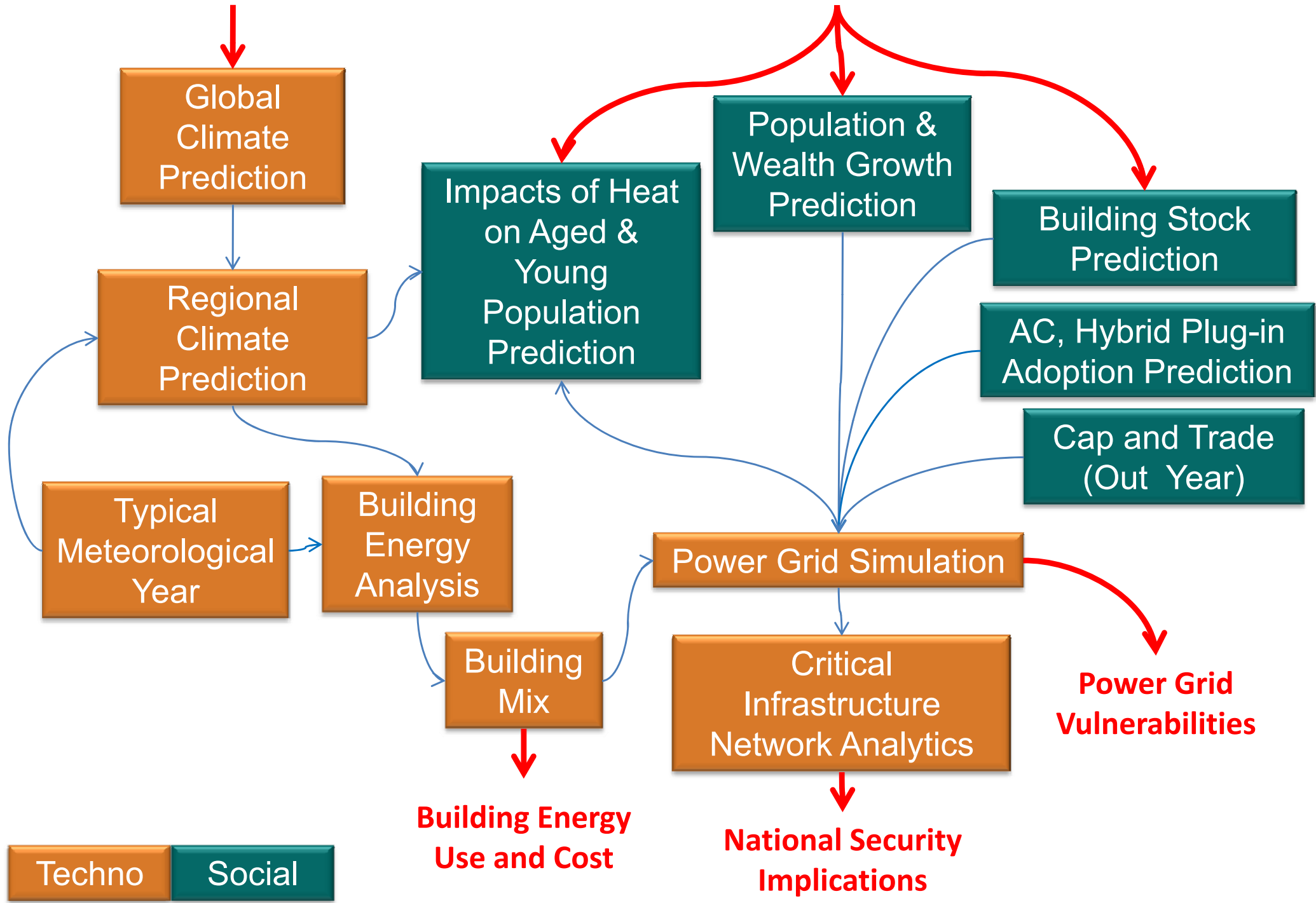
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Interdisciplinary Research Challenges

