



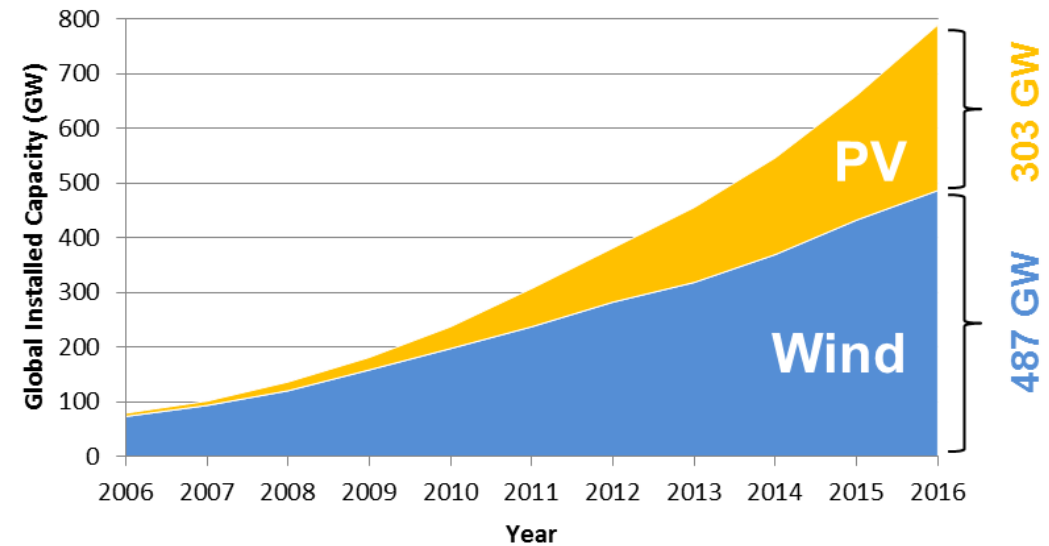
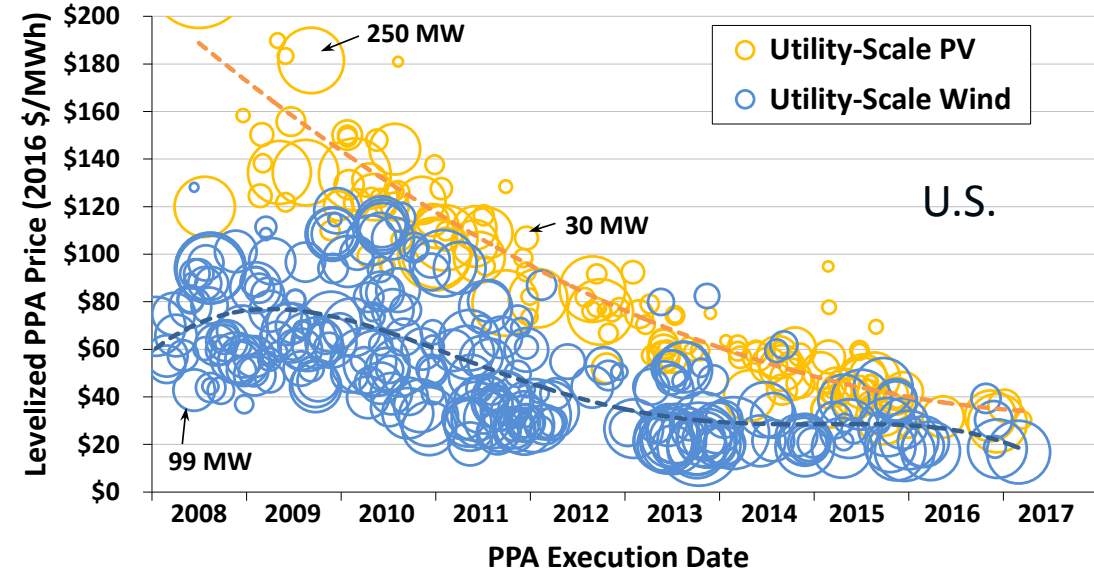
What we know (and don't know) about very high renewable penetrations

