High-Temporal-Resolution Analysis of UK Power System Used to Determine the Optimal Amount and Mix of Energy Storage Technologies

John Barton, j.p.barton@lboro.ac.uk

Murray Thomson, m.thomson@lboro.ac.uk

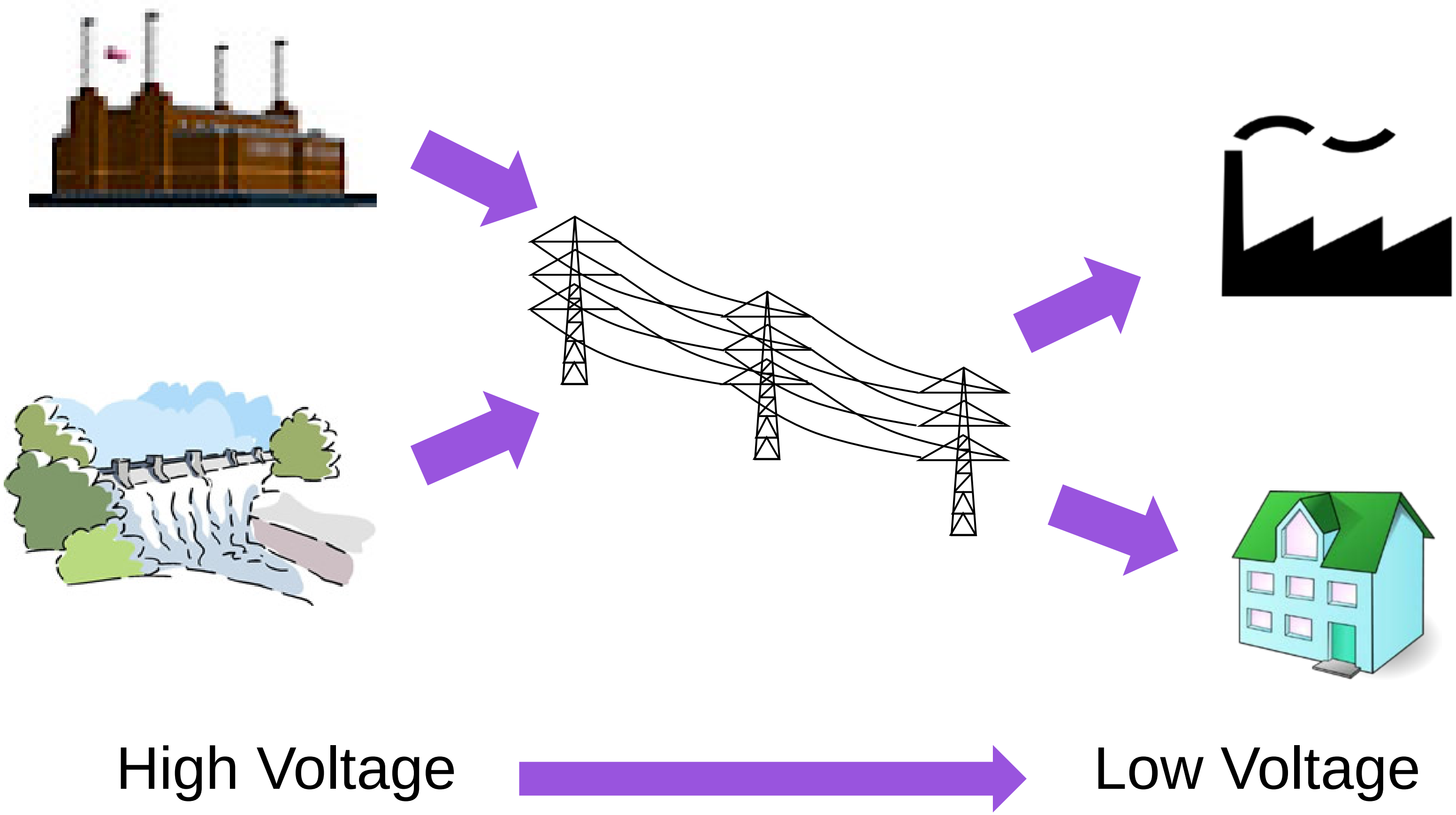
Centre for Renewable Energy Systems Technology (CREST),

Loughborough University

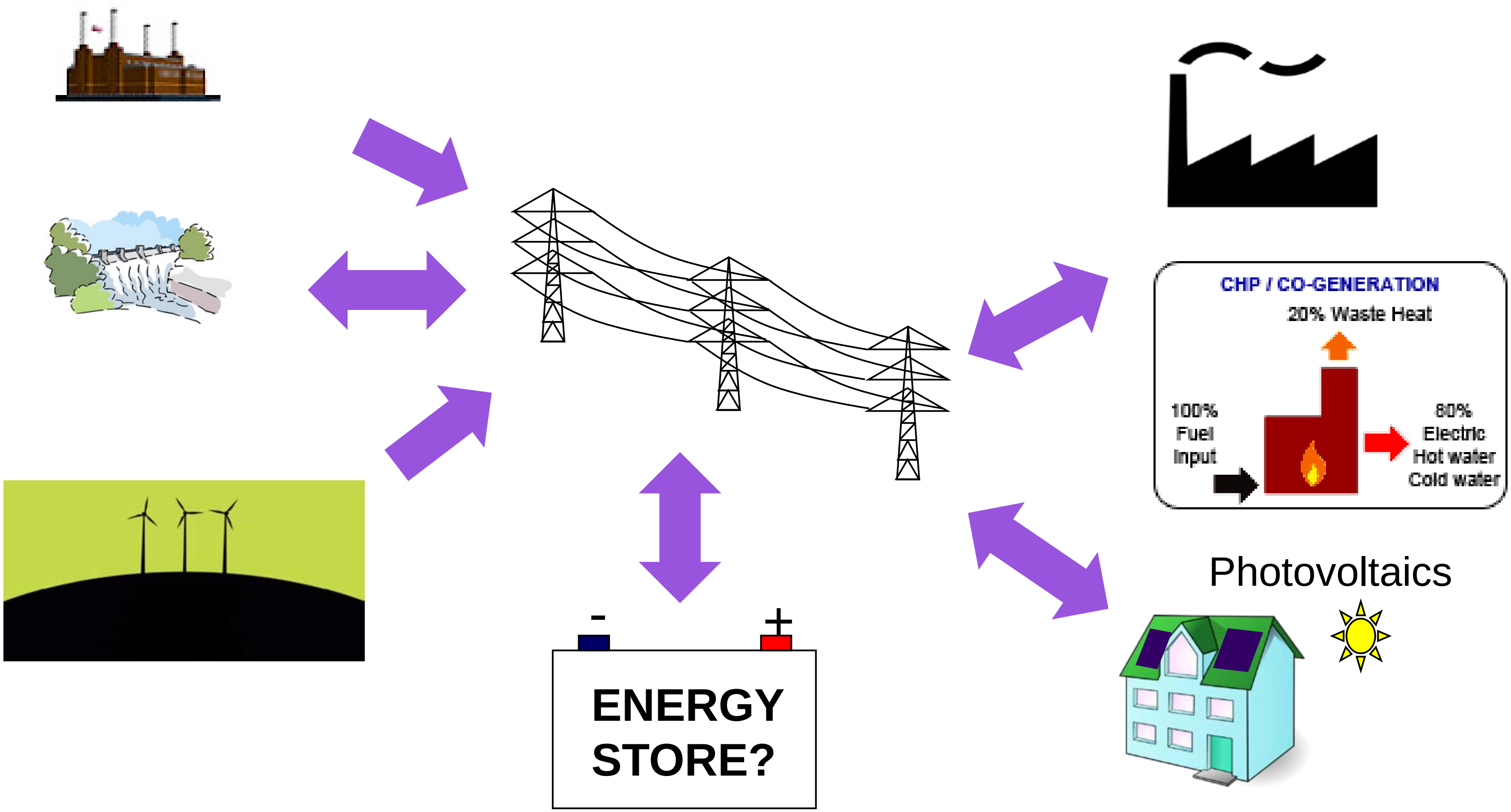
Analysis of UK Power System & Energy Storage

- Electricity System Modelling
- FESA Time-step model (my model)
- Electricity System Economics
- DECC 2050 Calculator and Example Scenarios
- Energy Storage Modelling Method
- Optimum Power / Energy Ratio
- Energy Storage Technologies
- Optimal Size and Technology Mix of Storage
- Conclusions

The Old System
Power stations generate whatever the loads demand
Power only flows one way

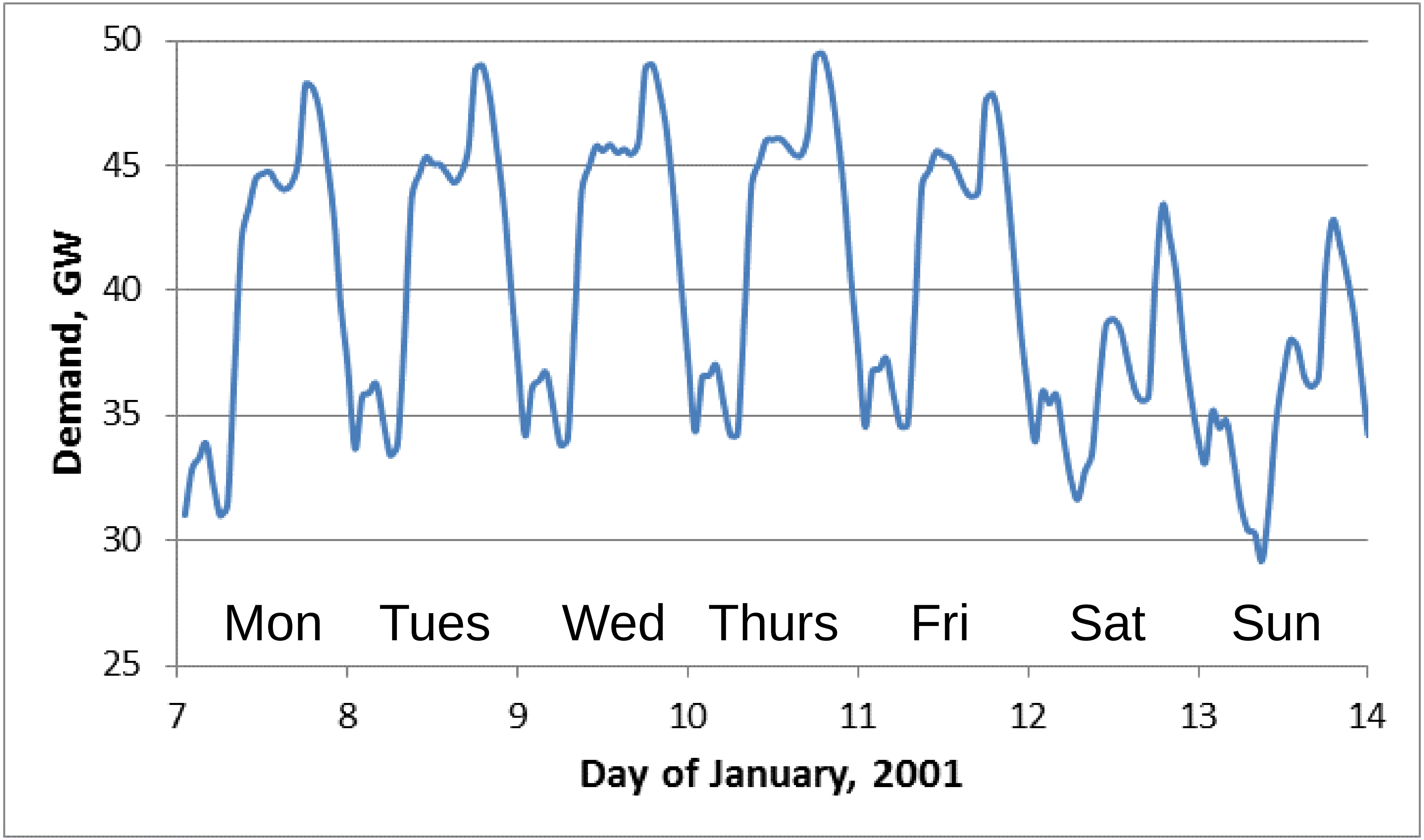


New System – More complicated
Power flows in all directions
Supply is much more variable