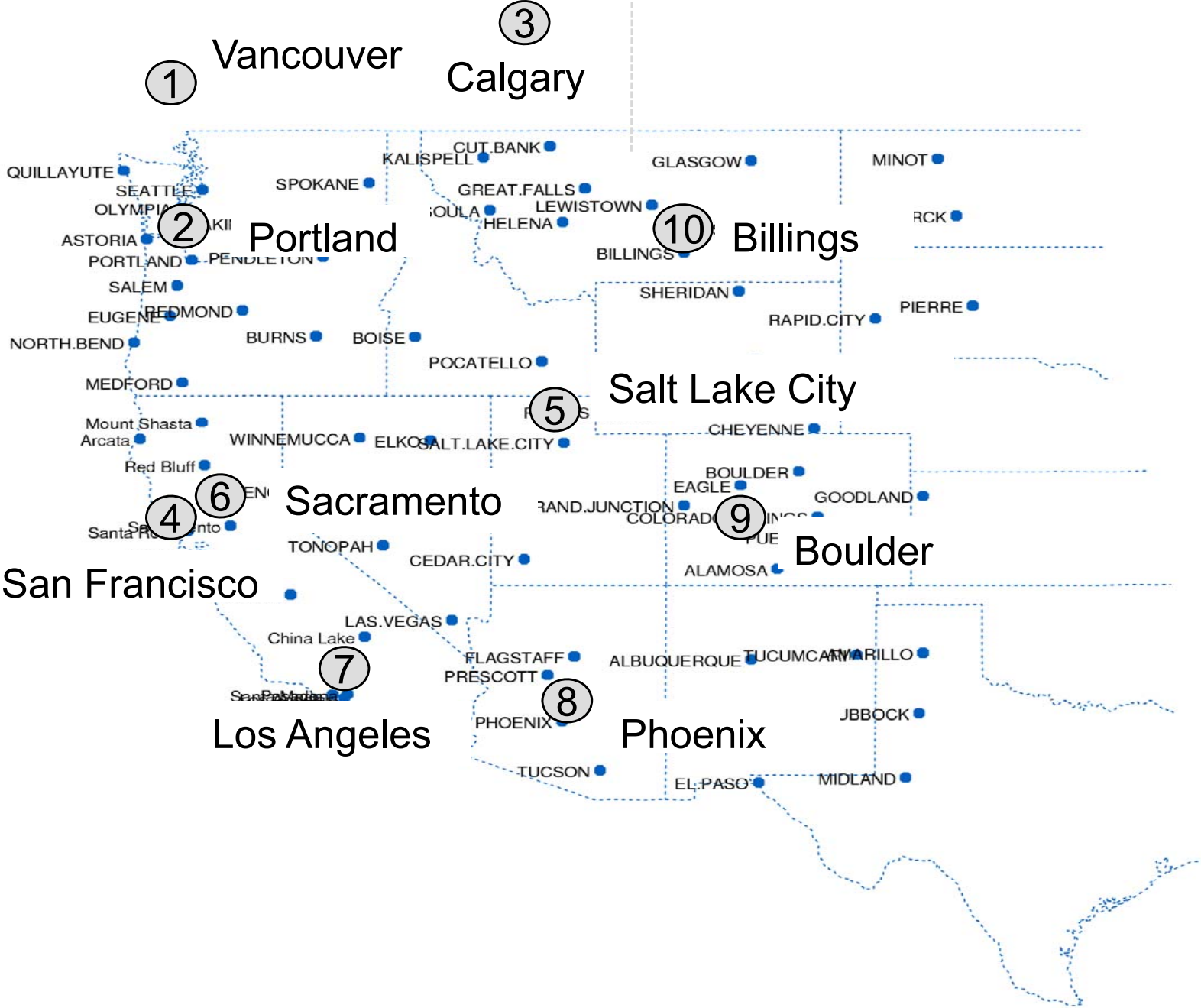
Challenges	Approaches
Use past trends to predict the future	(1991-2000) → (2045-2054)
Apply widely accepted models and theories developed by different communities	IPCC, DOE2, PSLF, CCSP, ACS, CBG, CBECS, EIA, RECS, NGA-Gold, WECC...
Align and optimize the focuses and emphases of different domain models	<ul style="list-style-type: none">• Global climate (low-res) → building/power grid (hi-res) → social analytics (very hi-res)• Bias-correct future estimates
Reduce data granularity of different computation models	Regress the climate variables to energy and power grid variables (e.g., daily maximum temperature vs. hourly temperature)
Unify models and achieve balanced and sustainable predictions	Integrate domain models with a thin visual analytics layer

