How to Deal with Intermittency and Large Amounts of Renewable Energy

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Wind Turbine & Other Research at UofC

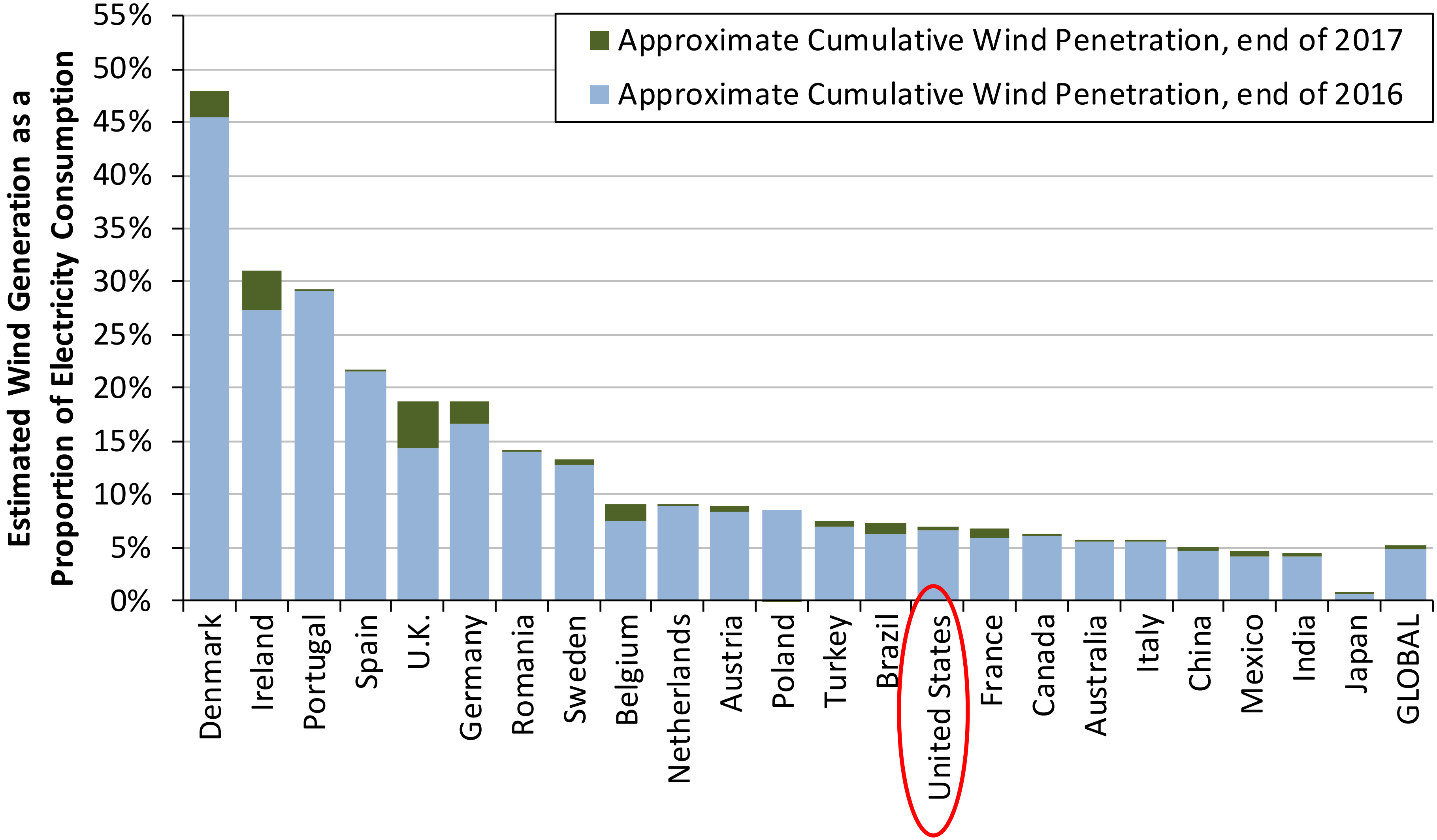
- Basic wind turbine aerodynamics
- Analysis of waterpumping windmills
- Multidimensional optimization of blade design
- Blade erosion
- Improved turbulence modeling for wind flow simulation for wind energy and photovoltaics applications
- Archimedes screw and crossflow hydroturbines
- Maximizing free convection heat transfer for electronic circuits to minimize need for cooling fans
- Understanding the heat transfer from conductor cables for dynamic rating of power lines
- Capturing the waste heat from photovoltaic installations

How to Deal with Intermittency and Large Amounts of Renewable Energy

Collaborators: Prof Joule Bergeson, Matt Tierney (MSc student)

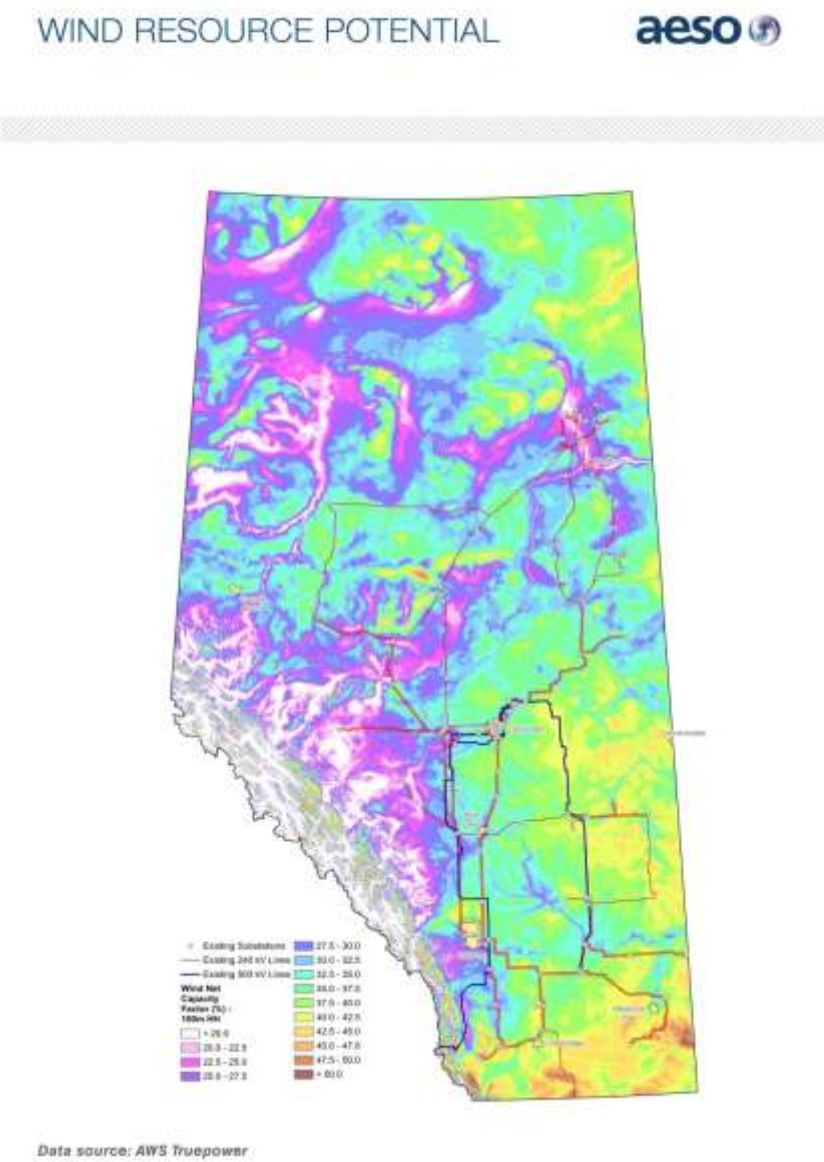
- How does the intermittency of wind and solar power effect the electricity grid?
- What are the methods to deal with intermittency?
- How can these methods be applied in Alberta?
- What is the ideal electricity system?