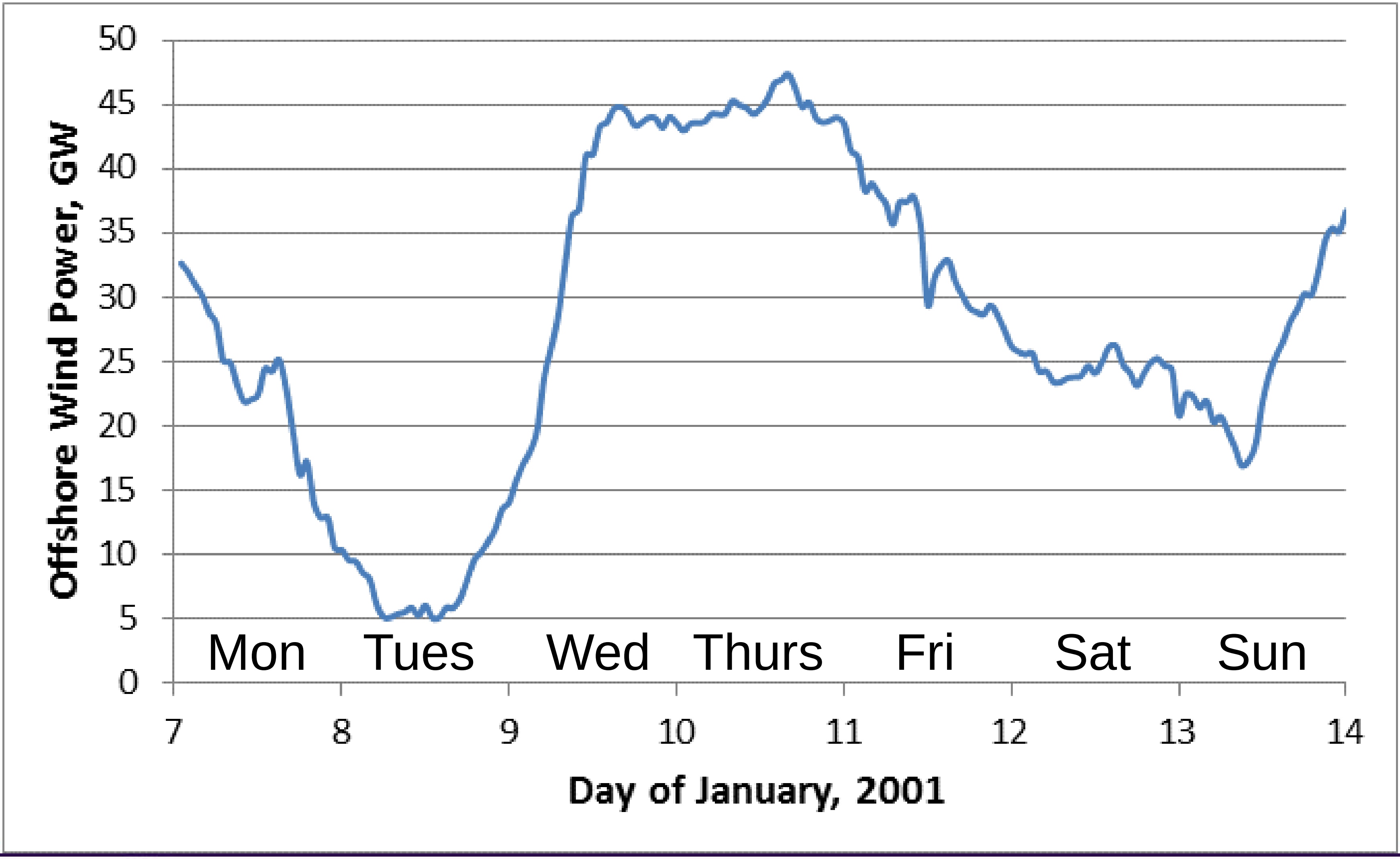


Loughborough University

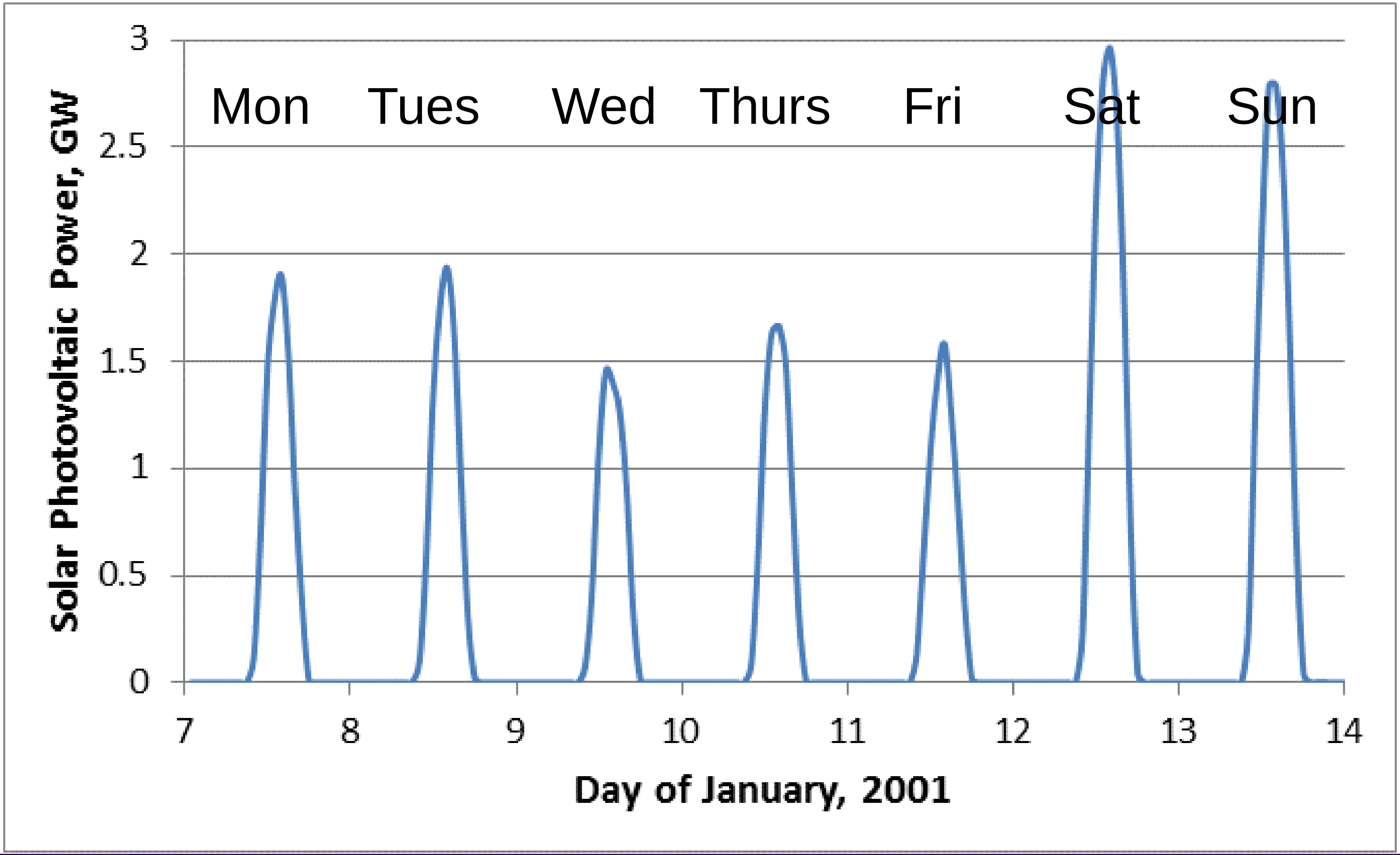
Electricity demand has a predictable, repeating pattern. Depends on weather, time of year, in a predictable way.



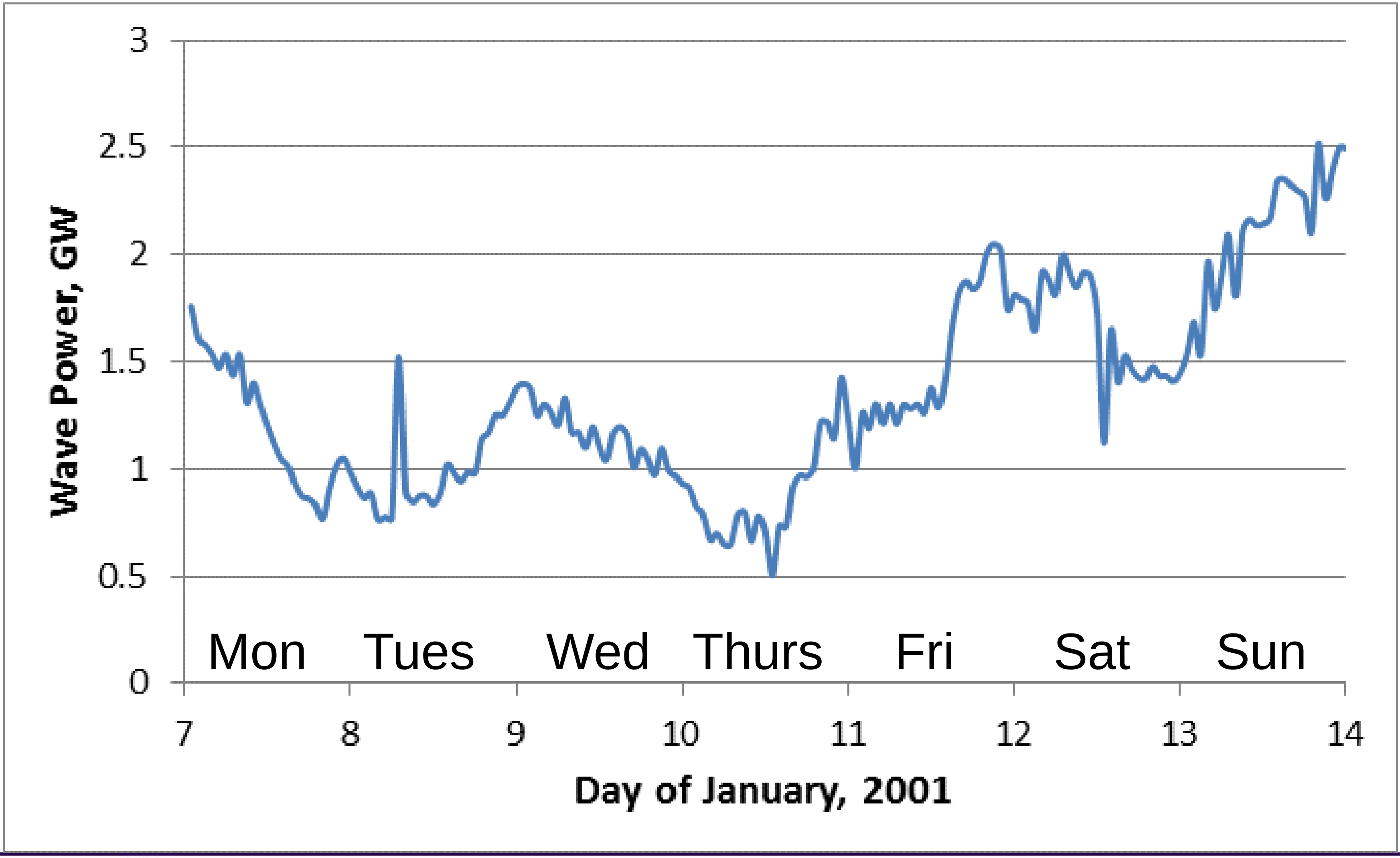
Wind power varies randomly, with greater min-max variation. A bit more wind in winter than summer



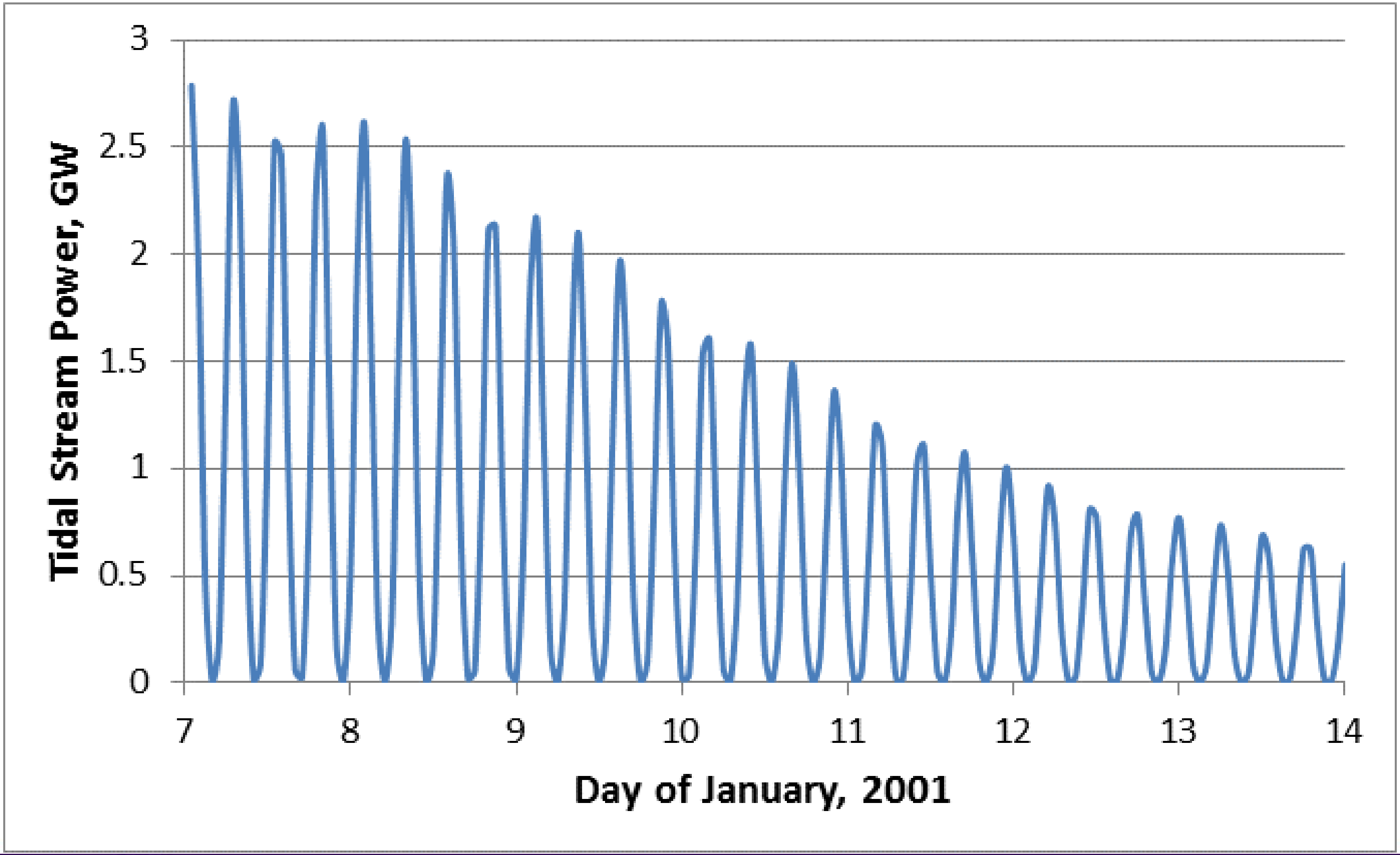
Solar PV is fairly predictable, but no contribution to peak demand, and much more in summer than winter



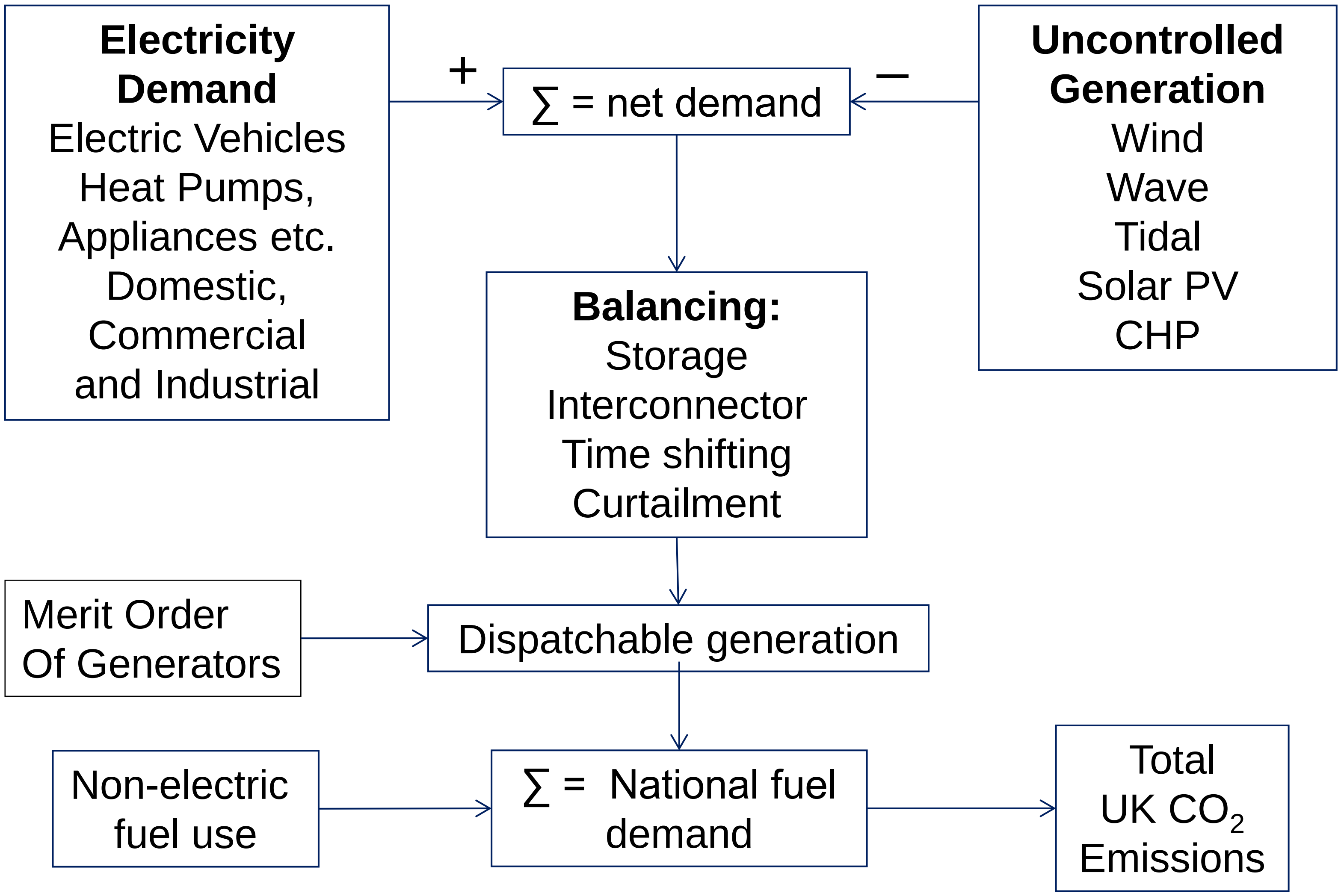
Wave power varies randomly, like wind power, but is a bit less variable. Bigger waves in winter than summer