Climate Change

Population and Demographics Changes



Coverage: 10 Cities in WECC



Building Types: 23 Commercial and 3 Residential

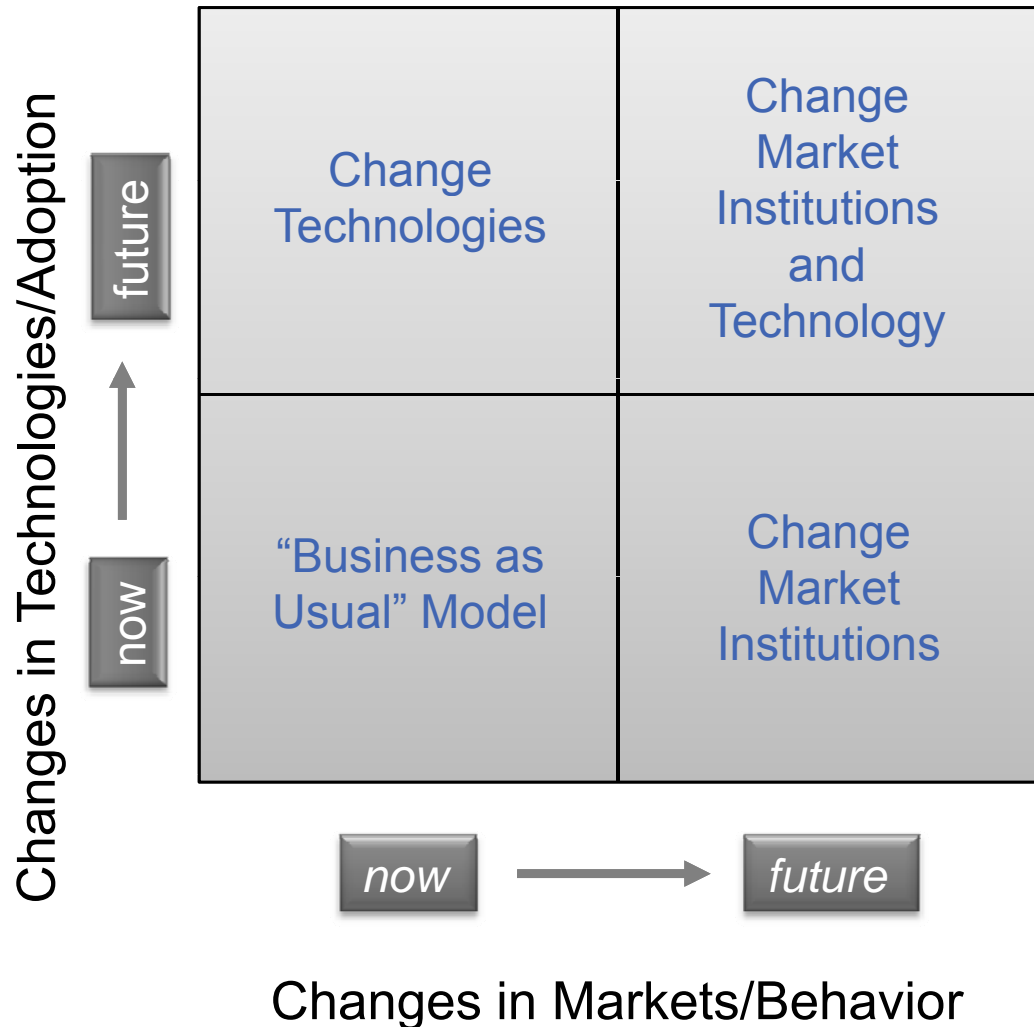
Commercial

- | | | | |
|-----|-------------------------------|-----|----------------------------------|
| 1. | Assembly | 12. | Manufacturing – Bio/Tech |
| 2. | Education – Primary School | 13. | Manufacturing – Light Industrial |
| 3. | Education – Secondary School | 14. | Office – Large |
| 4. | Education – Community College | 15. | Office – Small |
| 5. | Education – University | 16. | Restaurant – Sit-Down |
| 6. | Education – Relocatable | 17. | Restaurant – Fast-Food |
| 7. | Grocery | 18. | Retail – 3-Story Large |