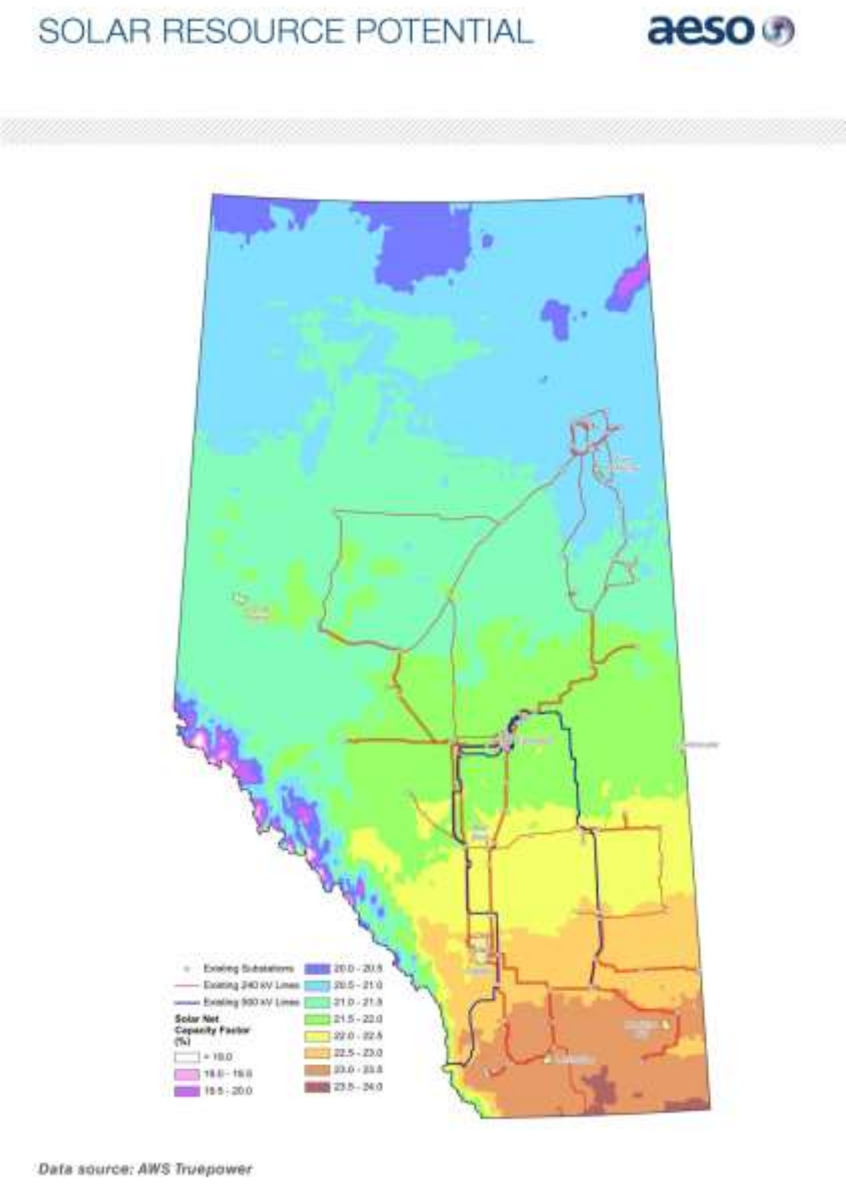
Canada is Lagging Other Countries in Wind as a Percentage of Electricity Consumption