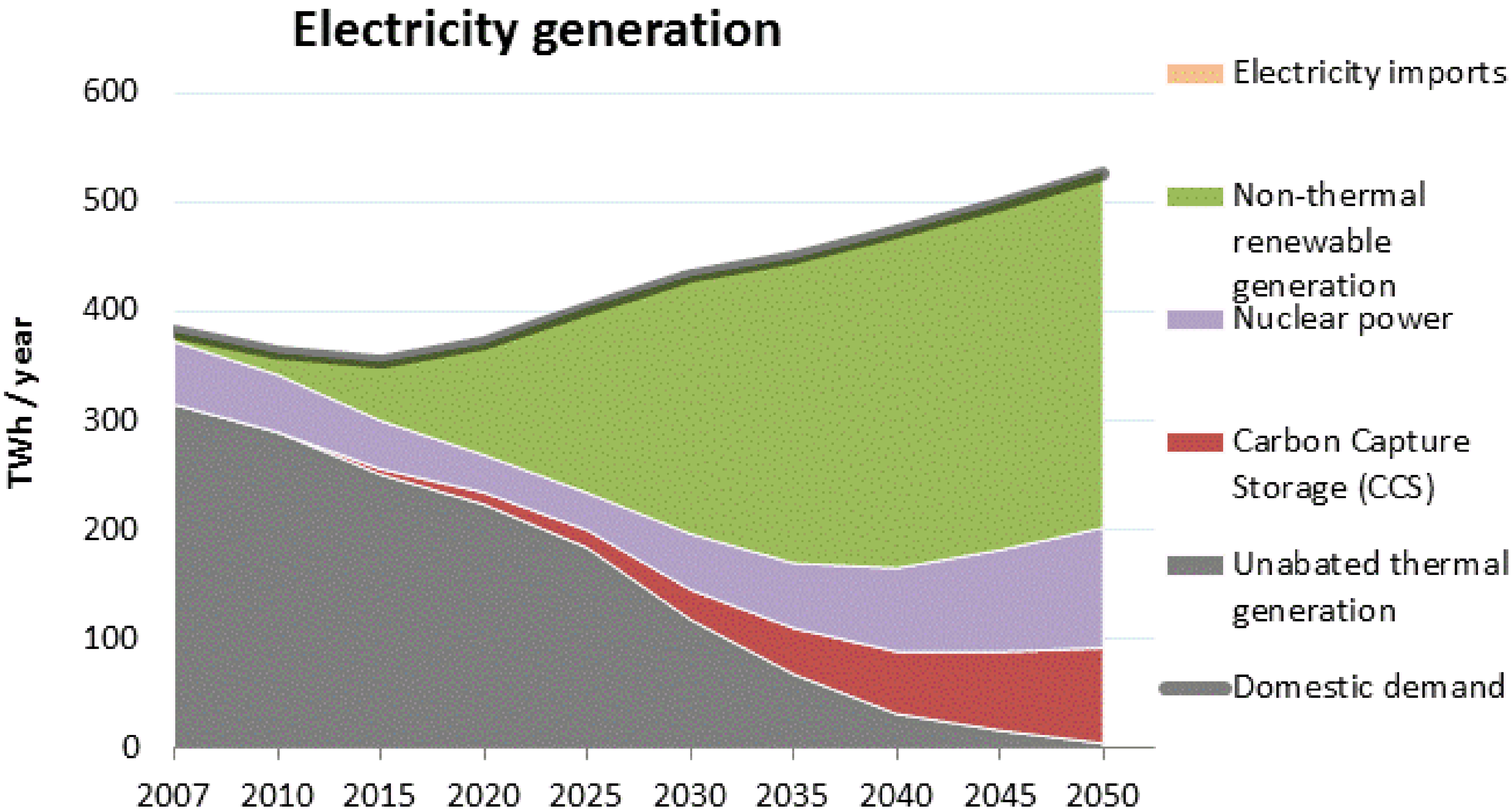
Tidal power is predictable but still very variable



Overview of FESA, "Future Energy Scenario Analysis"



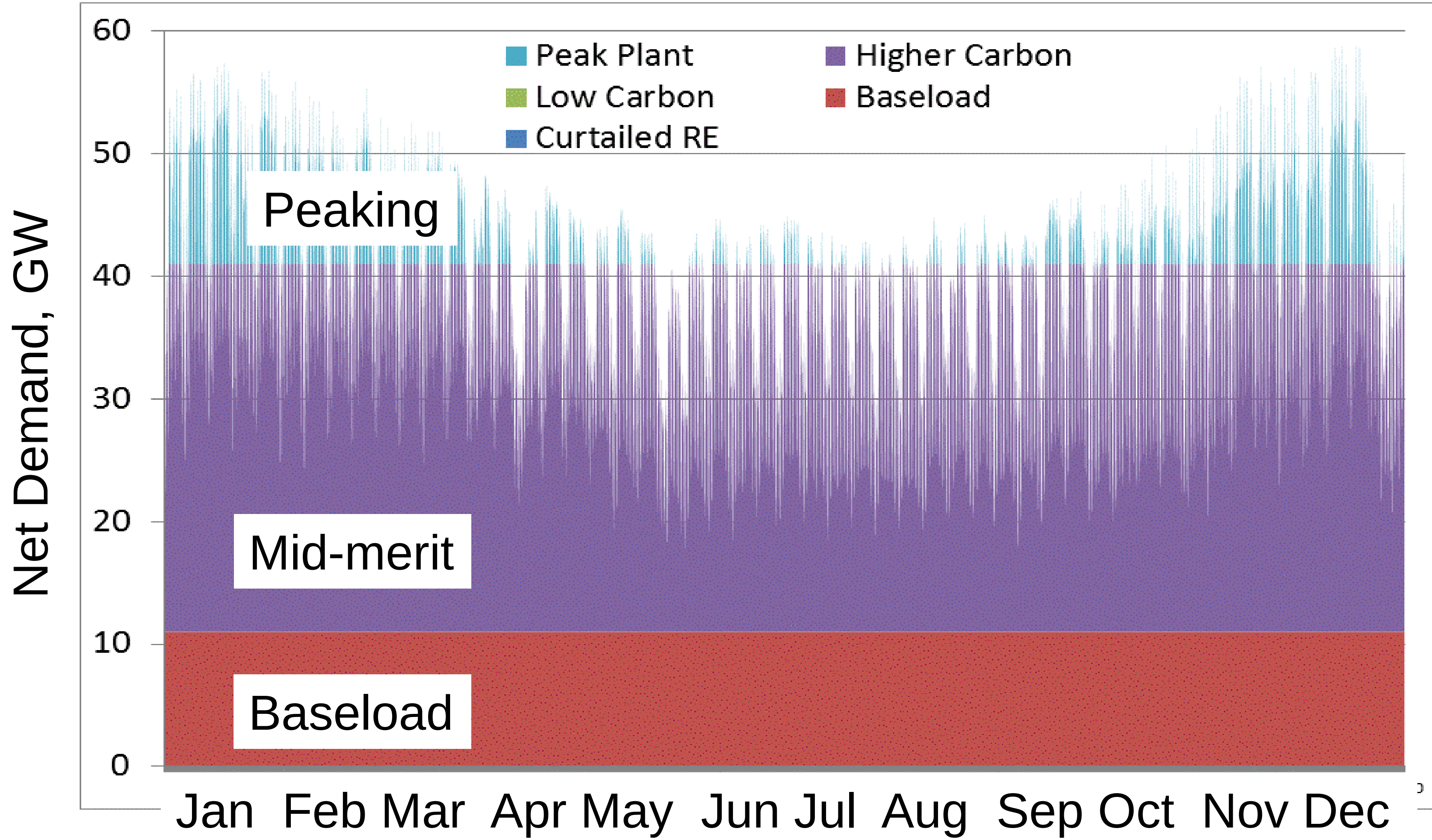
This is why net demand gets more variable



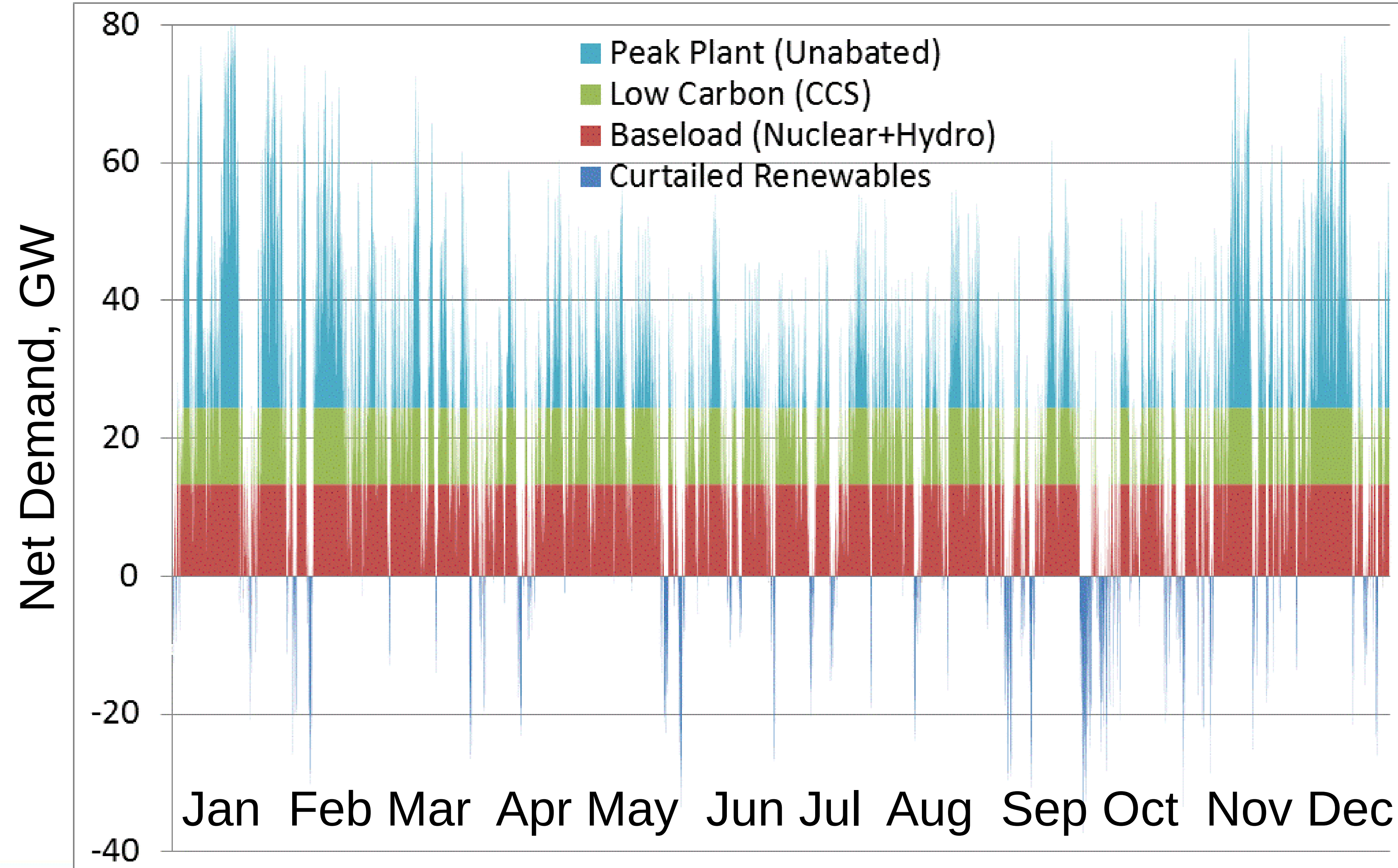
Merit Order of Generation

- Electricity companies first choose or ‘despatch’ the power stations with cheapest running costs = ‘baseload’.
  - E.g. nuclear likes to run all the time.
- Then ‘mid-merit’ generation.
  - Cheaper to build vs. more expensive to run
  - Typically coal or combined-cycle gas (CCGT)
- Finally ‘peaking’ plant
  - Cheap to build or very old power stations
  - Most expensive to run
  - Open cycle gas turbines (OCGT) or oil fired

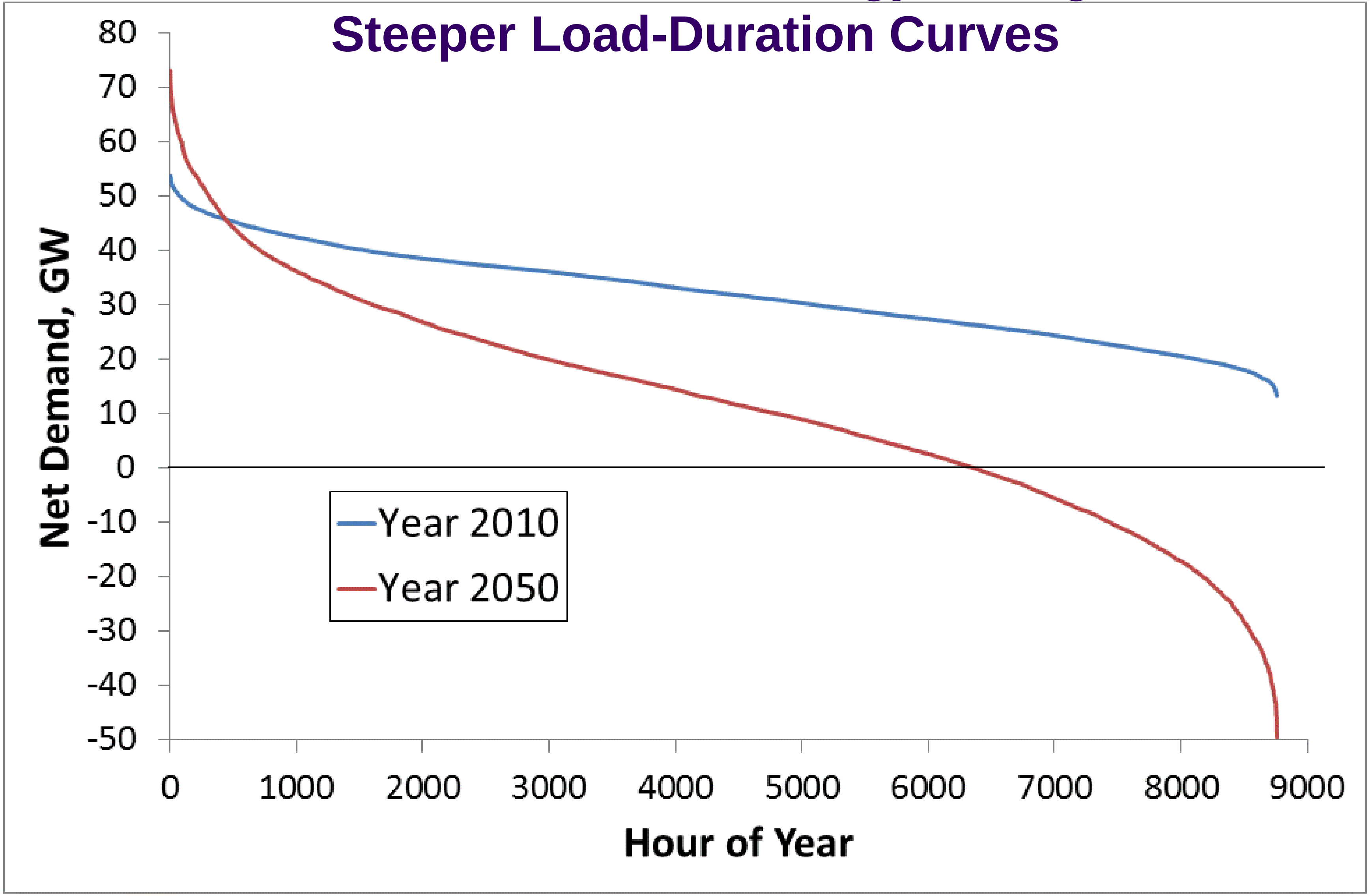
Net Demand in 2010 (Approximate Generation Mix)