| 8. | Health/Medical – Hospital | 19. | Retail – Single-Story Large |
| 9. | Health/Medical – Nursing Home | 20. | Retail – Small |
| 10. | Lodging – Hotel | 21. | Storage – Conditioned |
| 11. | Lodging – Motel | 22. | Storage – Unconditioned |
| | | 23. | Storage – Refrigerated Warehouse |

Residential

1. Single family
2. Multi-family
3. Manufactured Home

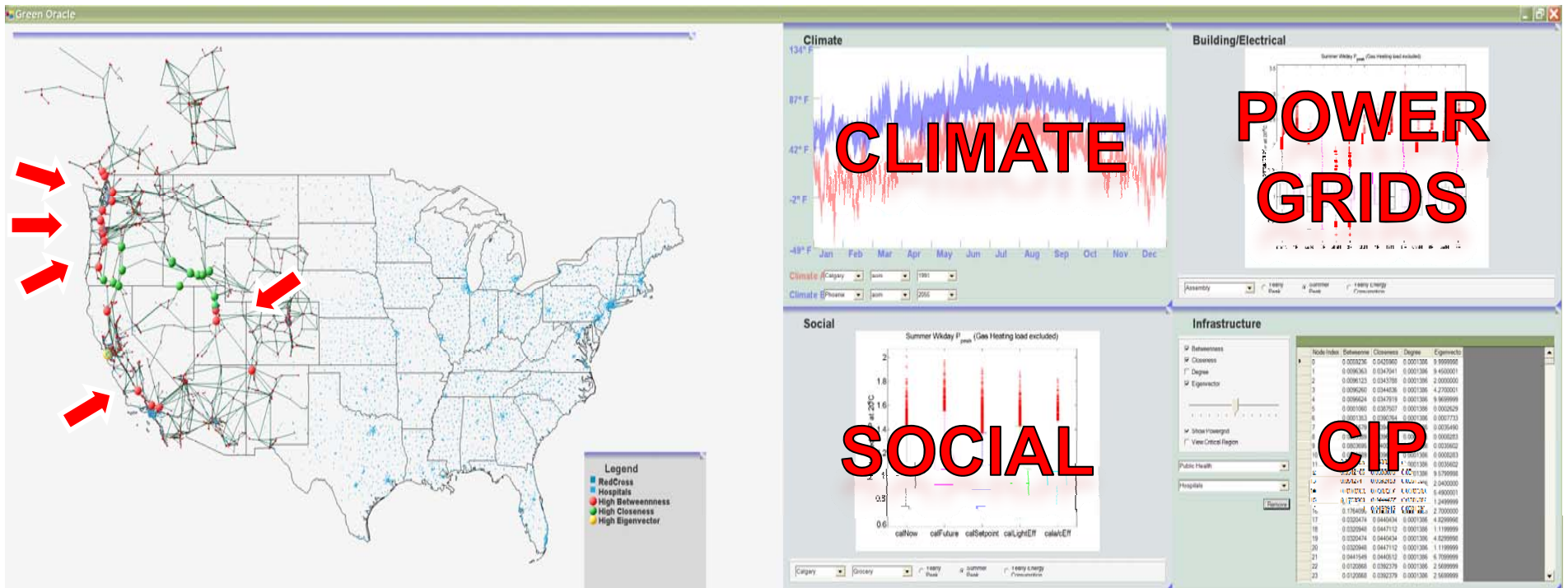
Exploring Socio-Economic Factors



Model Exploration Examples

- Localized and system wide impact of digital end-use technologies
- Demand change due to different dynamic pricing models
- Effects of PHEV, GHG mitigation options, price-responsive appliances...