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2017

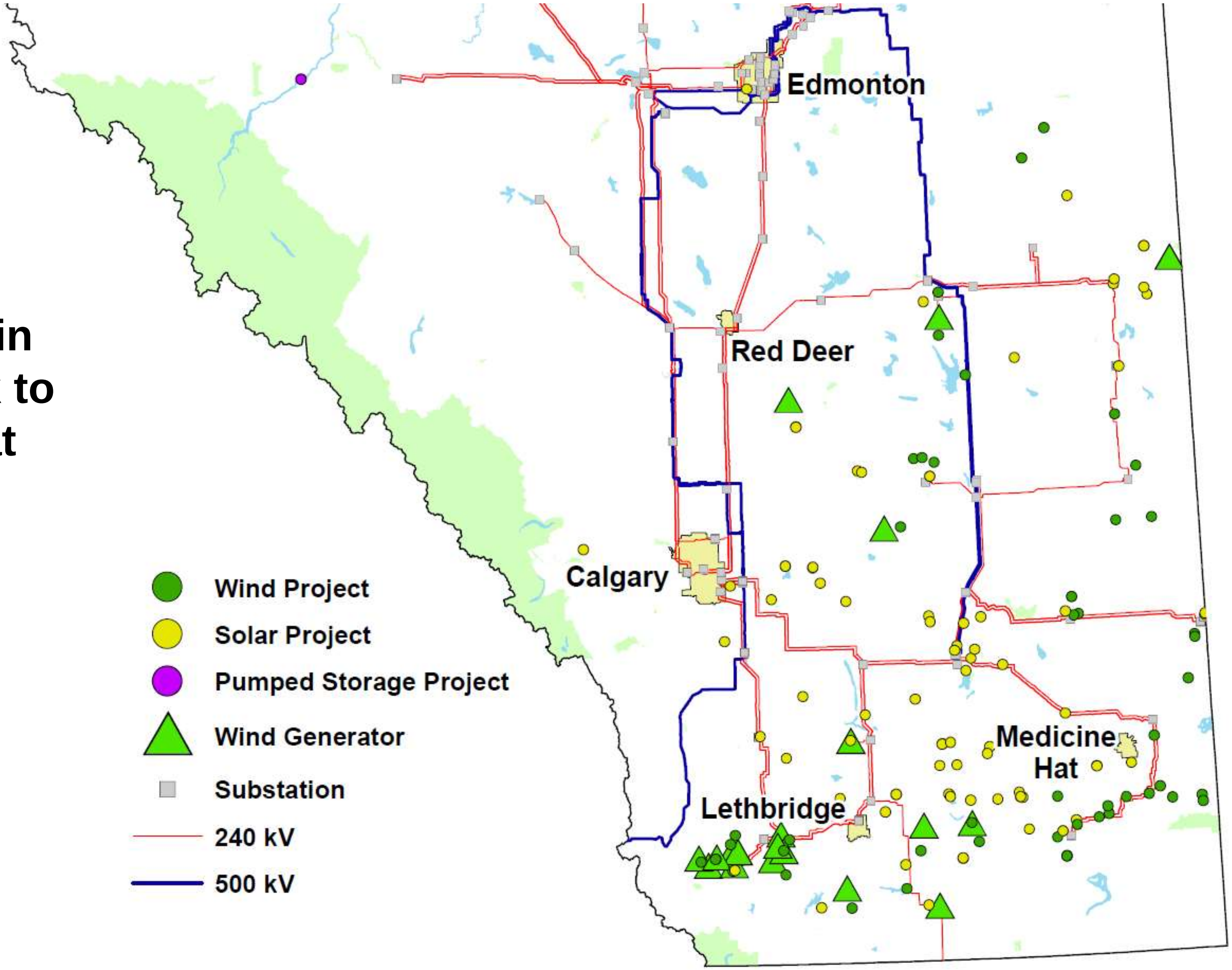
Renewable Energy Resources in Alberta





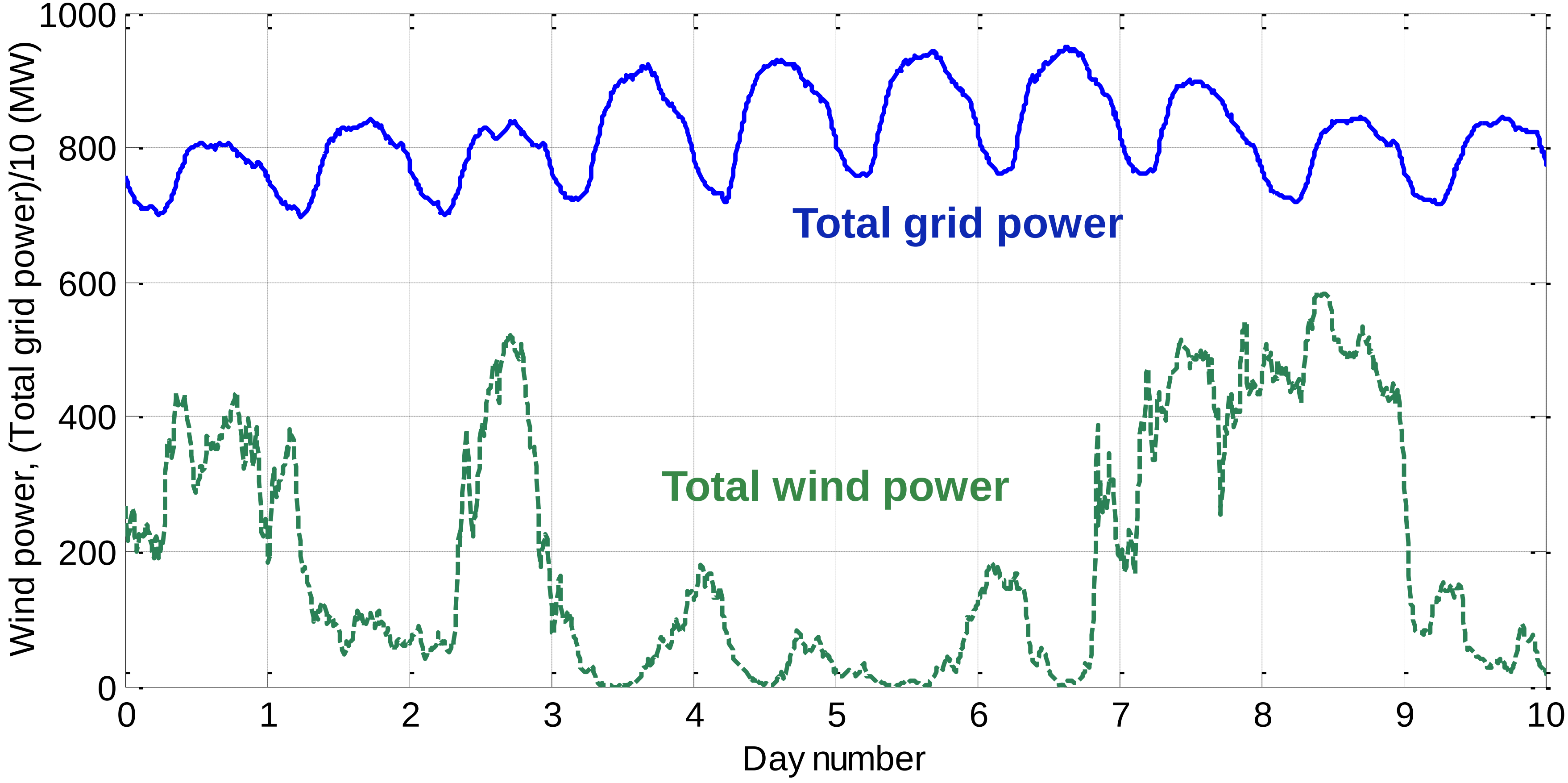
Wind Farms in Alberta

75% of wind in Pincher Creek to Medicine Hat corridor

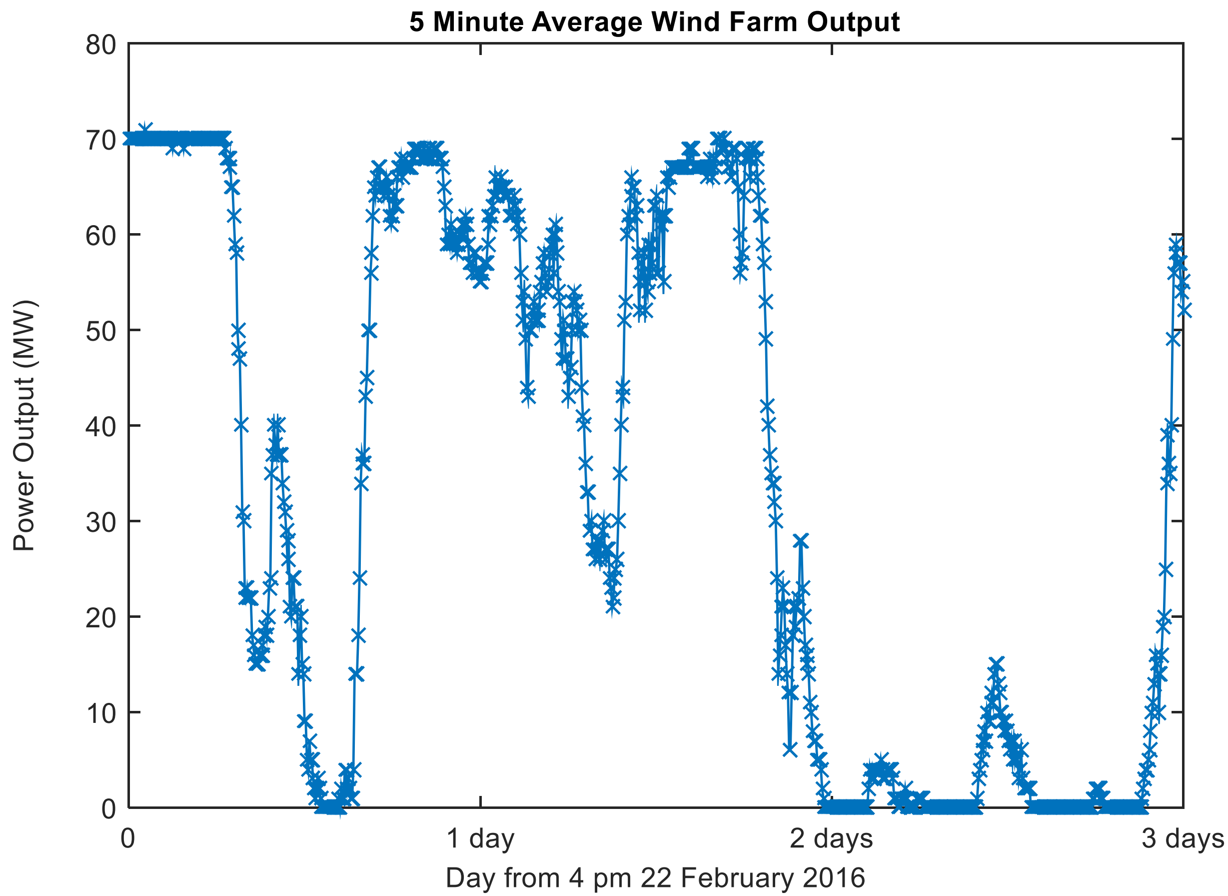


What does Intermittency Look Like?

10 days in Alberta in July 2011



Wind Farm Intermittency

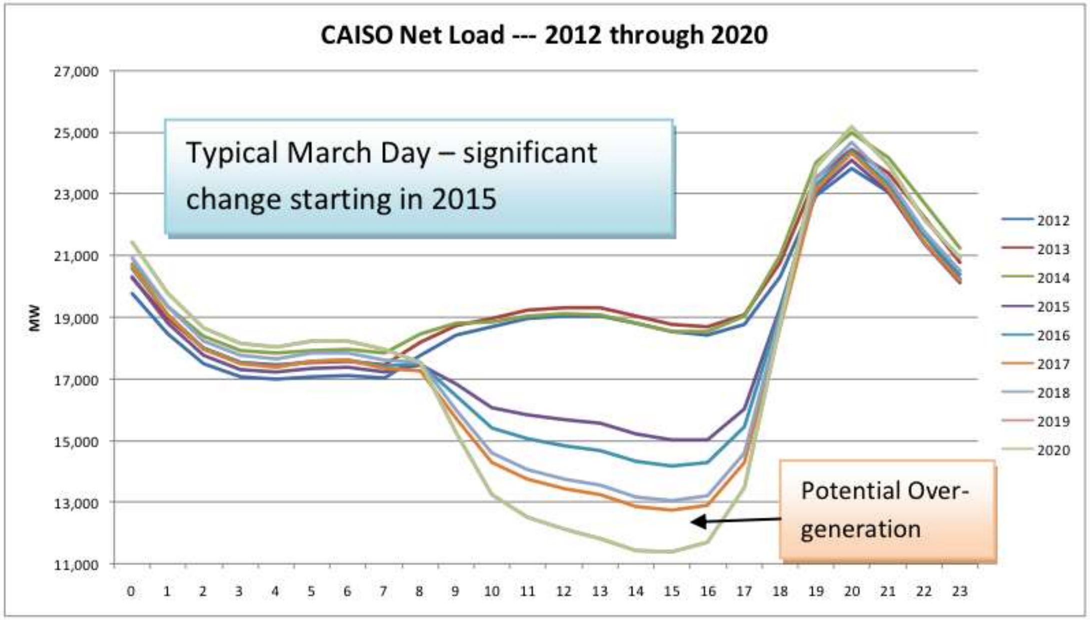


Over One Month:

- Max difference in 5 minute production = 34 MW
- Min difference in 5 minute production = -23 MW

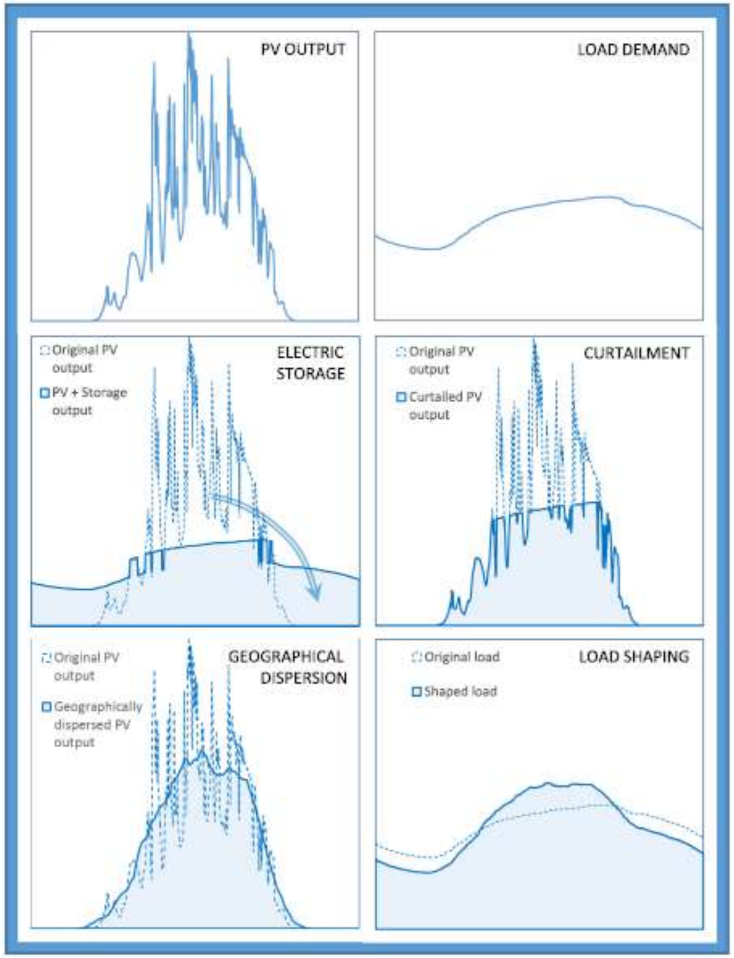
Dealing with Intermittency

California has 988,000 PV systems, most on rooftops. 8.24 MW capacity (http://www.gosolarcalifornia.org/)



Net load = System demand – renewable production

https://reneweconomy.com.au/graph-of-the-day-a-birds-eye-view-on-integrating-renewables-13656/



Perez, R., et al. (2016). Achieving very high PV penetration–The need for an effective electricity remuneration framework and a central role for grid operators. *Energy Policy*, *96*, 27-35.