Trieu Mai

September 20, 2017
Low-Emissions Solutions Conference

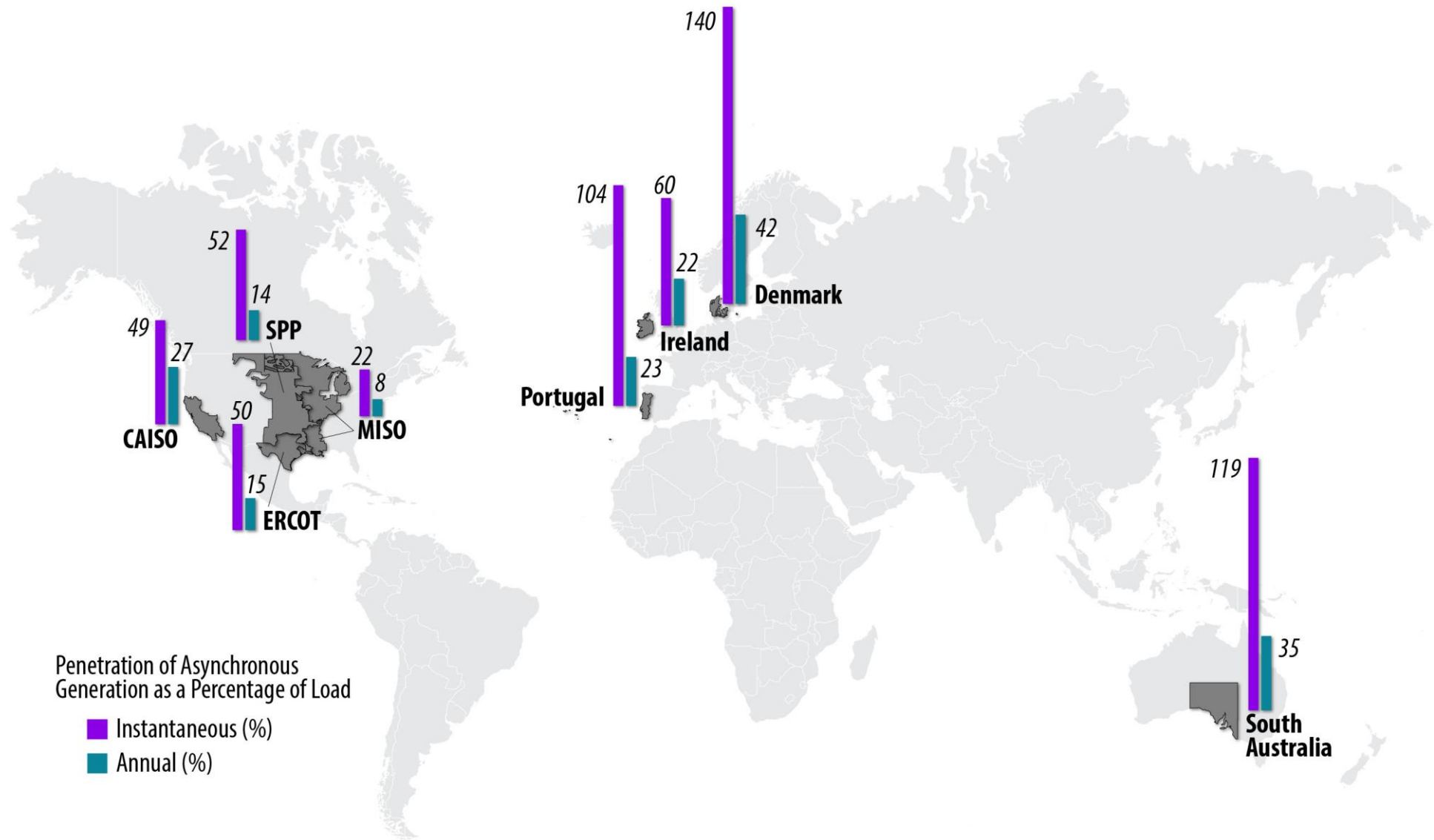
The Basics: Characteristics of Variable Renewable Energy

1. Dispersed
2. Variable and Uncertain
3. Inverter-based
4. Zero marginal costs
5. Zero emissions
6. Fast changing technologies