Visual Analytics System Prototype



- ▶ Windows-based system prototype
- ▶ C++/C#, .net, DirectX 9
- ▶ Multi-screen layout
- ▶ Access databases

Selected Conclusions

- ▶ By mid-century, building yearly energy consumption and peak load will increase in the cities such as Phoenix, Salt Lake City, and Boulder.
 - The peak load months will spread out beyond the summer months to include spring and autumn months.
- ▶ Cities such as Portland, Vancouver, Calgary, and Billings will experience more hot days in the summer months.
 - The penetration and use of air conditioning systems in the Pacific Northwest is likely to increase significantly over the years.
- ▶ Overall, the Western U.S. grid may see more simultaneous peaks across the North and South in the summer months.
- ▶ The air conditioning load will increase.
 - More reactive power consumption and require stronger voltage support from the grid.
 - Fault induced delayed voltage recovery phenomena may be seen across the system. This poses a great threat to system voltage stability.
- ▶ **Technology changes will mitigate the adverse impacts caused by the climate changes.**

Synergistic & Complementary R&D at PNNL

- ▶ Serious Gaming
- ▶ Knowledge Based Collaboration
- ▶ Integration
- ▶ Evaluation

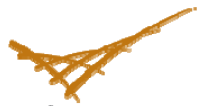
Selected Publications

- ▶ Pak Chung Wong, L. Ruby Leung, Ning Lu, Mia Paget, James Correia Jr., Wei Jiang, Patrick Mackey, Z. Todd Taylor, YuLong Xie, Jianhua Xu, Steve Unwin, and Antonio Sanfilippo, "Predicting the Impact of Climate Change on U.S. Power Grids and Its Wider Implications on National Security," *Proceedings AAAI Spring Symposium on Technosocial Predictive Analytics 2009*, March 2009.
- ▶ Pak Chung Wong, L. Ruby Leung, Ning Lu, Michael J. Scott, Patrick Mackey, Harlan Foote, Bryce Bragg, James Correia Jr., Wei Jiang, Z Todd Taylor, YuLong Xie, Jianhua Xu, Stephen D. Unwin, and Antonio Sanfilippo, "Collaborative Visual Analytics in Multidisciplinary Technosocial Predictive Studies," 2009. Submitted for publication.
- ▶ Ning Lu, Z. Todd Taylor, Wei Jiang, James Correia Jr., L. Ruby Leung, and Pak Chung Wong, "Climate Change Impacts on Residential and Commercial Loads in the Western U.S. Grid," *IEEE Transactions on Power Systems*, 2009. To appear.
- ▶ Ning Lu, Z Todd Taylor, Wei Jiang, James Correia Jr., L. Ruby Leung, and Pak Chung Wong, "The Temperature Sensitivity of the Residential Load and Commercial Building Load," *Proceedings 2009 IEEE PES General Meeting*, Calgary, Alberta, Canada, July 2008. To appear.
- ▶ Antonio Sanfilippo, Andrew Cowell, Liz Malone, Rick Riensche, Jim Thomas, Stephen Unwin, Paul Whitney, and Pak Chung Wong, "Technosocial Predictive Analytics: A Multidisciplinary Approach to Naturalistic Decision Making," *Proceedings (NDM9) The 9th Bi-annual International Conference on Naturalistic Decision Making*, London, U.K., June 2009. To appear.
- ▶ Pak Chung Wong, Kevin Schneider, Patrick Mackey, Harlan Foote, George Chin Jr., Ross Guttromson, and Jim Thomas, "A Novel Visualization Technique for Electric Power Analytics," *IEEE Transactions on Visualization and Computer Graphics*, Volume 15, Issue 3, Pages 410-423, May 2009. To appear

Acknowledgements

▶ Acknowledge support from

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- National Visualization and Analytics Center (NVAC, <http://nvac.pnl.gov>)
- Electricity Infrastructure Operations Center (EIOC, <http://eioc.pnl.gov>)

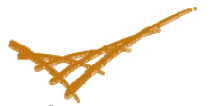


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Questions

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