Smoothing Output by Geographical Dispersion

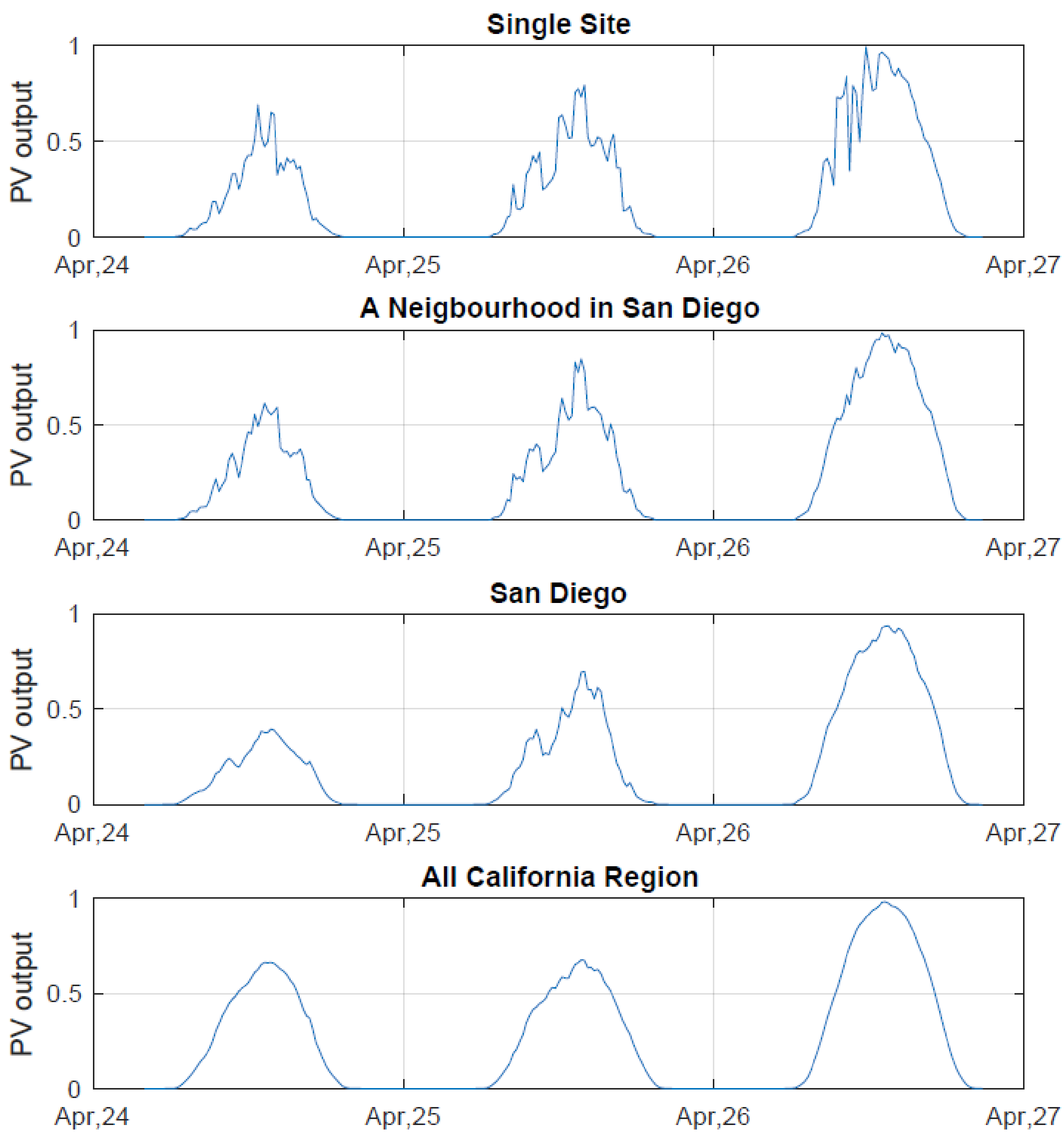
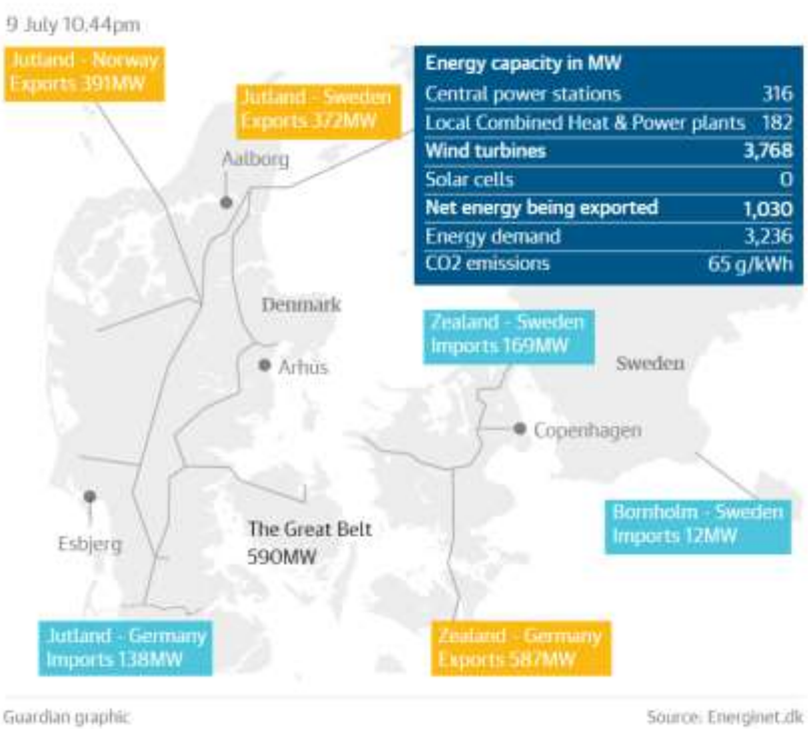


Figure provided by Dr Hamid Shaker

The Importance of Interties

Wind power generates 140% of Denmark's electricity demand

Unusually high winds allowed Denmark to meet all of its electricity needs – with plenty to spare for Germany, Norway and Sweden too



Energy capacity in MW	
Central power stations	316
Local Combined Heat & Power plants	182
Wind turbines	**3,768**
Solar cells	0
Net energy being exported	**1,030**
Energy demand	3,236
CO2 emissions	65 g/kWh

https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand

Features of the Alberta Electricity System

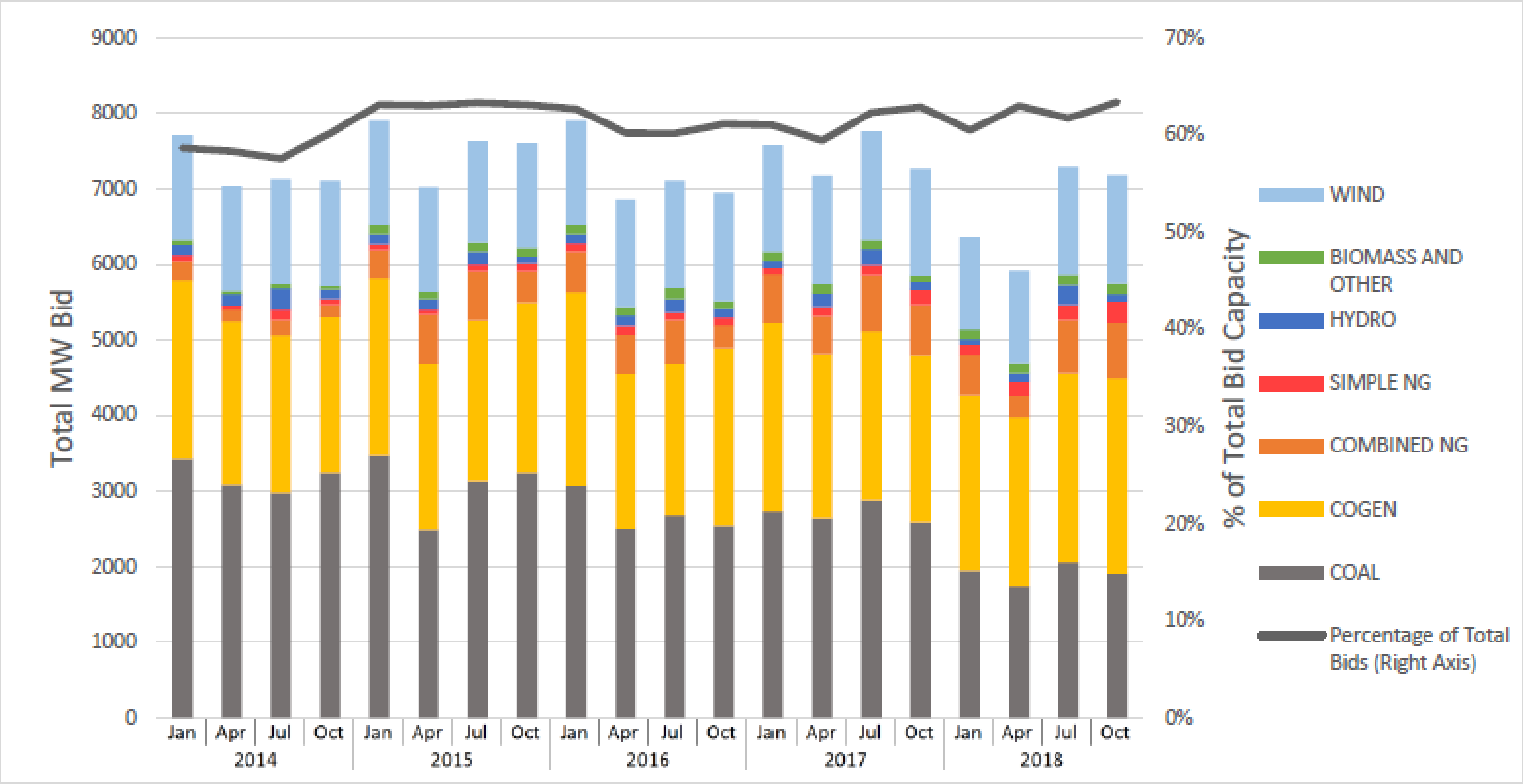


Figure 1: $0.00 bids for the period of January 2014-October 2018. The bars belong to the left-hand axis, showing the total MW bid for each generation type. The line belongs to the right-hand axis, showing percentage of total bids at $0.00. Note that wind bids prior to 2017 are estimated based on total capacity as wind bids did not appear until 2017.