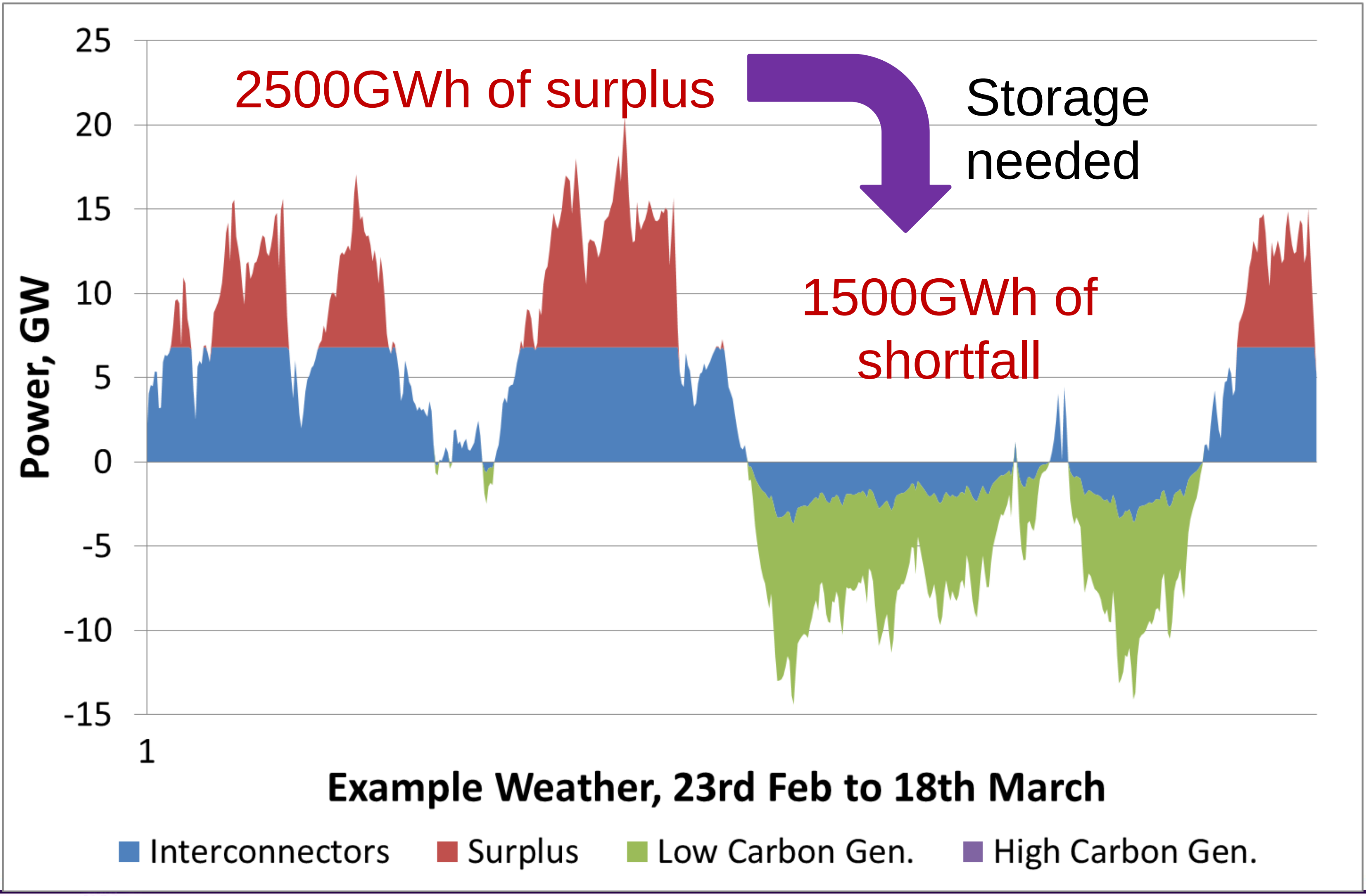
DECC 2050 Calculator (Higher Renewables Scenario in 2050)



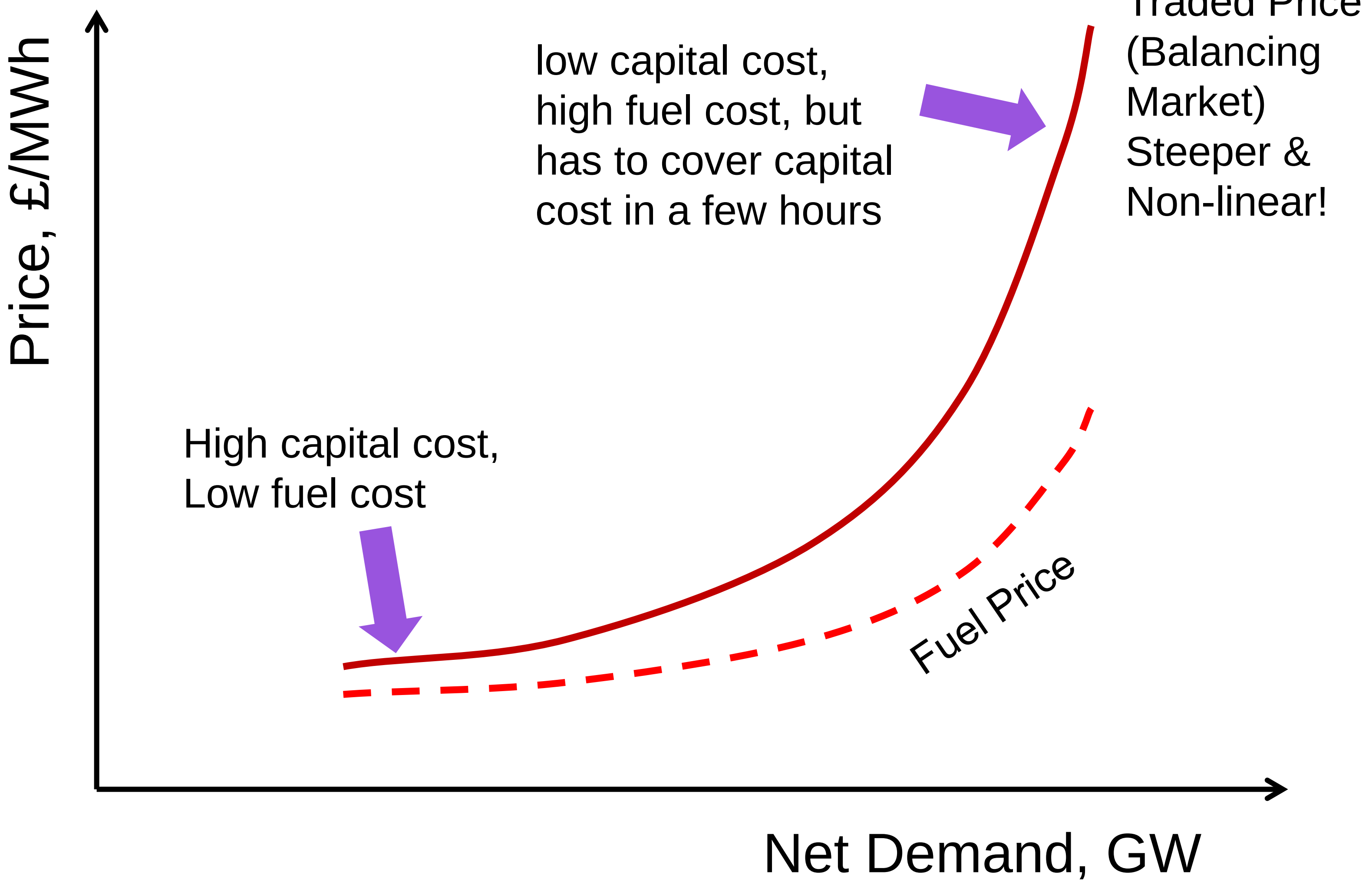
The Future Need for Energy Storage: Steeper Load-Duration Curves



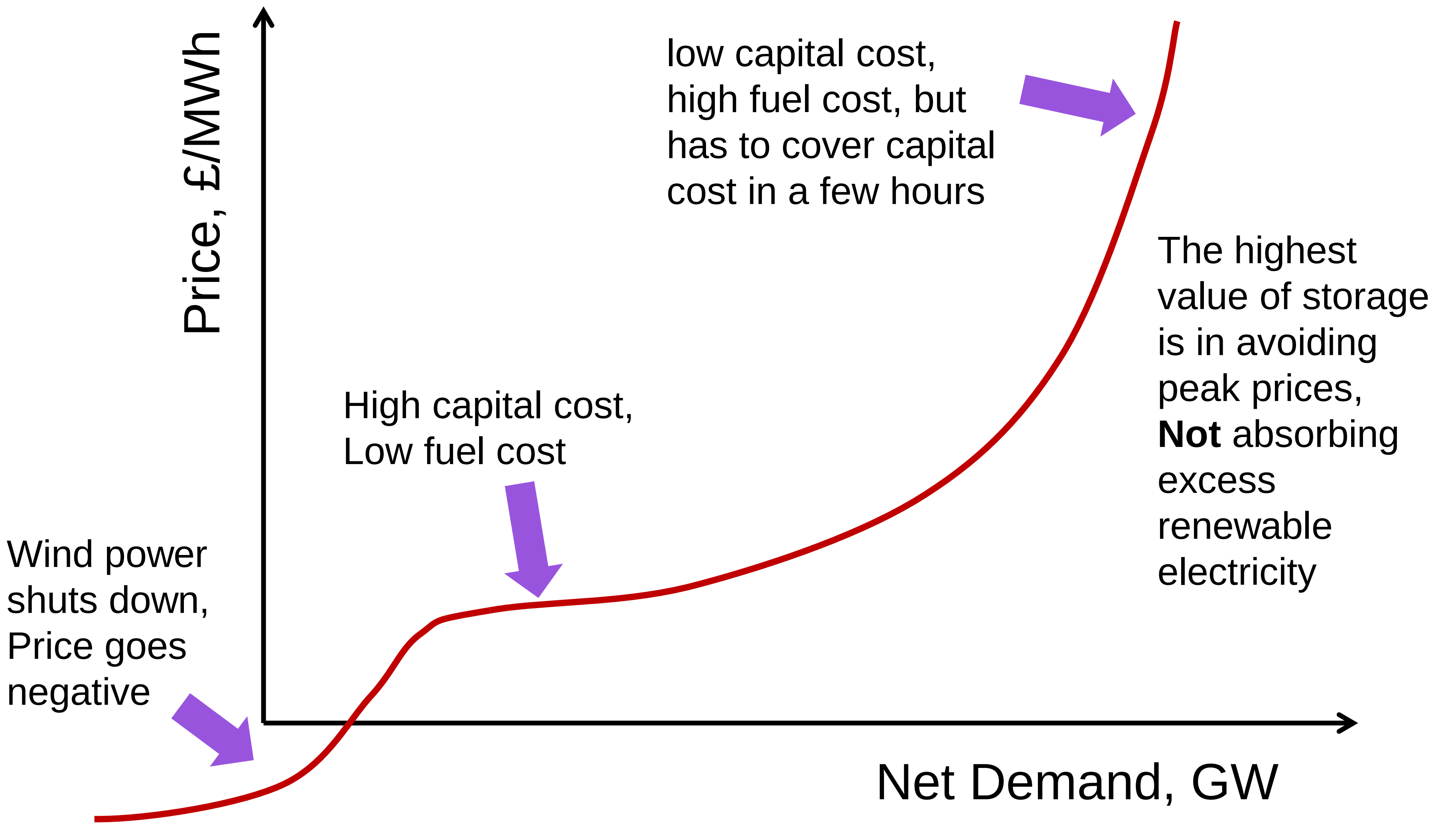
‘Thousand Flowers’ Low-Carbon Pathway in 2050
12 days of surplus, 10 days of deficit, 2 days surplus



Demand – Price Graph, 2010



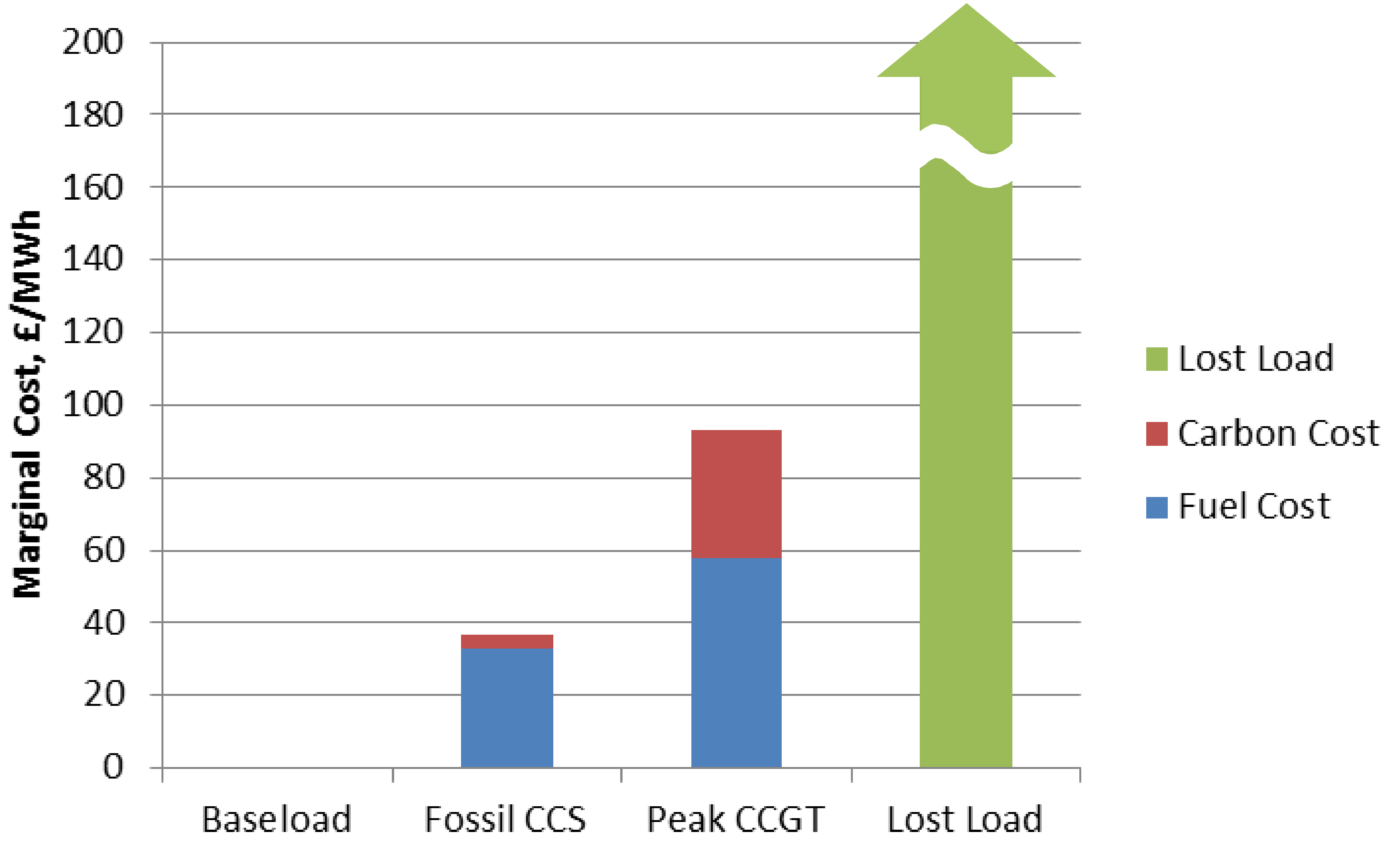
Demand – Market Market Price Graph, 2050



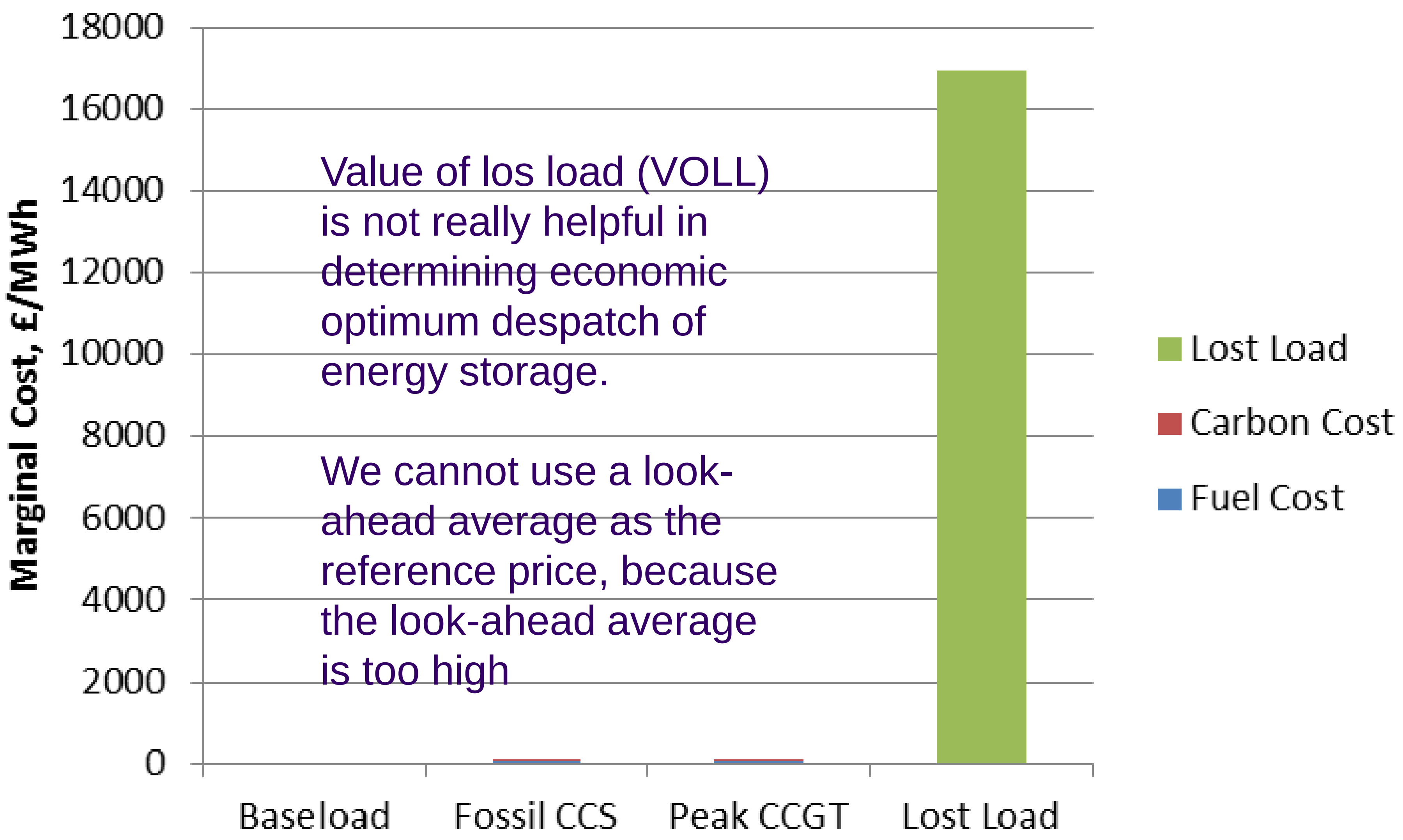
Modelled Costs of Electricity Generation in 2050

- Baseload and renewables: High capital cost but ‘free’ running costs
- Fuel costs:
  - £16/MWh_e for CCS,
  - £23/MWh_e for peak gas-fired plant
- Carbon price: £76/tonne of CO_2 equivalent
  - Peak gas plant 460kg/MWh_e
  - CCS plant 50kg/MWh_e
- Value of Lost Load (DECC & Ofgem) £16,940/MWh_e !