Top figure: from Wiser et al. (2017). Bottom figure: data from REN21 (2017)

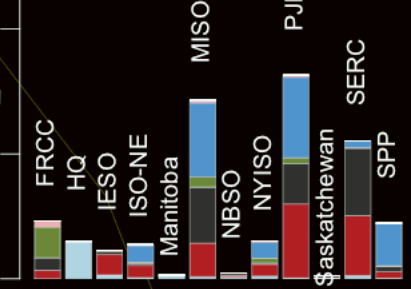
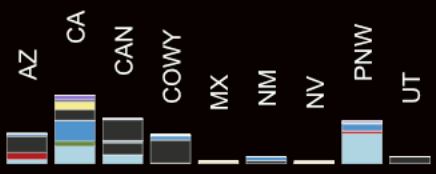
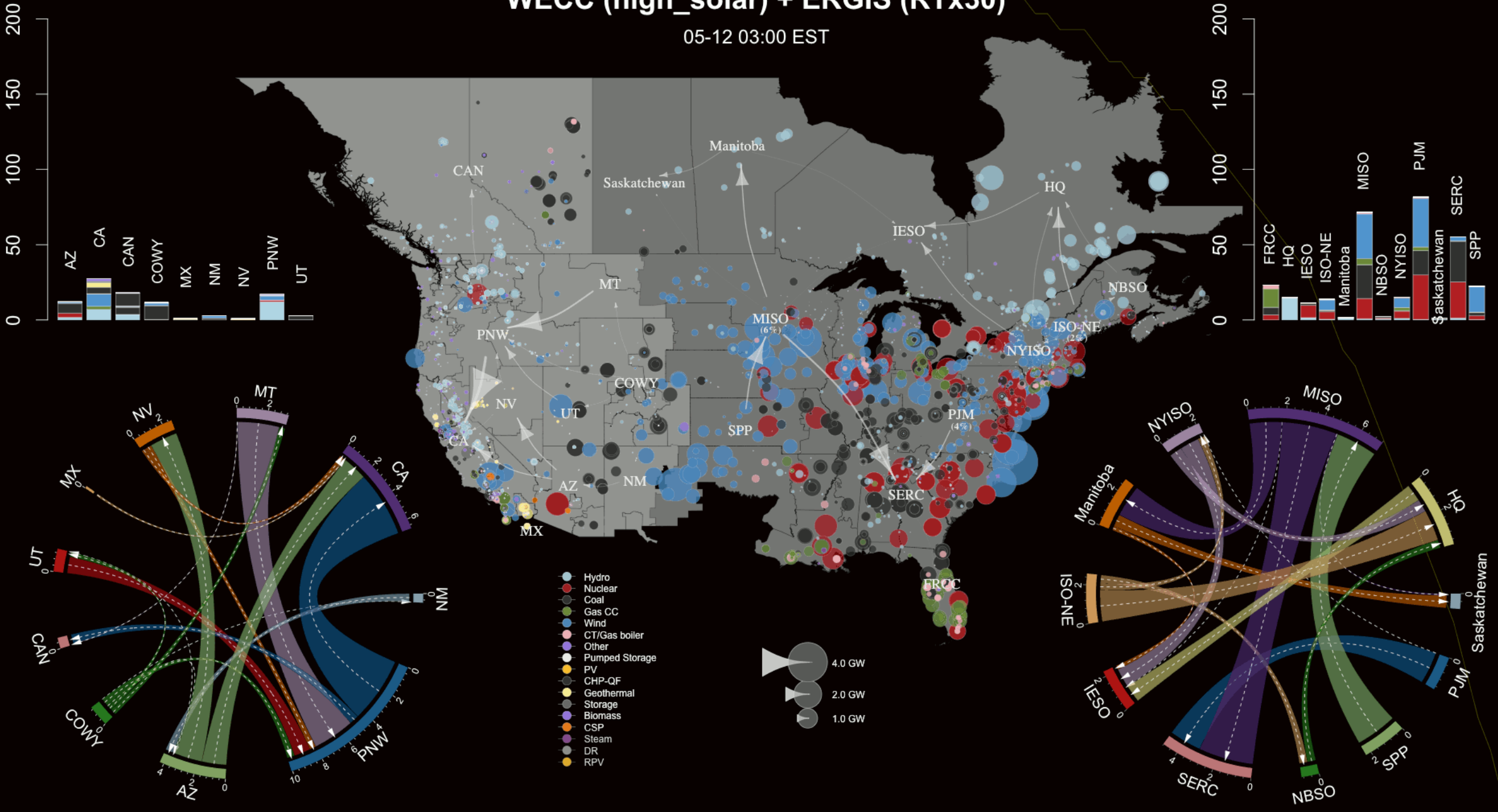
Current Penetration Records