Alberta Electricity Pool Prices

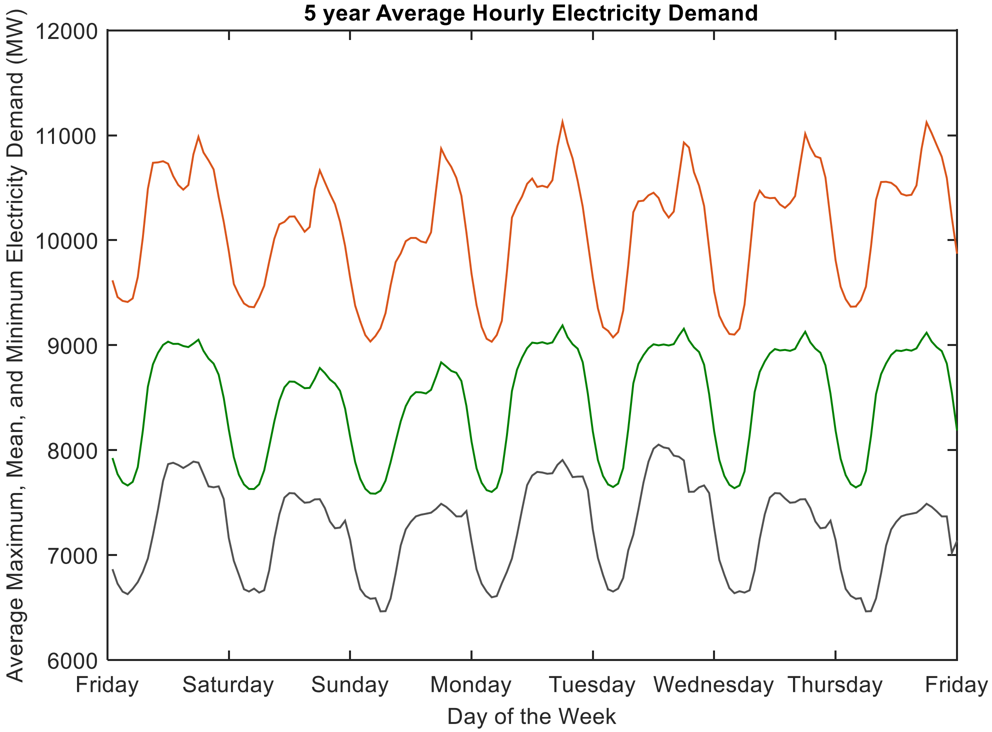
- Alberta has high fluctuations in electricity spot prices, moderate fluctuations in demand
- This data from 2011-2016
- Renewable Energy penetration currently < 10%
- Very small interties with BC, SK

As of December 2015

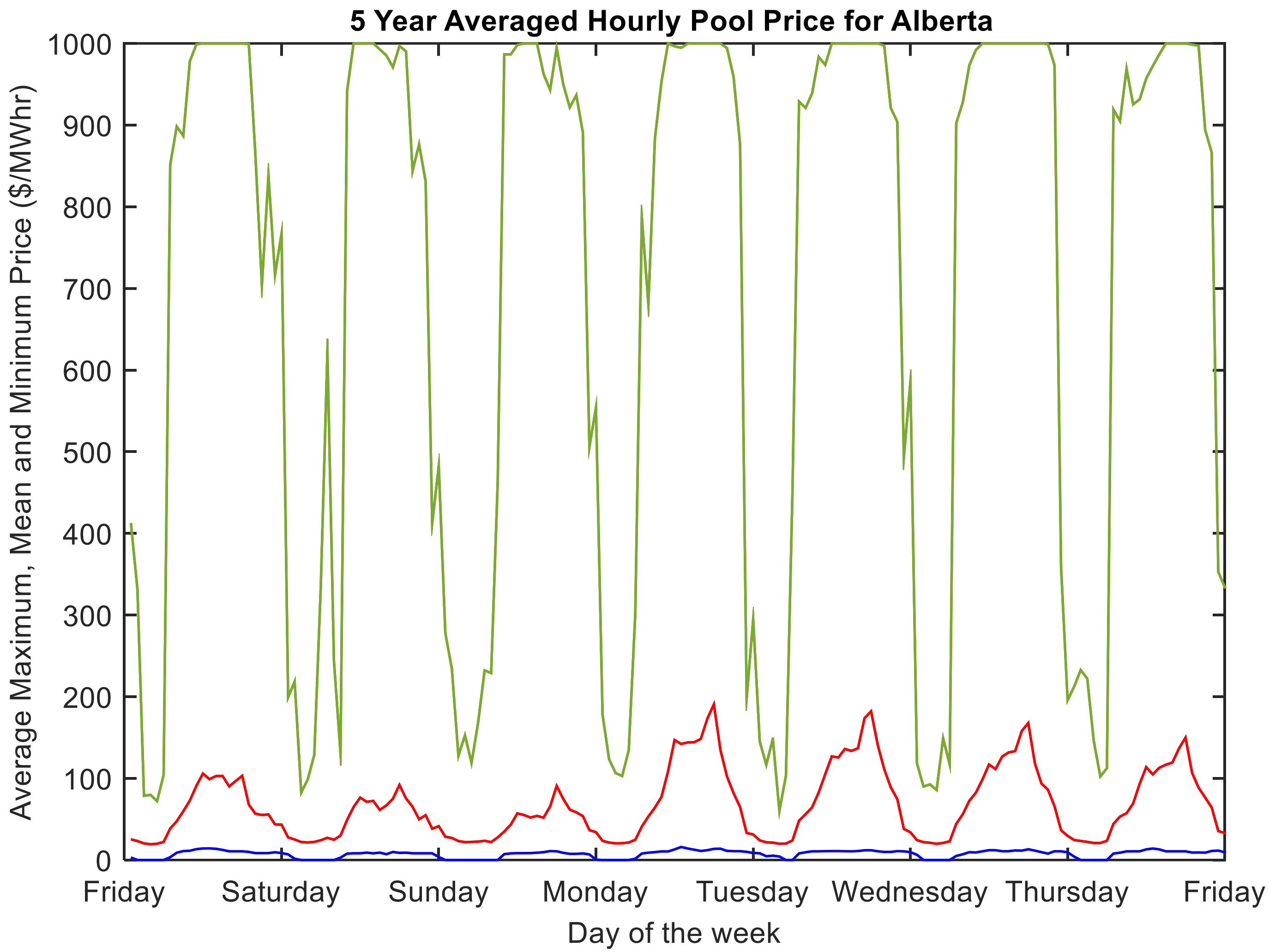
Generation	Gigawatt Hour (GWh)	Generation Share By Fuel
Coal	41,378	51%
Natural Gas	32,215	39%
Hydro	1,745	2%
Wind	3,816	5%
Biomass	2,149	3%
Others*	318	0%
Total	**81,621**	**100%**

*Others include solar, wind, fuel oil and waste heat

Source: Alberta Utilities Commission (AUC)