Marginal Costs of Generation (1)



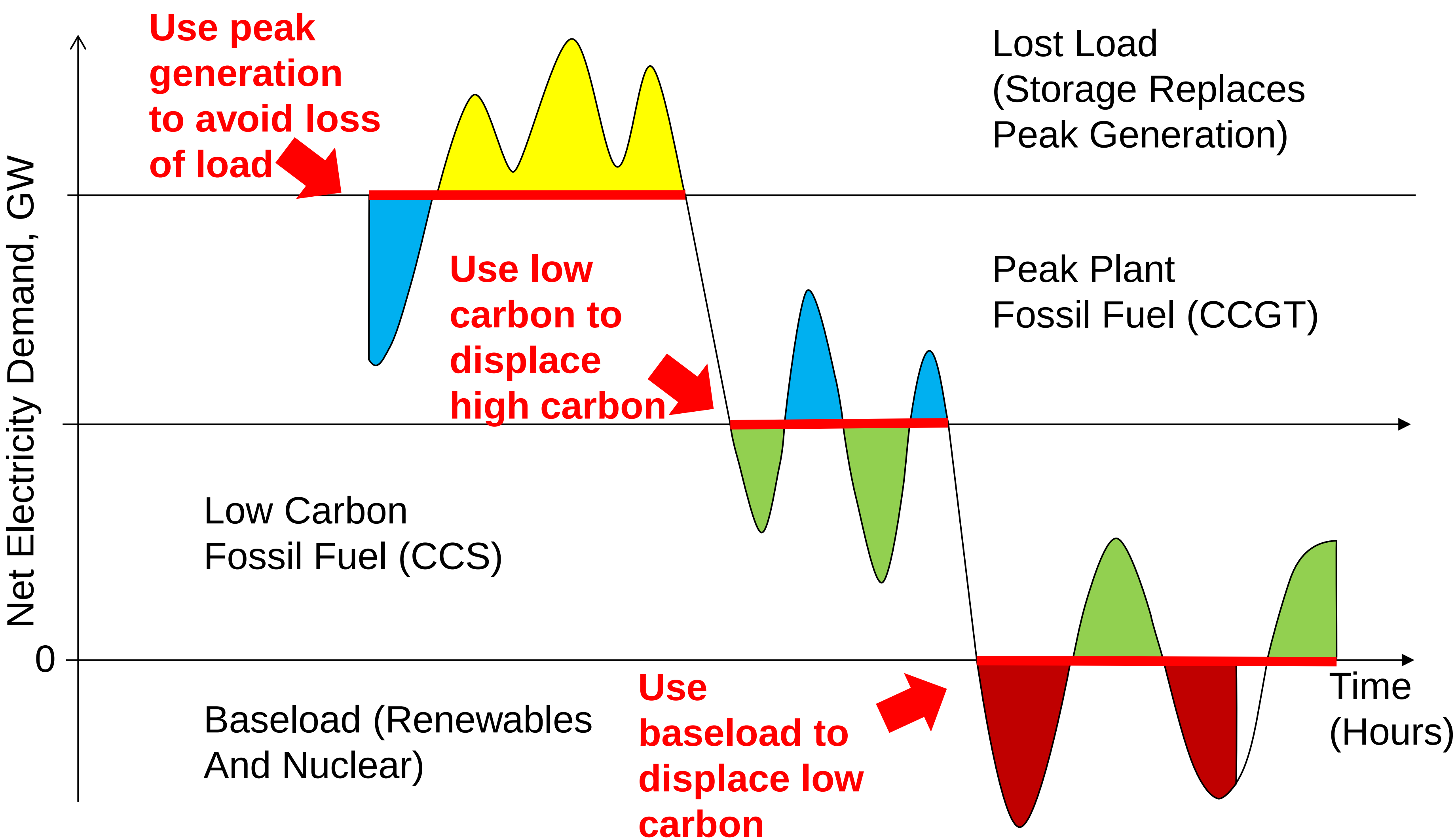
Marginal Costs of Generation (2)



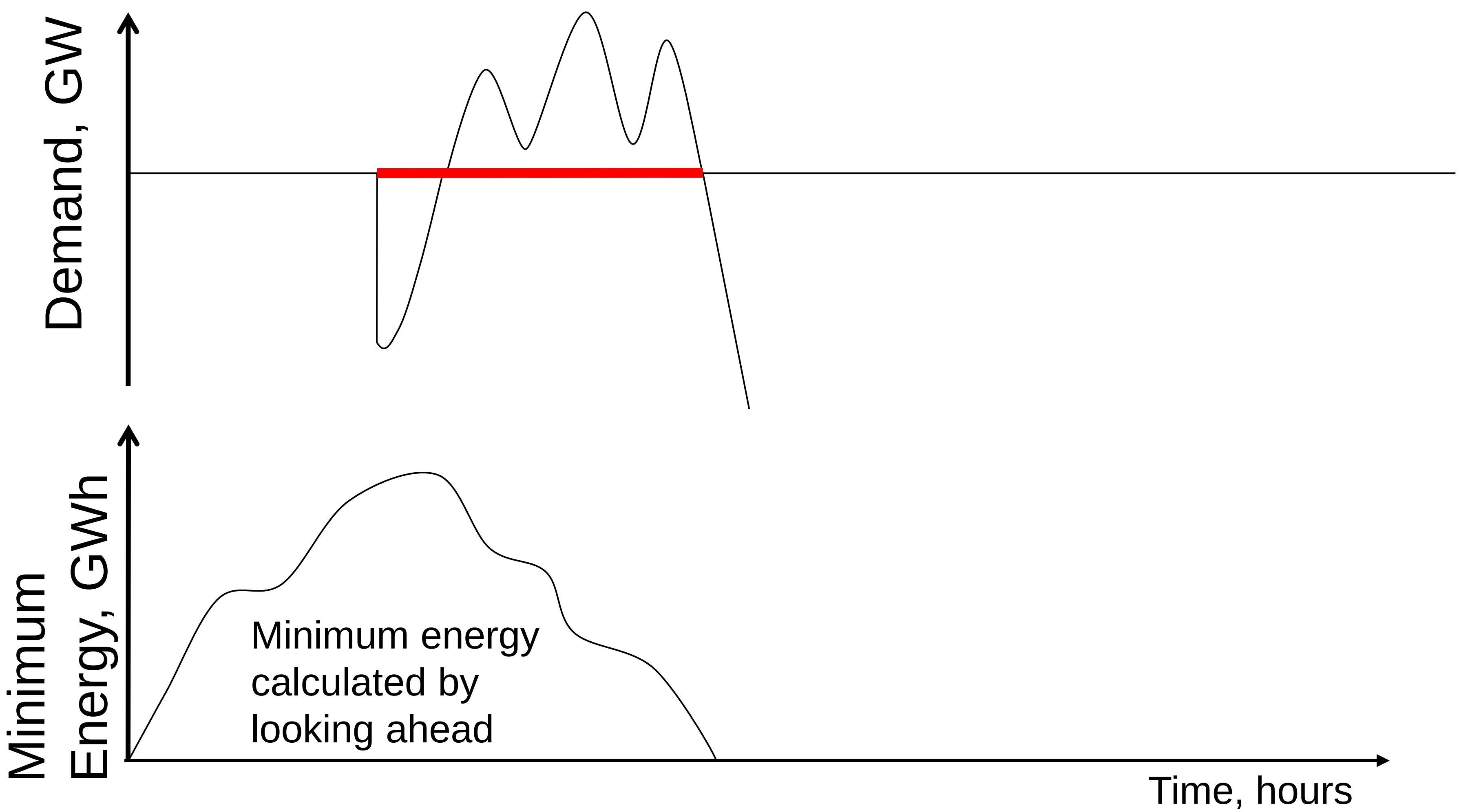
Value of los load (VOLL) is not really helpful in determining economic optimum despatch of energy storage.

We cannot use a look-ahead average as the reference price, because the look-ahead average is too high

3 Thresholds of Storage

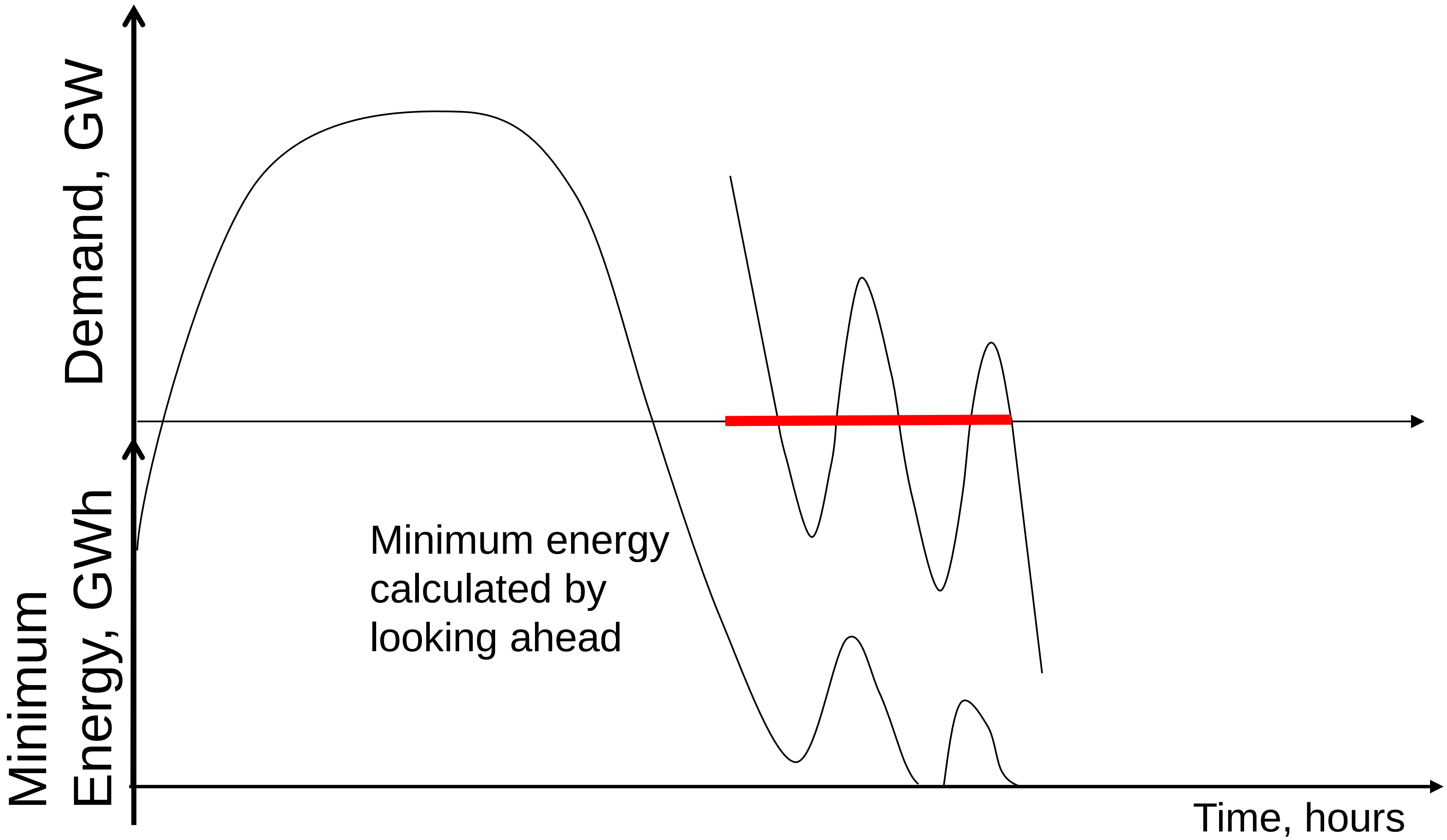


Priority 1 – Meet peak demand, avoid power cuts



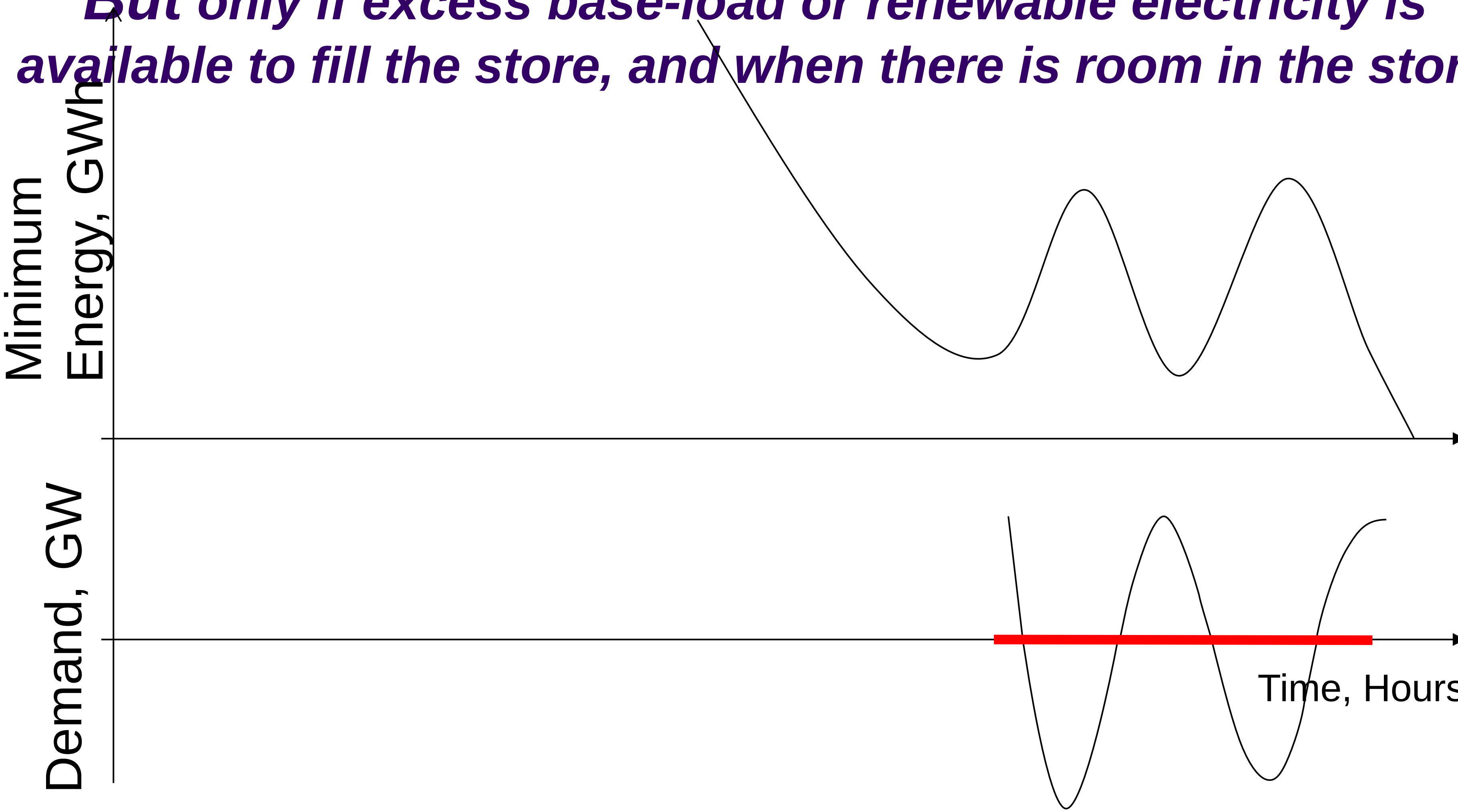
Priority 2 – Stay full enough to avoid high carbon generation