Map and data: Billy Roberts and Aaron Bloom (2017)

WECC (high_solar) + ERGIS (RTx30)

05-12 03:00 EST



- Hydro
- Nuclear
- Coal
- Gas CC
- Wind
- CT/Gas boiler
- Other
- Pumped Storage
- PV
- CHP-QF
- Geothermal
- Storage
- Biomass
- CSP
- Steam
- DR
- RPV

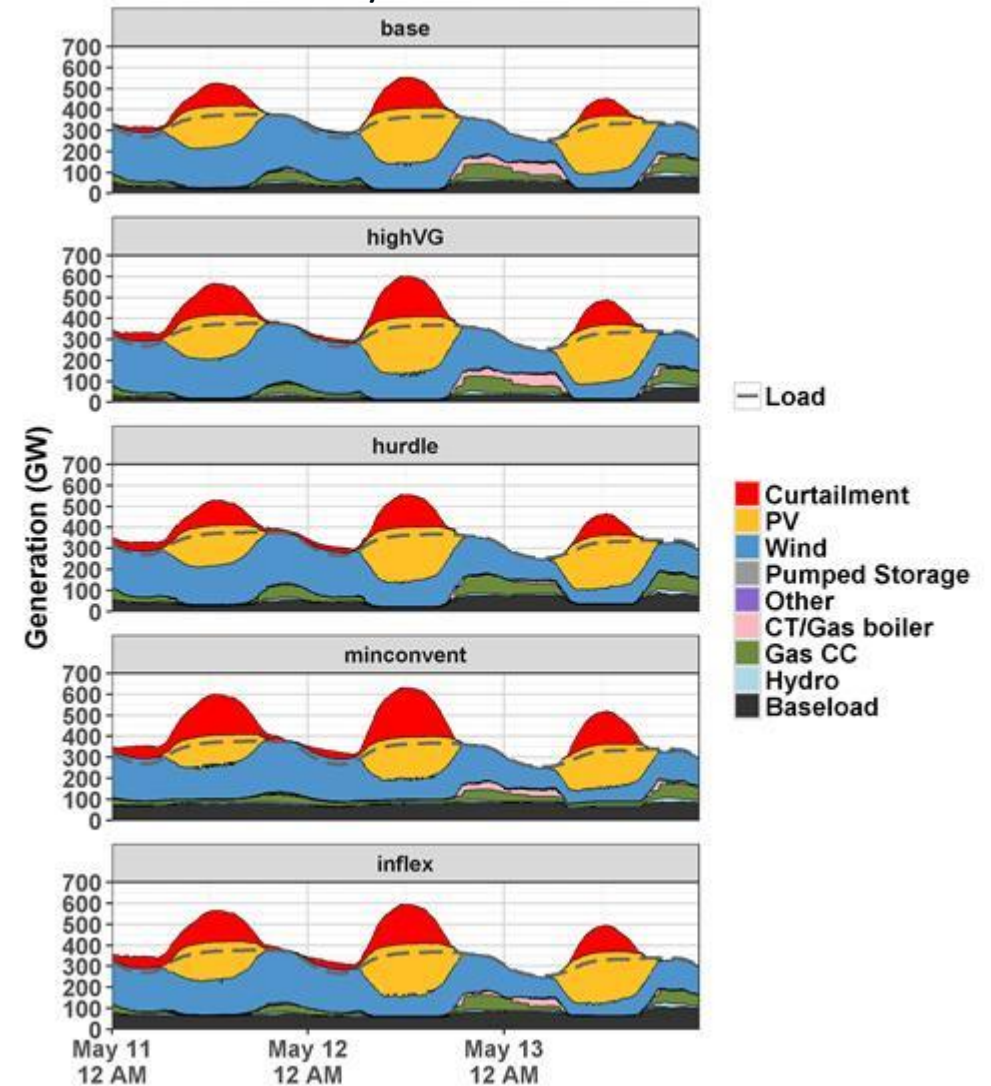
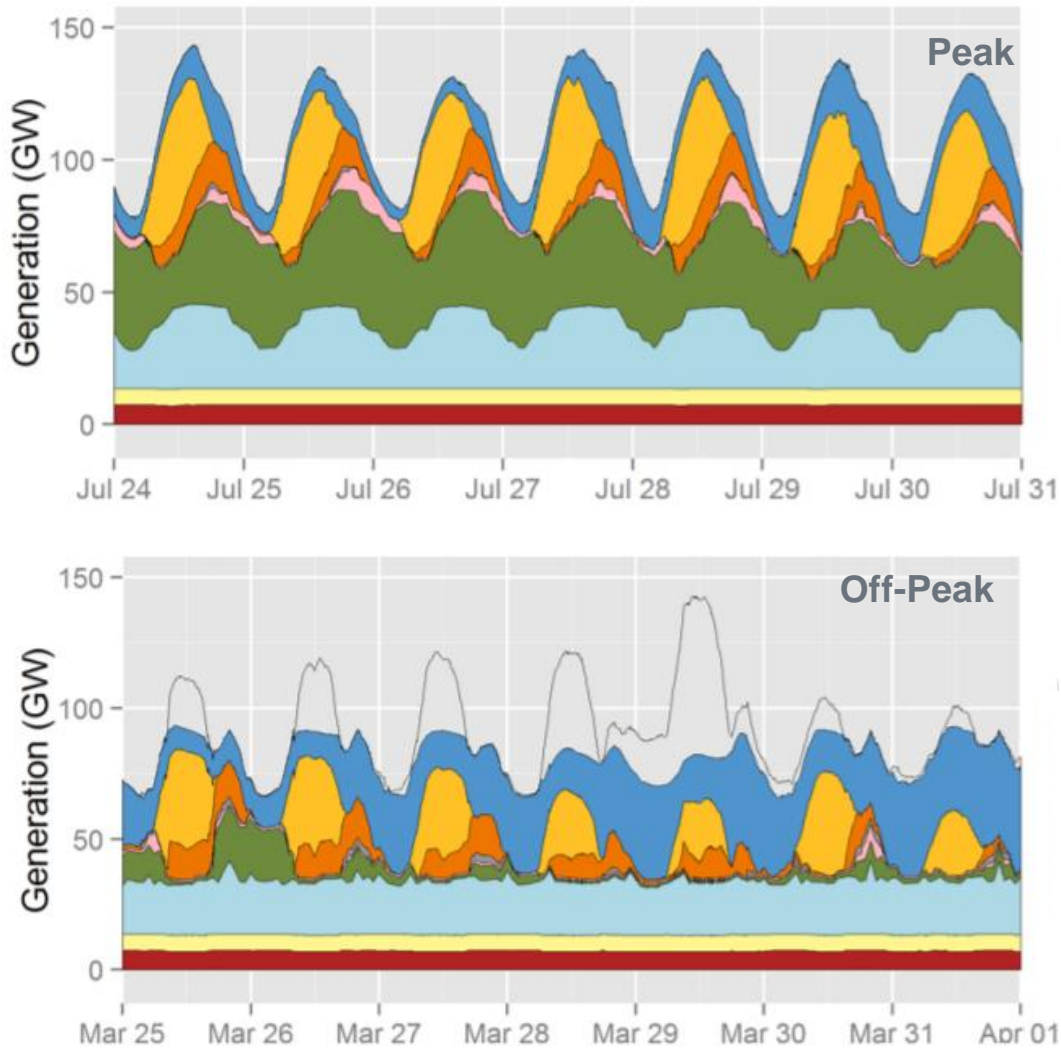