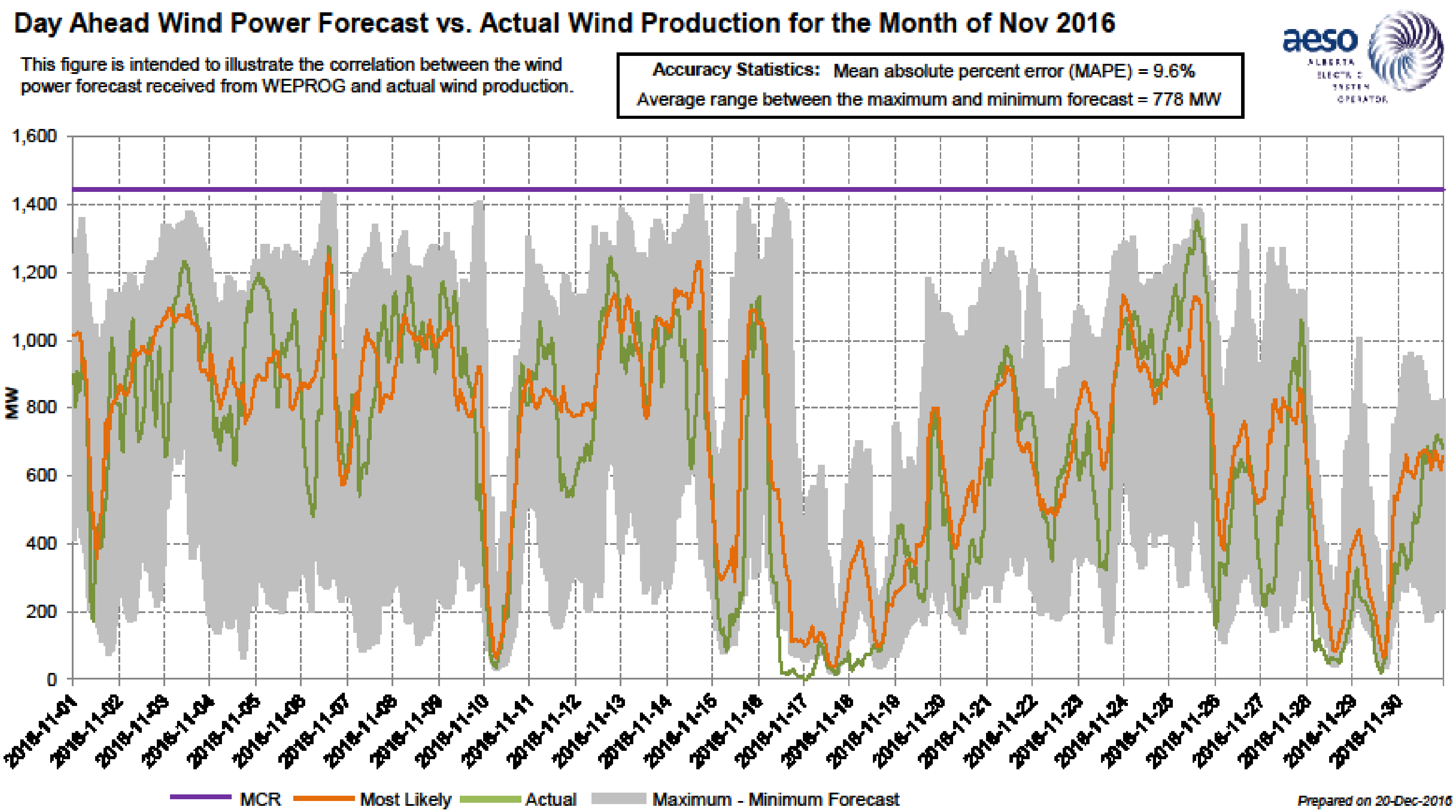


Alberta Electricity Pool Prices



This and the demand figure on the next slide from: Abiola Adebayo “Techno-economics of Energy Storage Systems in Electricity Market”, MSc thesis, University of Calgary, Sept 2016

Alberta Wind Power Forecasting



If We Knew the Merit Order – Demand Management

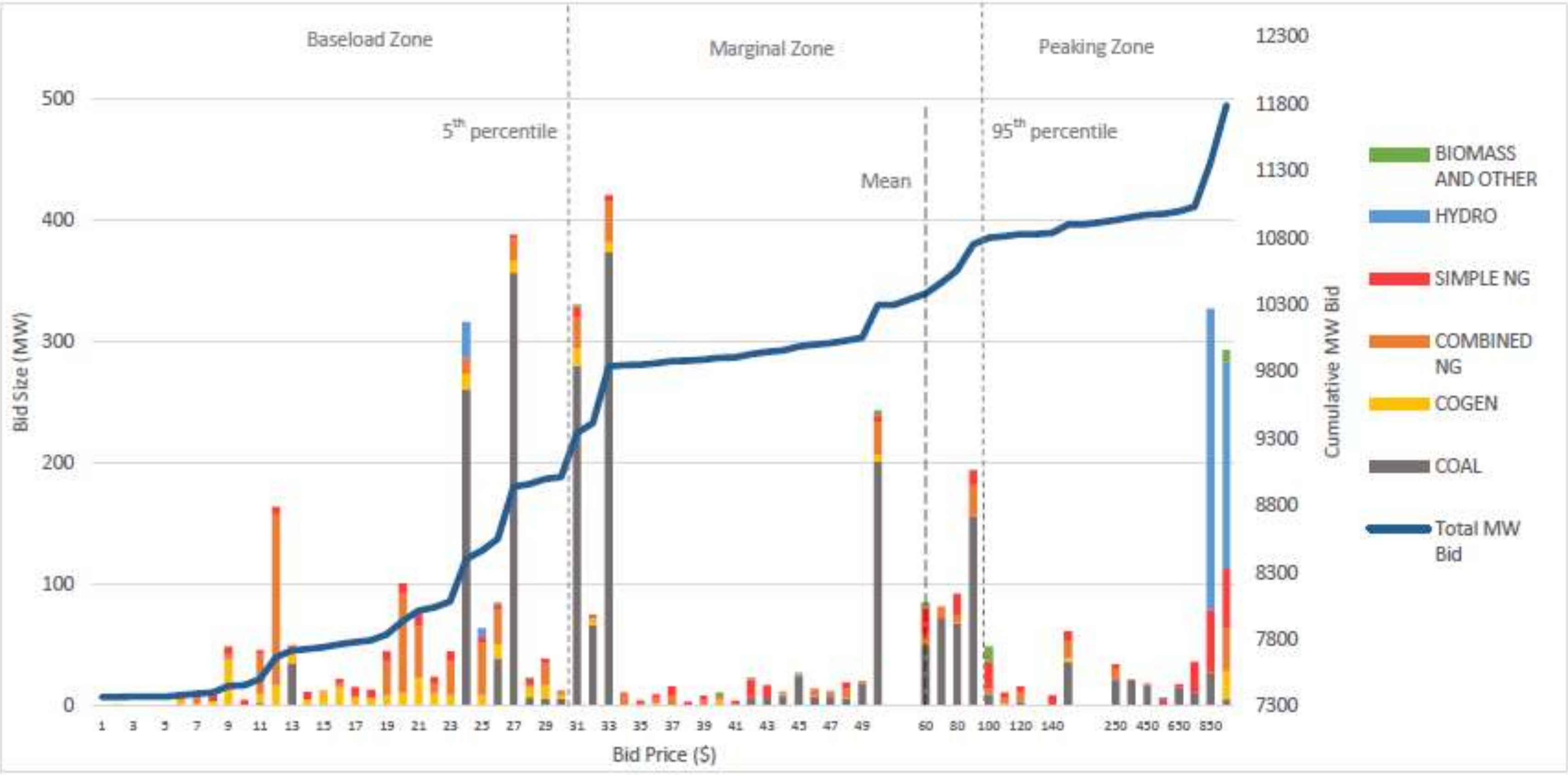


Figure 2: Power bids allocated based on bid price for the month of October 2018. Bars belong to the left-hand axis, showing the power capacity of bids in MW. The line belongs to the right-hand axis, showing the sum of the bids up to that price. The vertical lines represent the 5th percentile, mean, and 95th percentile of spot price in October 2018. The marginal zone is defined between the 5th and 95th percentile where price regularly fluctuates, baseload is below the 5th percentile, and peaking above the 95th. Note that the right axis beings at 7,300 MW where $0.00 bids end and the breaks in the x-axis scale at $50 and $150.