But only if spare low carbon generation is available

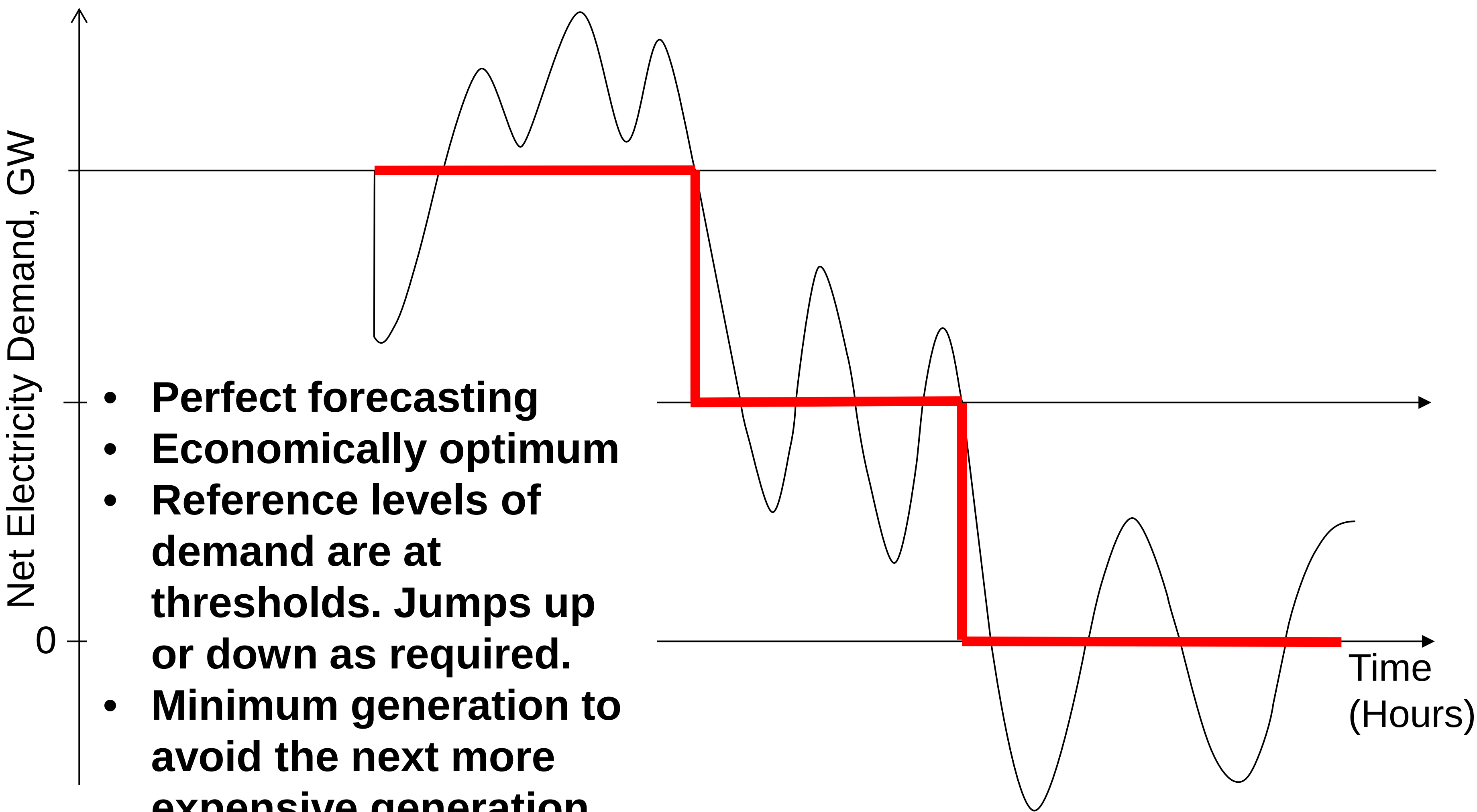


Priority 3 – Stay full enough to avoid low carbon generation

But only if excess base-load or renewable electricity is available to fill the store, and when there is room in the store



Three Thresholds of Storage



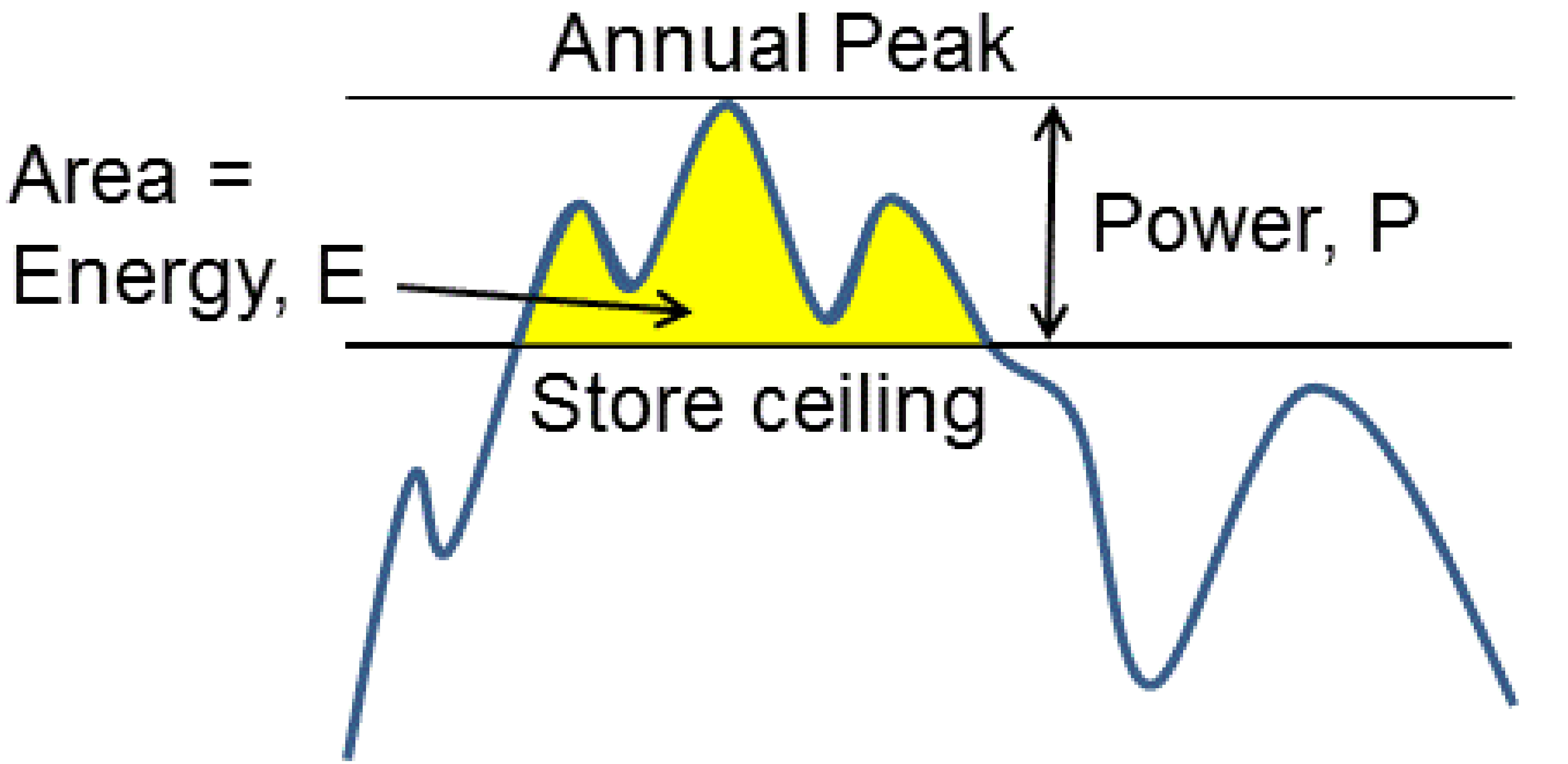
- **Perfect forecasting**
- **Economically optimum**
- **Reference levels of demand are at thresholds. Jumps up or down as required.**
- **Minimum generation to avoid the next more expensive generation**

Ideally, Energy Store is Always in One of Three States… (Inspired by Energy Economists at Warwick)

1. Constant reference price.
   - Fills when demand / price is below the level.
   - Discharges when demand is above that level
2. Store is full and reference price is rising
3. Store is empty and reference price is falling

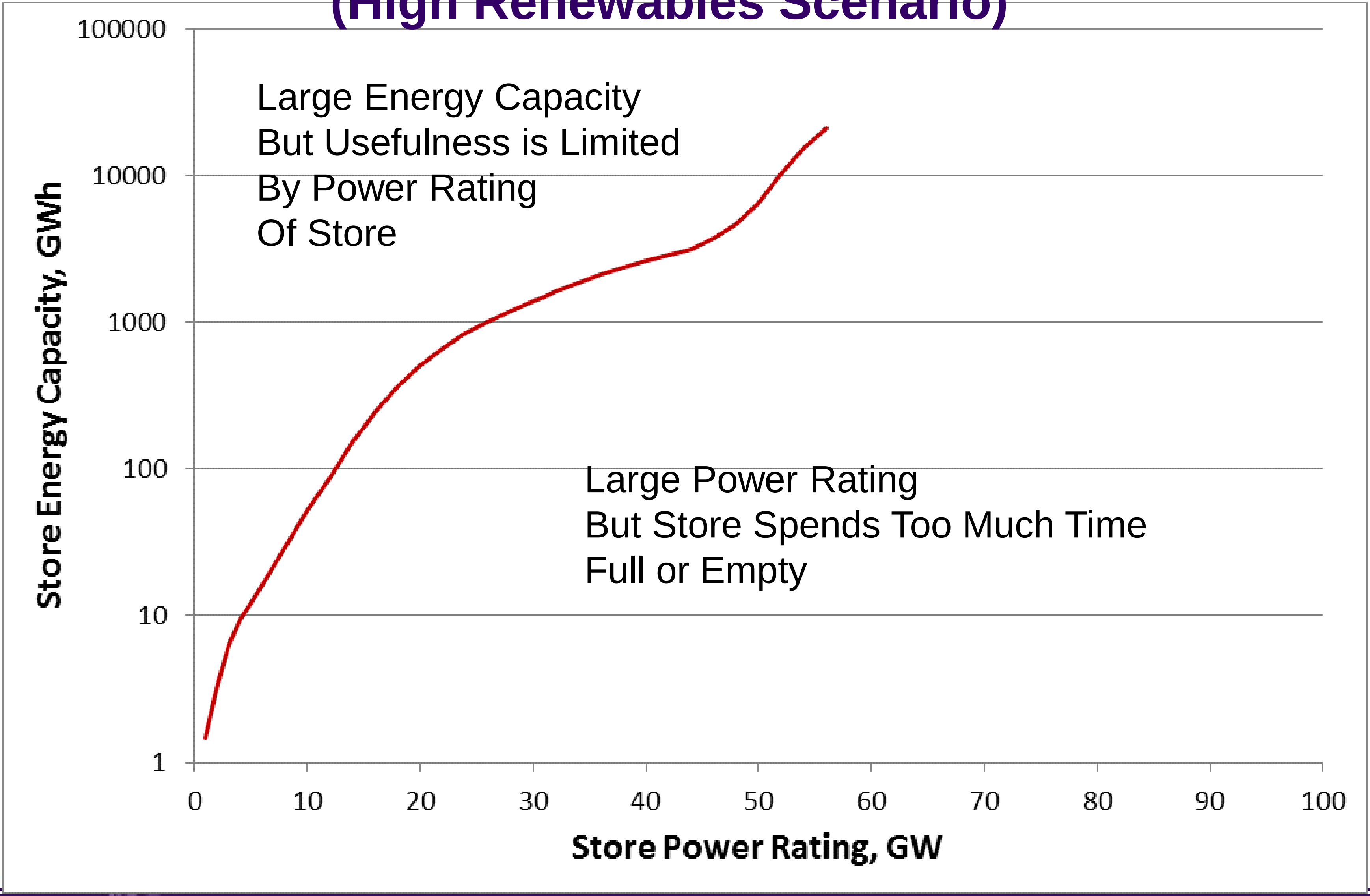
- With an infinite number of possible reference levels, this might be possible.
- My model has discrete levels
- My model is always empty as price falls but not full as price rises

Choosing the size of the energy store (energy / power ratio)

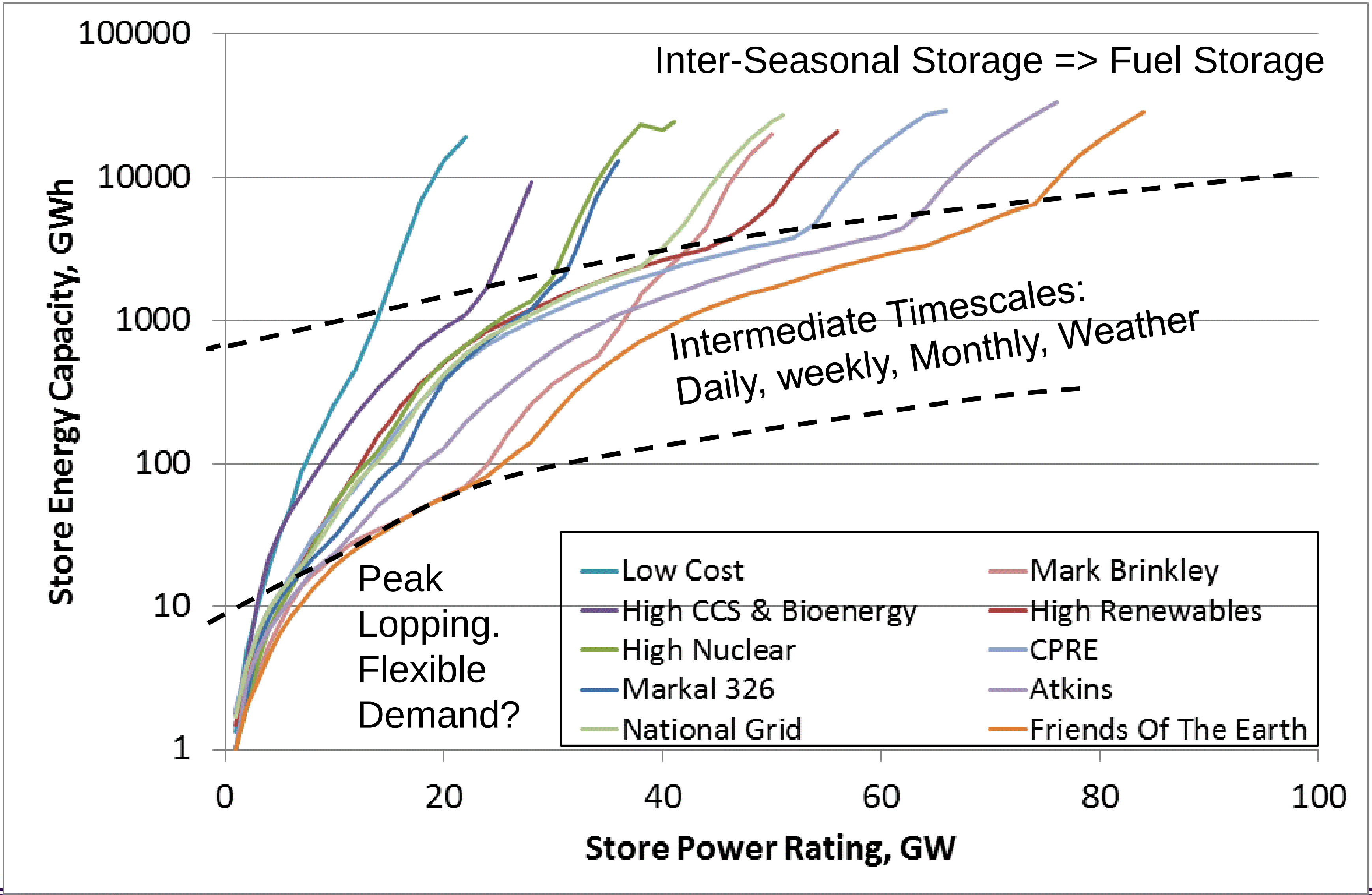


Move the ceiling down.
Increasing power, P = peak generation saved
Calculate the energy capacity, E = store capacity