Saskatchewan

Gaining confidence that 50-70% wind and solar (and higher RE) is feasible

45% VG / 88% RE in the West

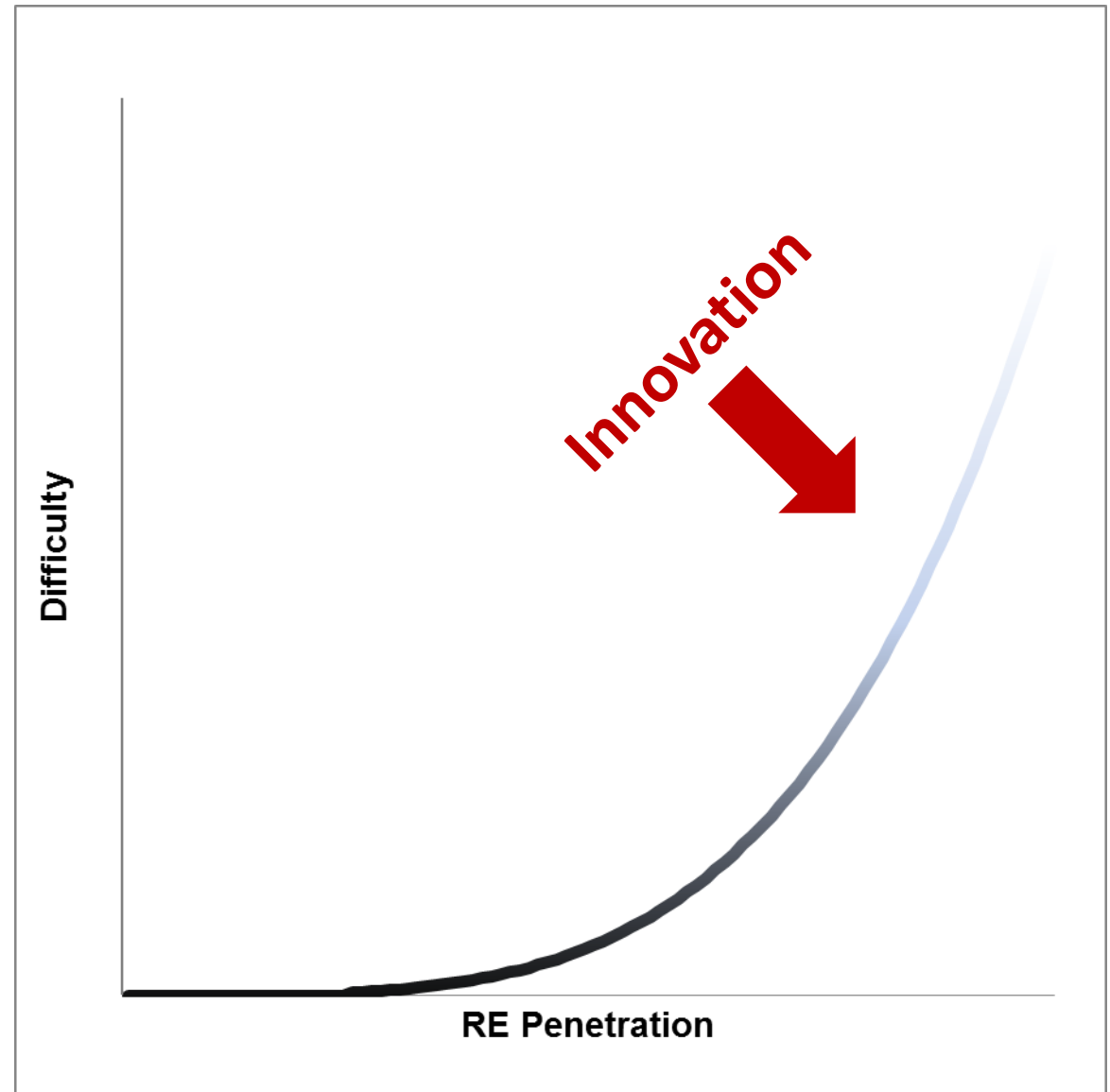
71% VG / 74% RE in the East



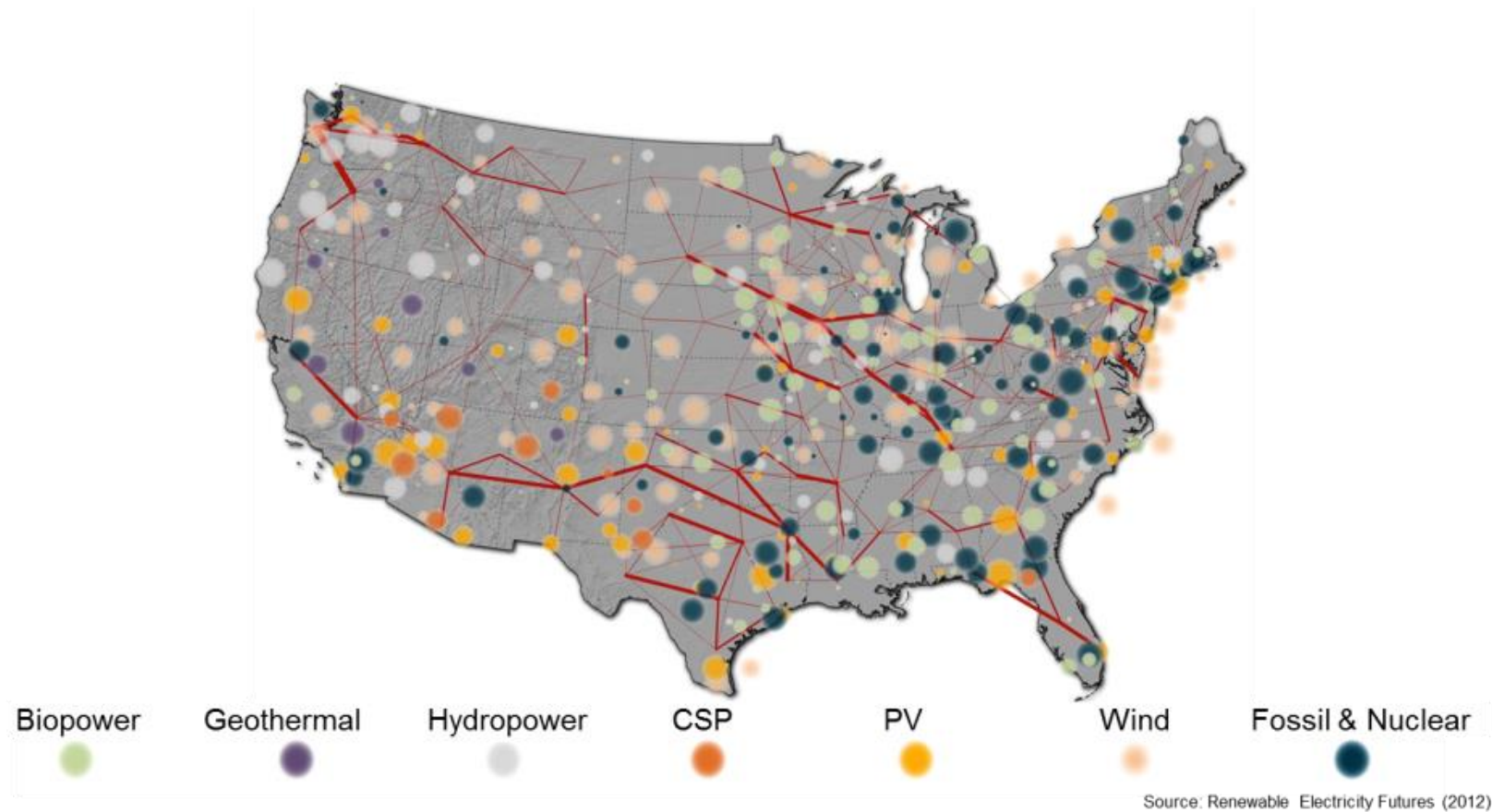
Left figure: Brinkman (2015). Right figure: Novacheck and Brinkman (forthcoming)

Things we don't know

1. System stability
>35% annual, >60% instantaneous
2. Future market design
3. Role of the demand side
demand response, electrification
4. Distribution systems
5. Future innovation



A future U.S. electricity system that is largely powered by renewable sources is possible, and further work is warranted to investigate this clean generation pathway.



Thank you.
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