Storage: Power & Energy

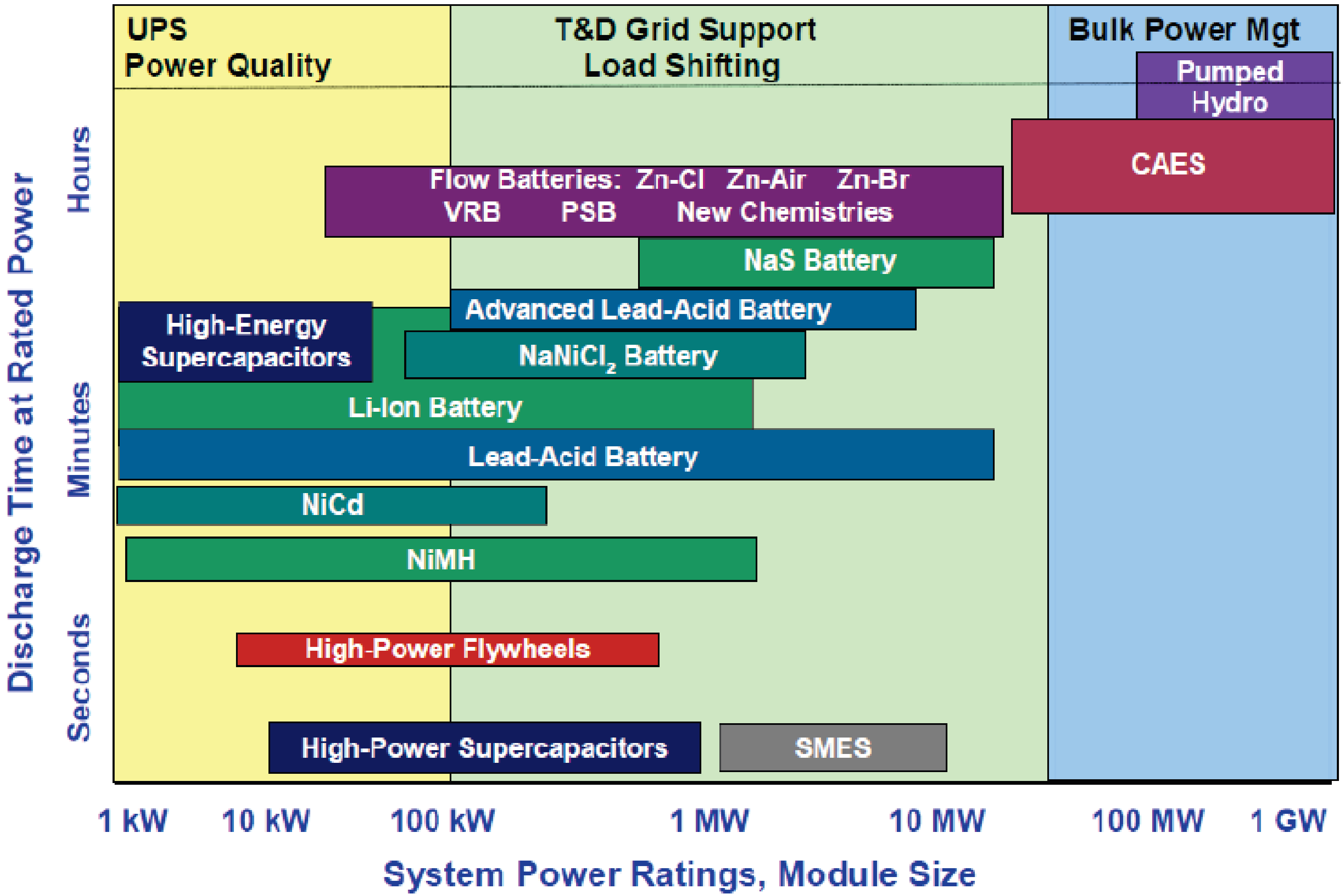
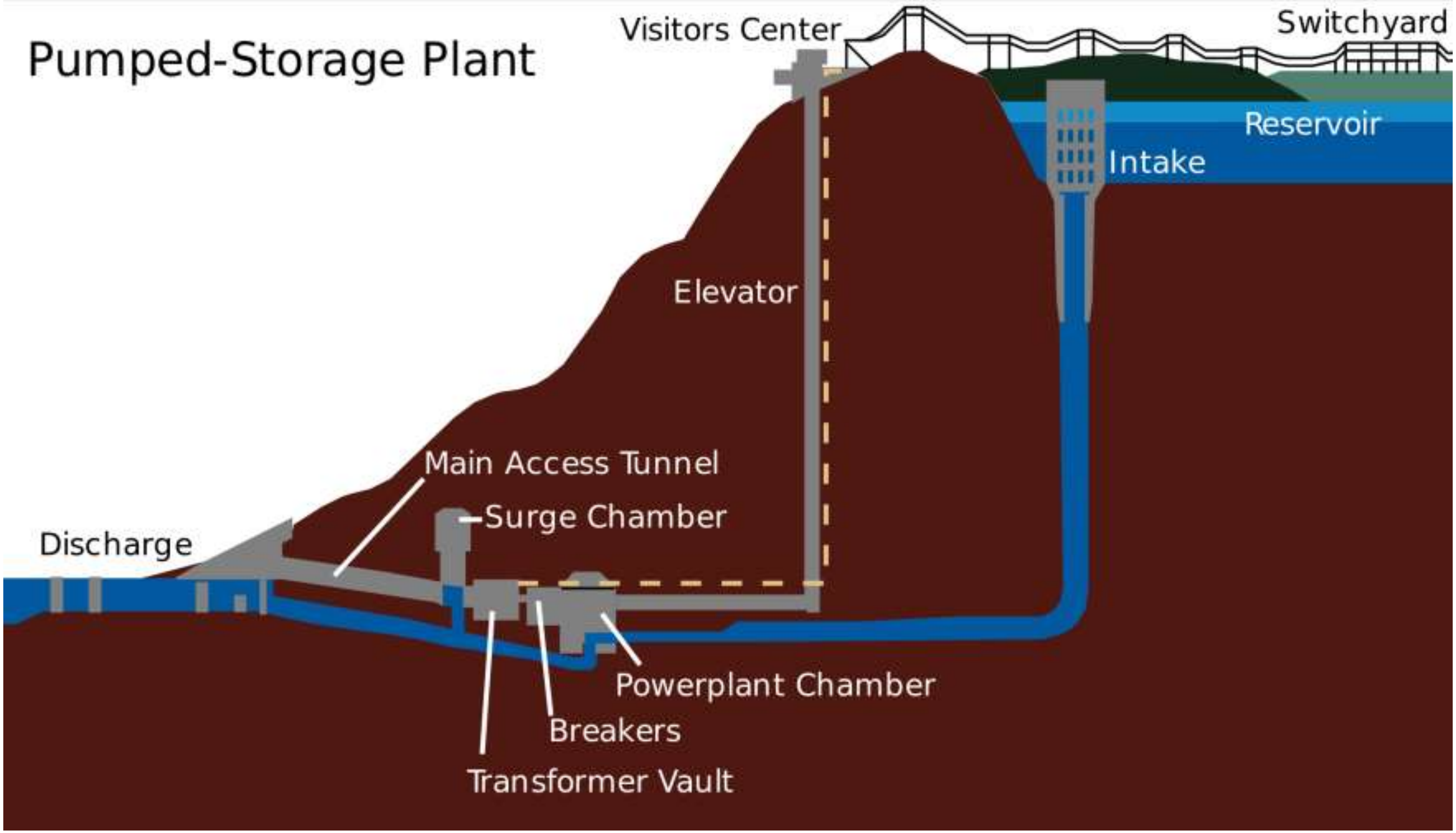


Figure 19. Positioning of Energy Storage Technologies

https://www.osti.gov/biblio/1431469-doe-epri-electricity-storage-handbook-collaboration-nreca

Raccoon Mountain Pump Storage
1650 MW for 22 hours



https://commons.wikimedia.org/wiki/File:Raccoon_Mountain_Pumped-Storage_Plant.svg

Flywheels

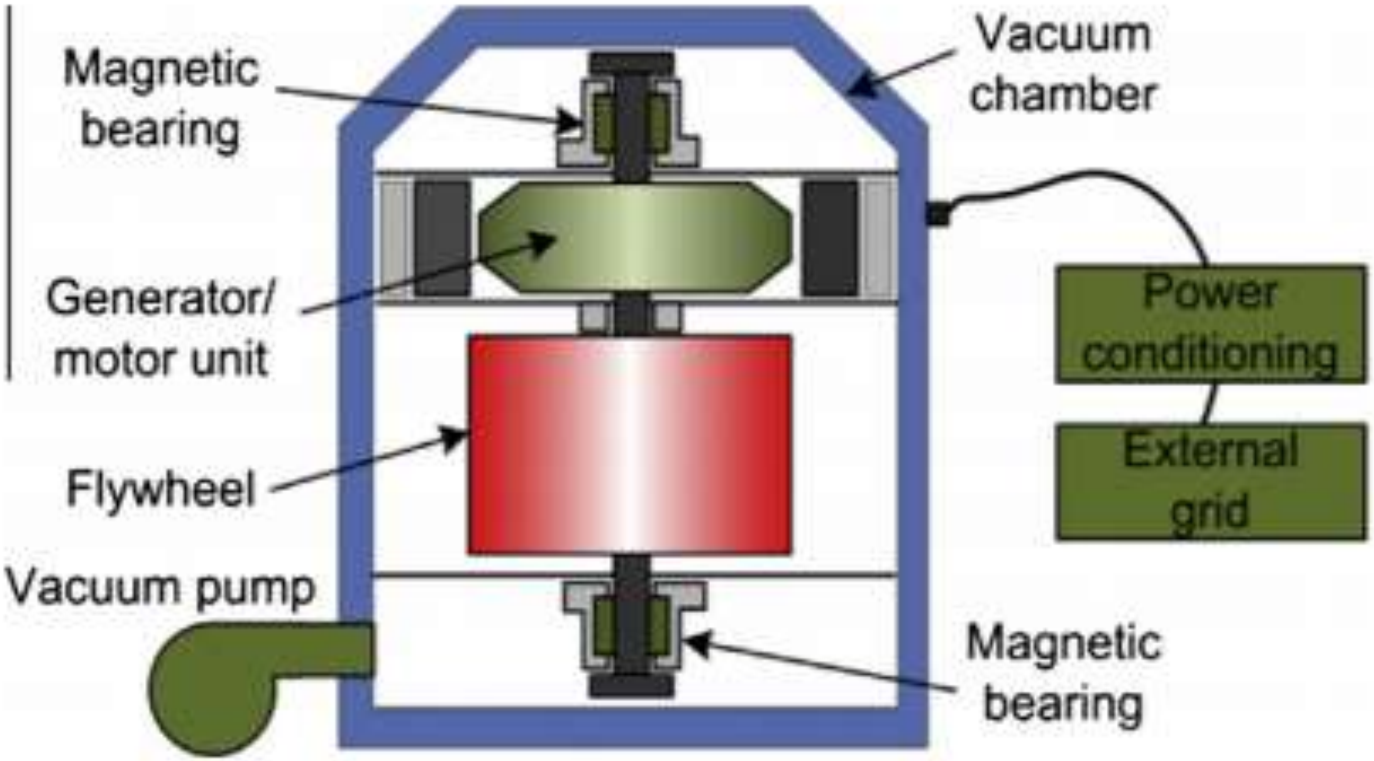


Fig. 6. System description of a flywheel energy storage facility.