Optimum Ratio of energy Capacity to Power (GWh/GW) (High Renewables Scenario)



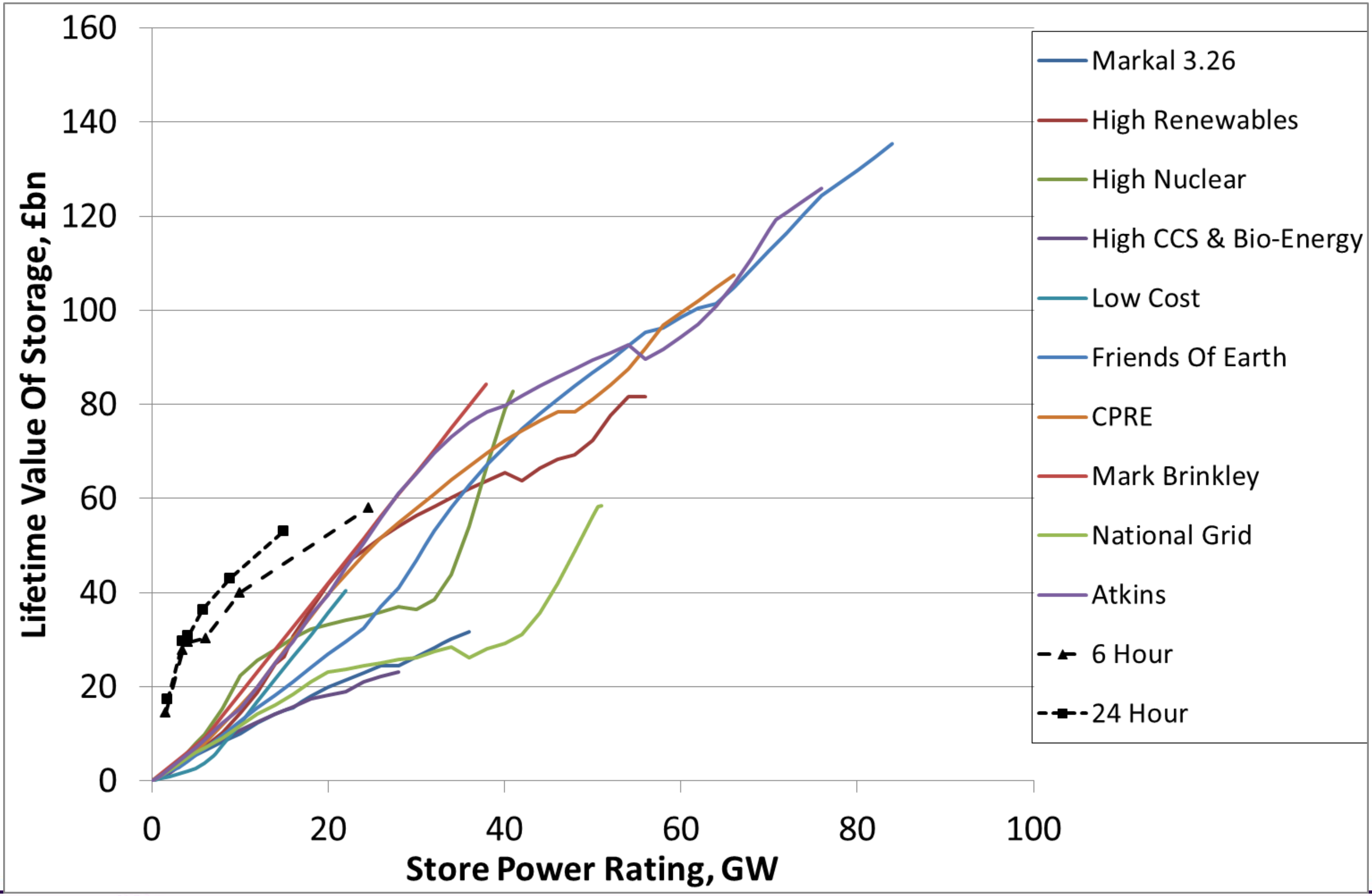
Optimum Ratio of energy Capacity to Power (GWh/GW)



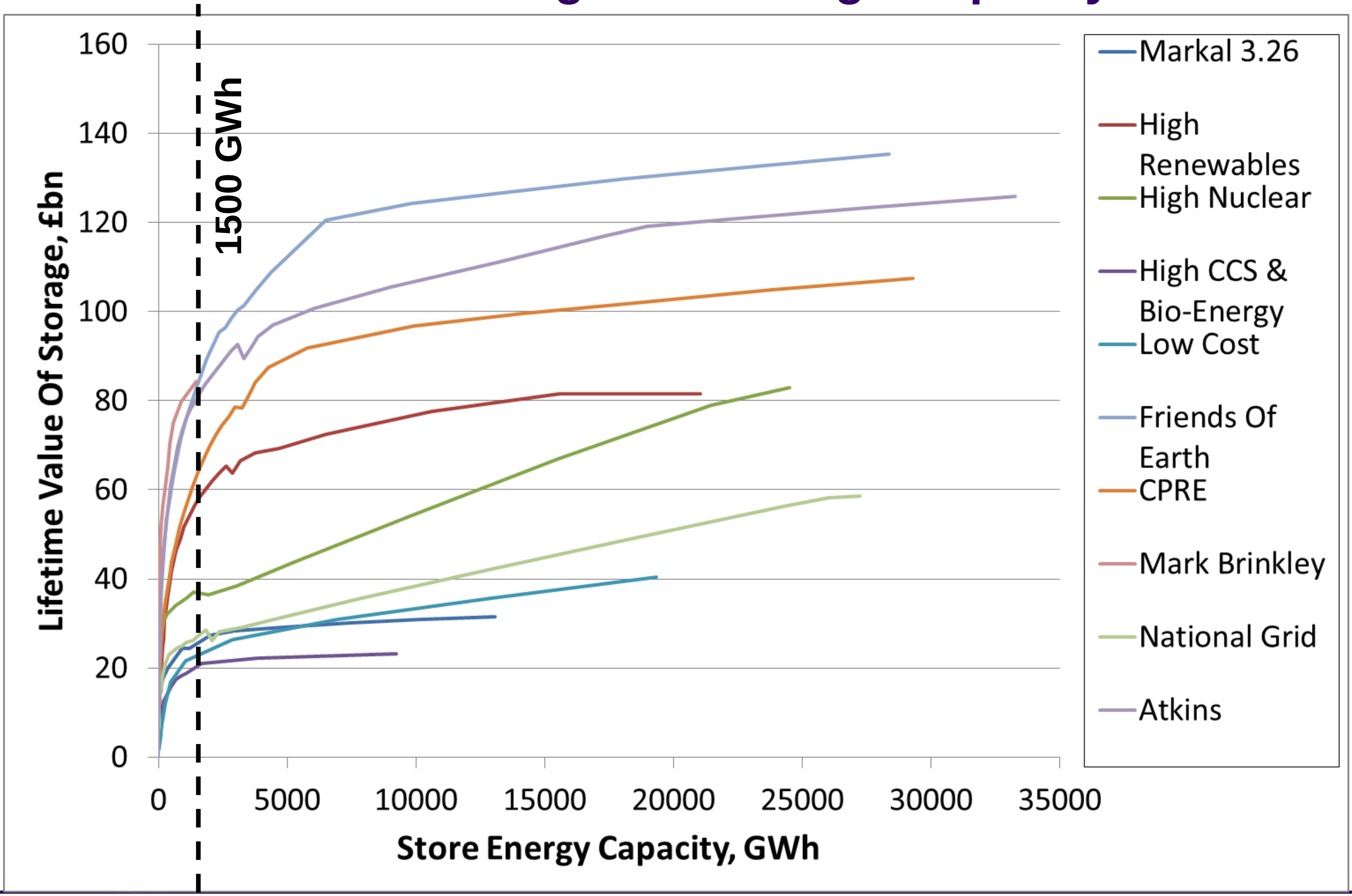
Value of Storage

1. Replacing generating capacity
   - power stations you don't have to build or maintain.
   - Capital expenditure (CAPEX) saved
2. Fuel saved
   - More efficient power stations used
   - Cheaper fuel
   - Renewables or nuclear
3. Carbon saved
   - Lower carbon power stations used