Luo, X., Wang, J., Dooner, M., & Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Applied Energy*, *137*, 511-536. (next slide as well)

Compressed Air Energy Storage

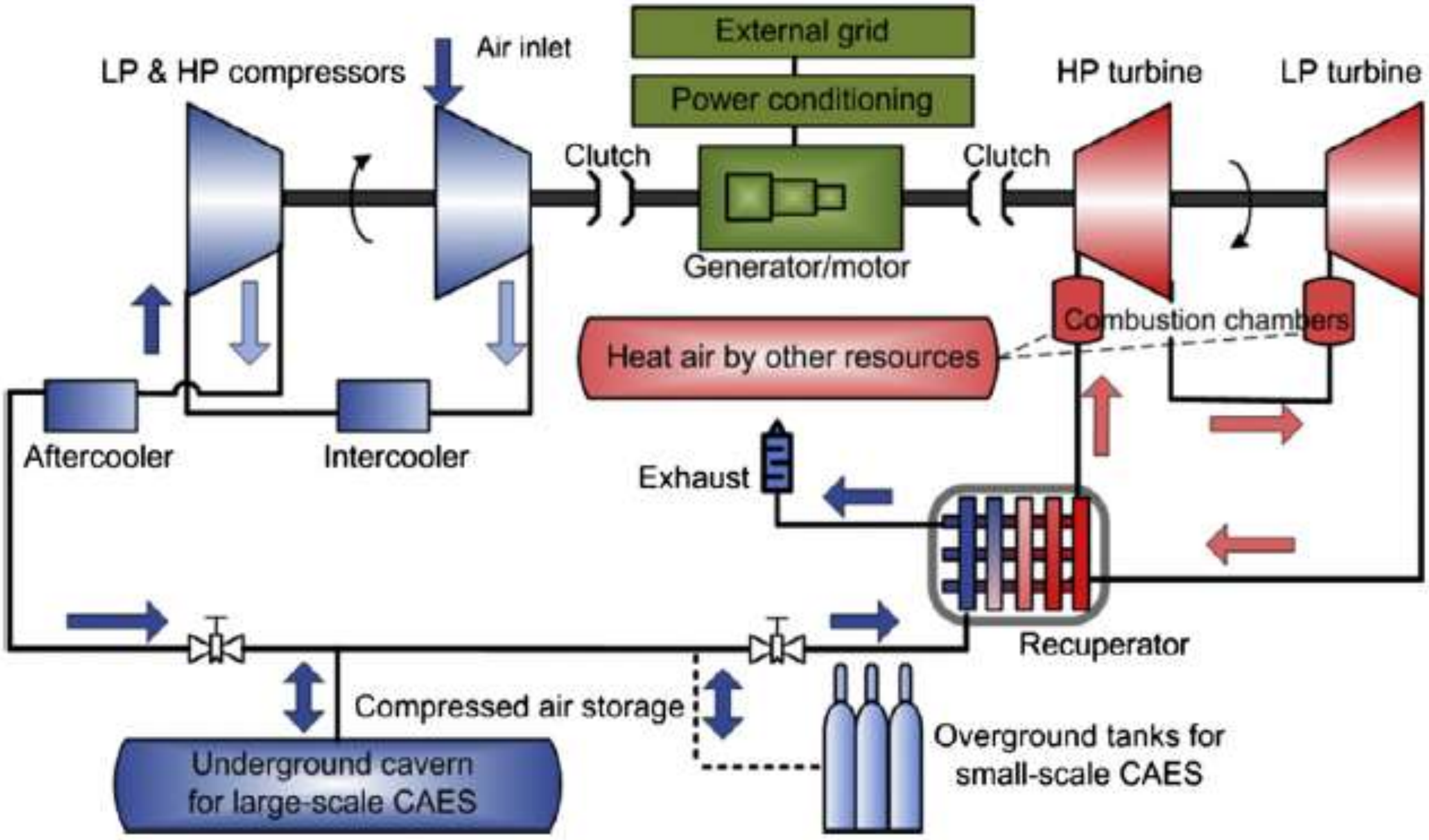
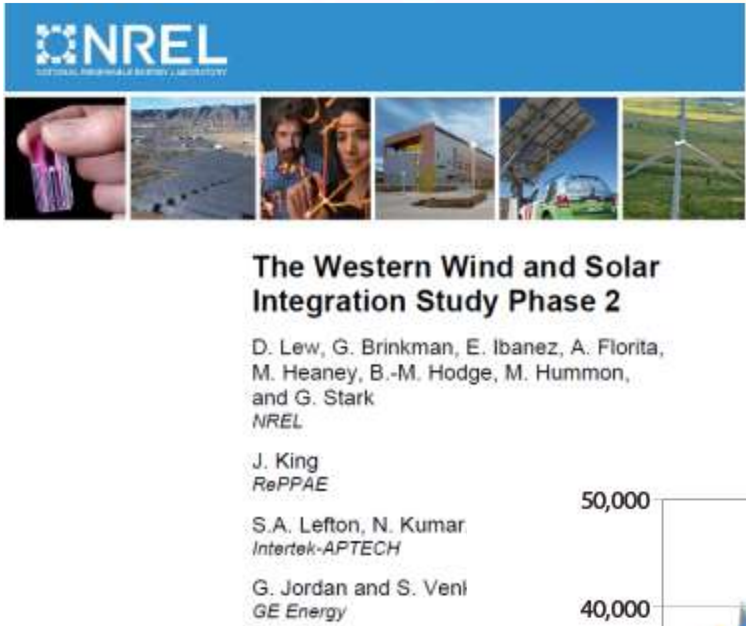


Fig. 5. Schematic diagram of a CAES plant/facility.

https://estoolbox.org/index.php/background/8-samples/9-caes-introduction

How Quickly Can a Generator Ramp Up or Down?

- Hydro and gas turbines ramp times are in minutes
- Flywheels, Batteries and CAES also in minutes
- Coal can be fast but rapid ramping can damage the system
- Nuclear very slow



NREL

The Western Wind and Solar Integration Study Phase 2

D. Lew, G. Brinkman, E. Ibanez, A. Florita, M. Heaney, B.-M. Hodge, M. Hummon, and G. Stark
NREL

J. King
RePPAE

S.A. Lefton, N. Kumar
Intertek-APTECH

G. Jordan and S. Venl
GE Energy

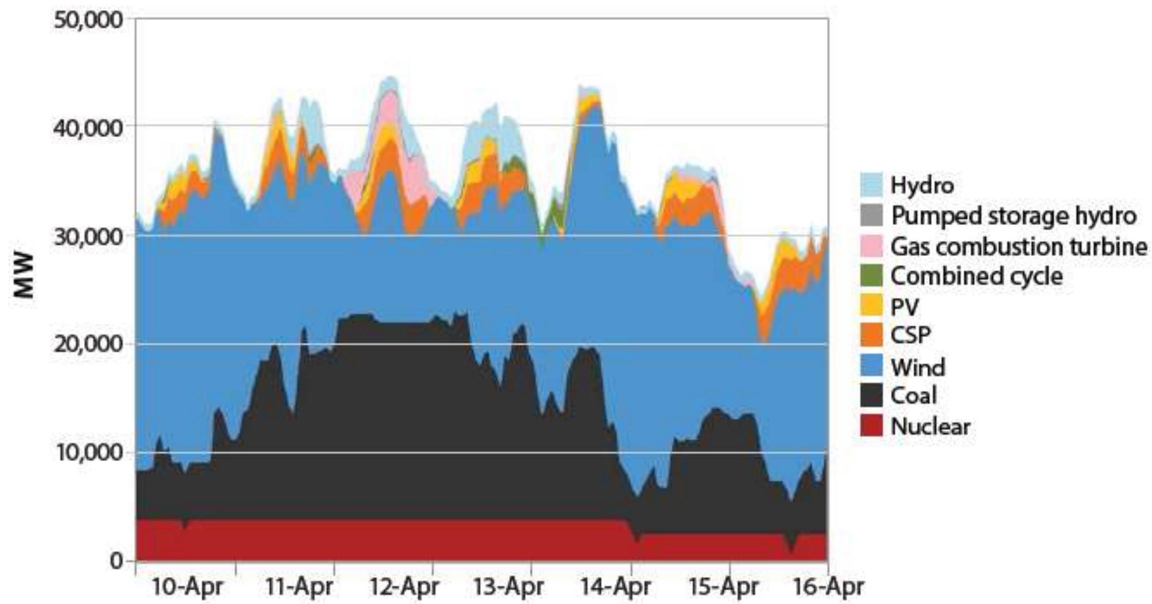


Figure ES-1. WWSIS-1 dispatch for the most challenging week of 3 years of data analyzed

Notes: PV, photovoltaic; CSP, concentrating solar power

What is Your Dream Electricity System?

- As much wind power as possible
- As much solar power as possible
- Strong interties with BC to get hydro power when needed
- Sufficient batteries to share with hydro power
- Keep the gas turbines
- Retire coal power
- Do not allow nuclear power
- Transparency in system operation to allow consumers to see the merit order
- Encouragement of demand management:
  - Data centres
  - Large cold stores