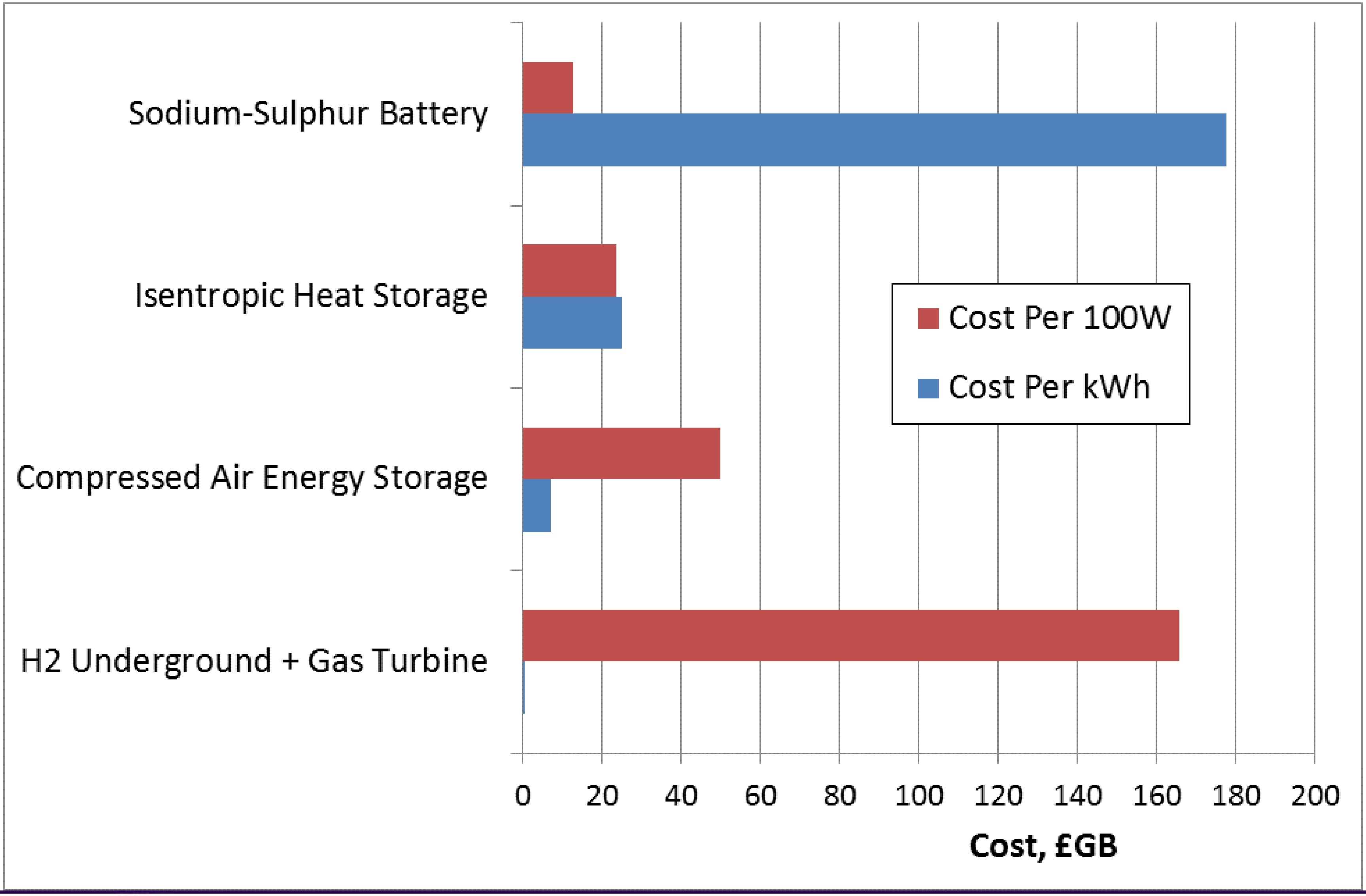
Value of Storage vs. Store Power



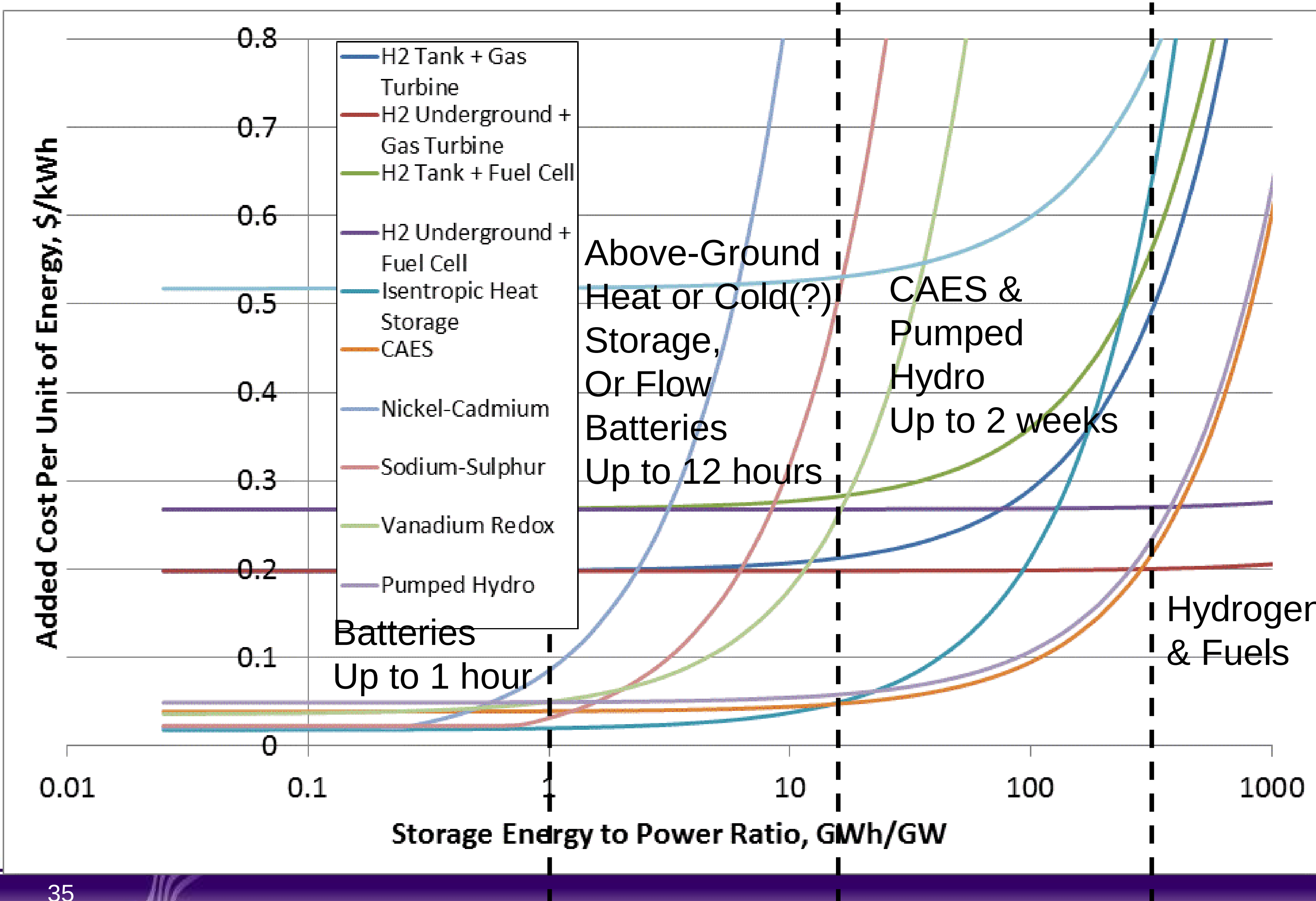
Value of Storage vs. Storage Capacity



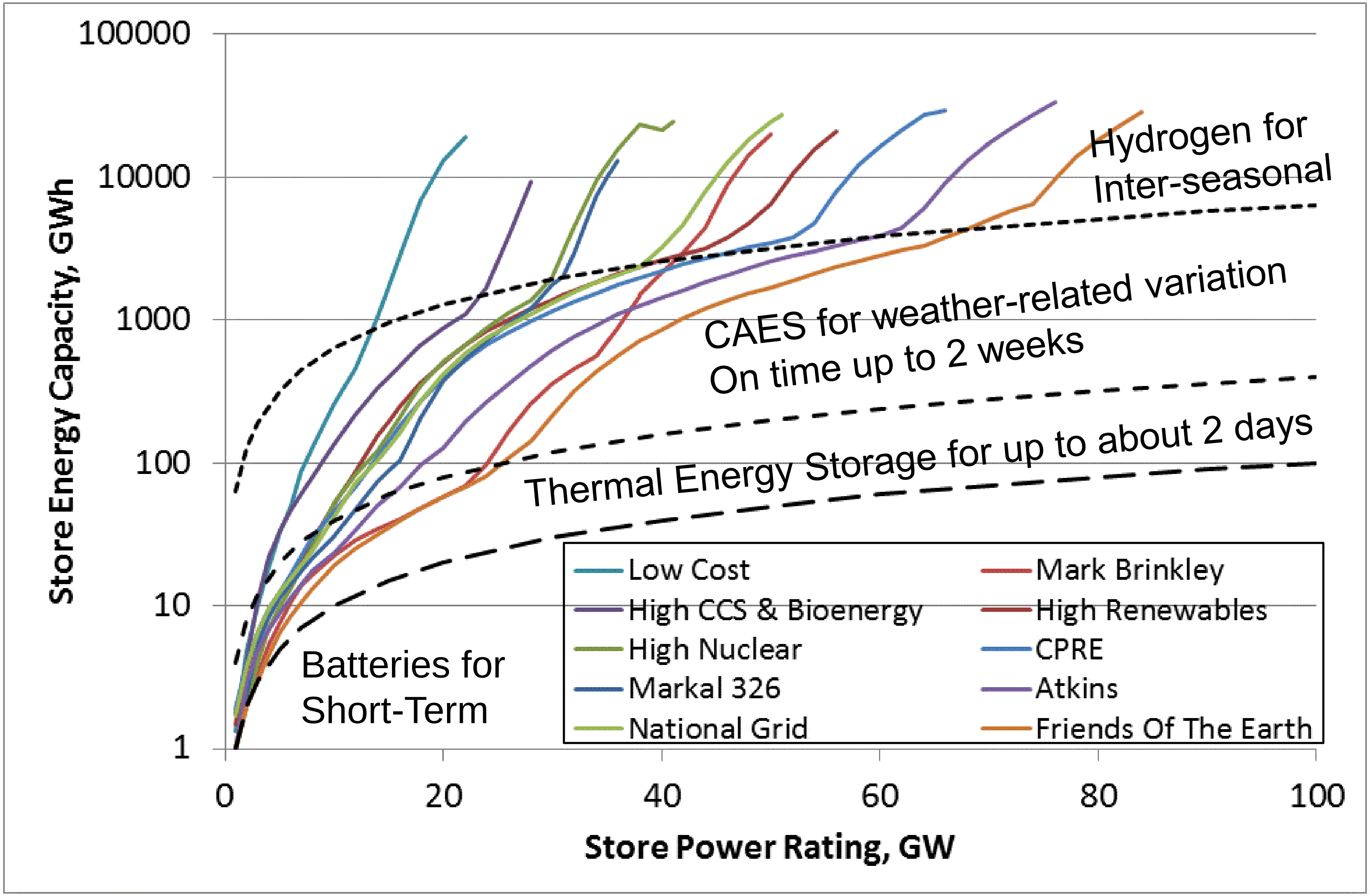
Capital Costs Per Power and Energy for Energy Storage



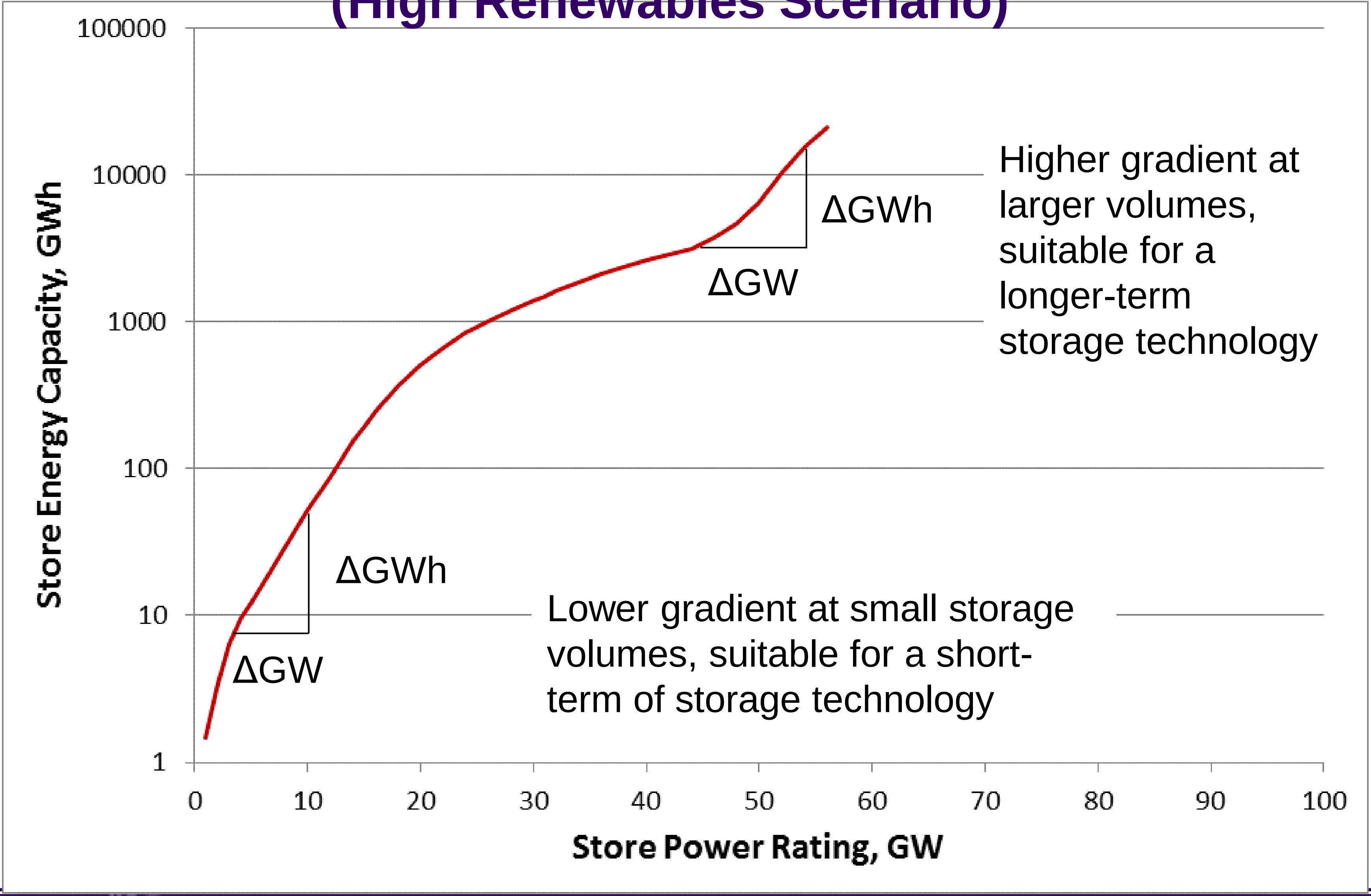
Cost of Storage with Increasing Timescales



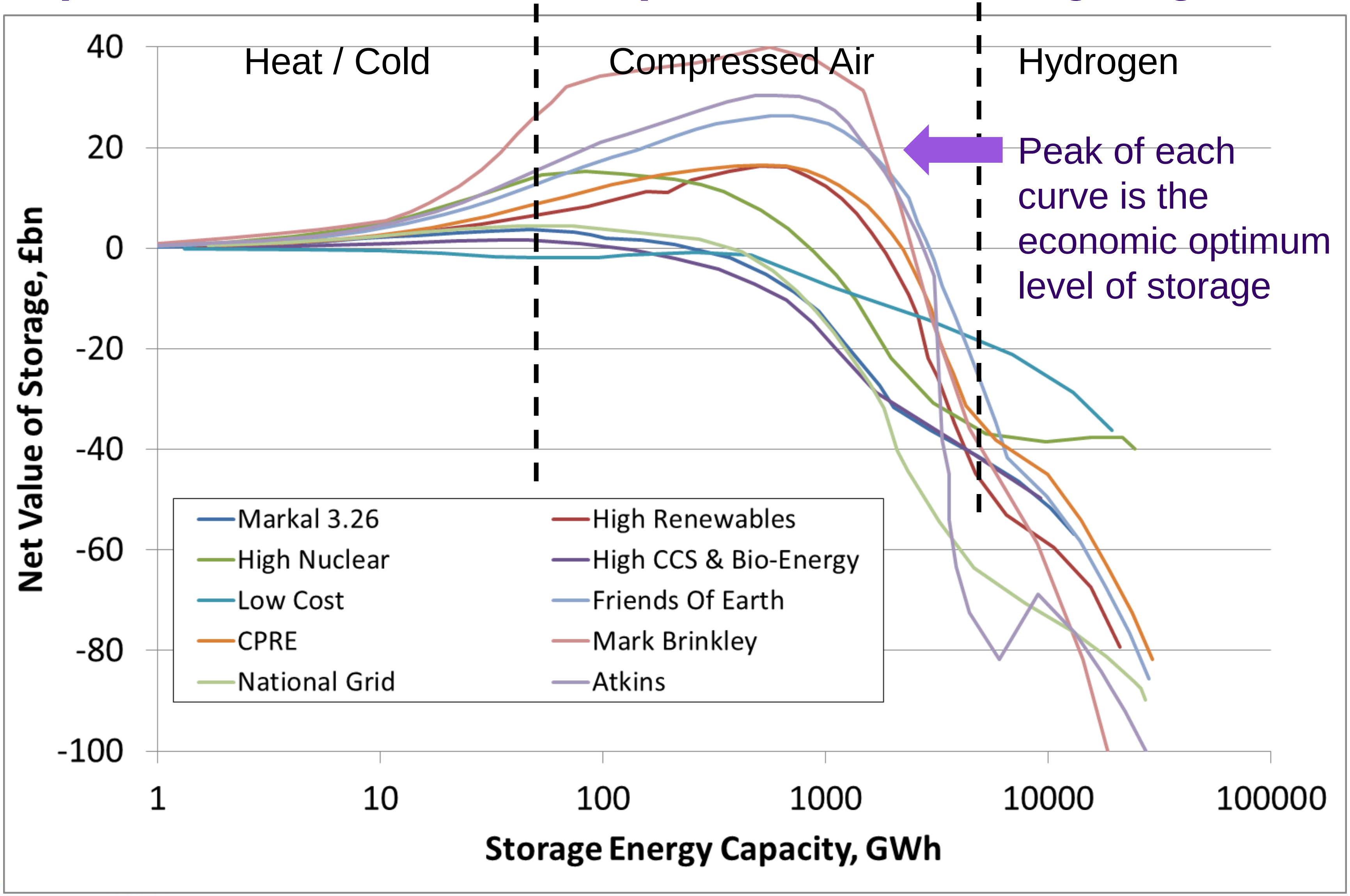
Size of Storage and Appropriate Technology by Application



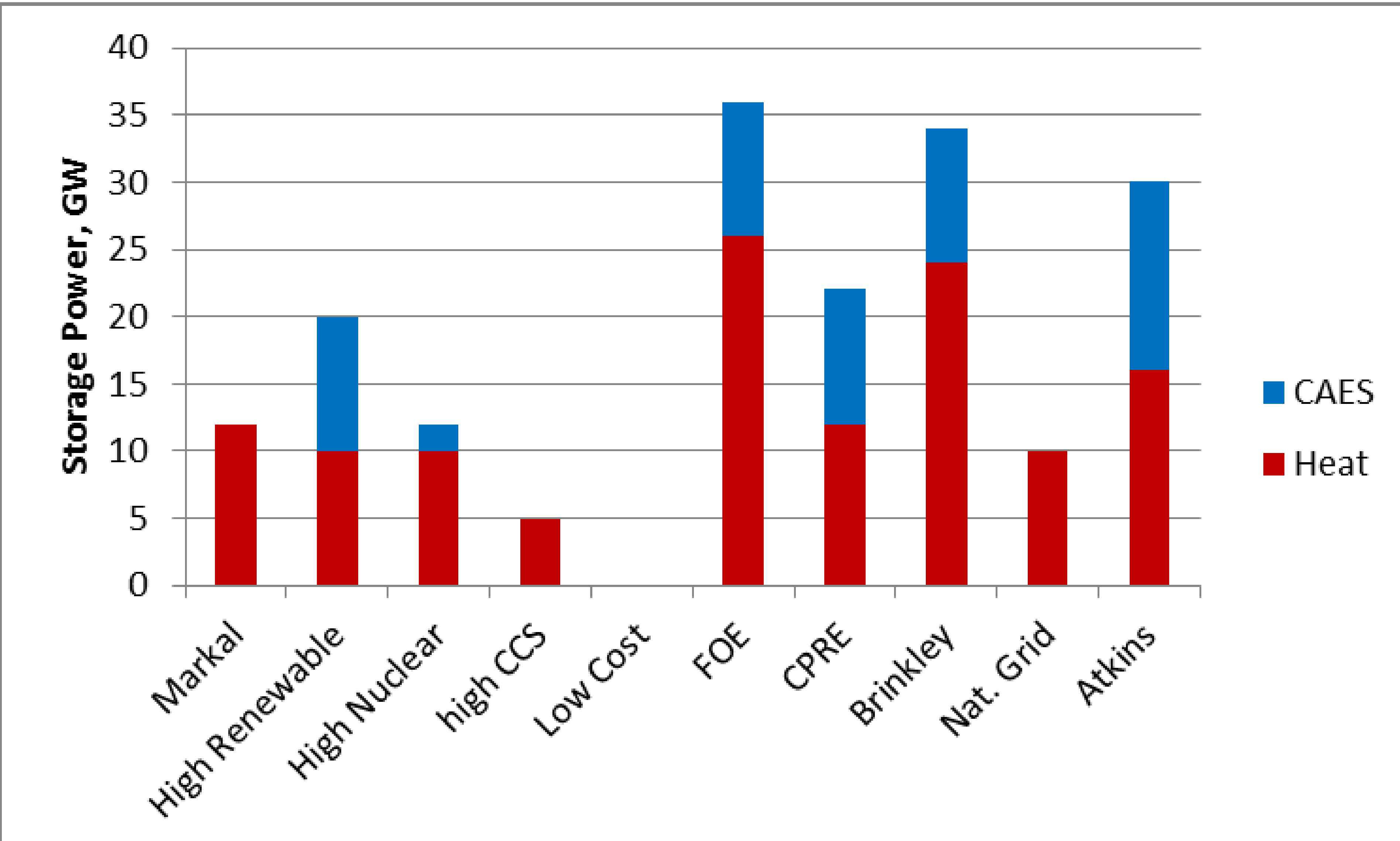
Optimum Ratio of energy Capacity to Power (GWh/GW) (High Renewables Scenario)



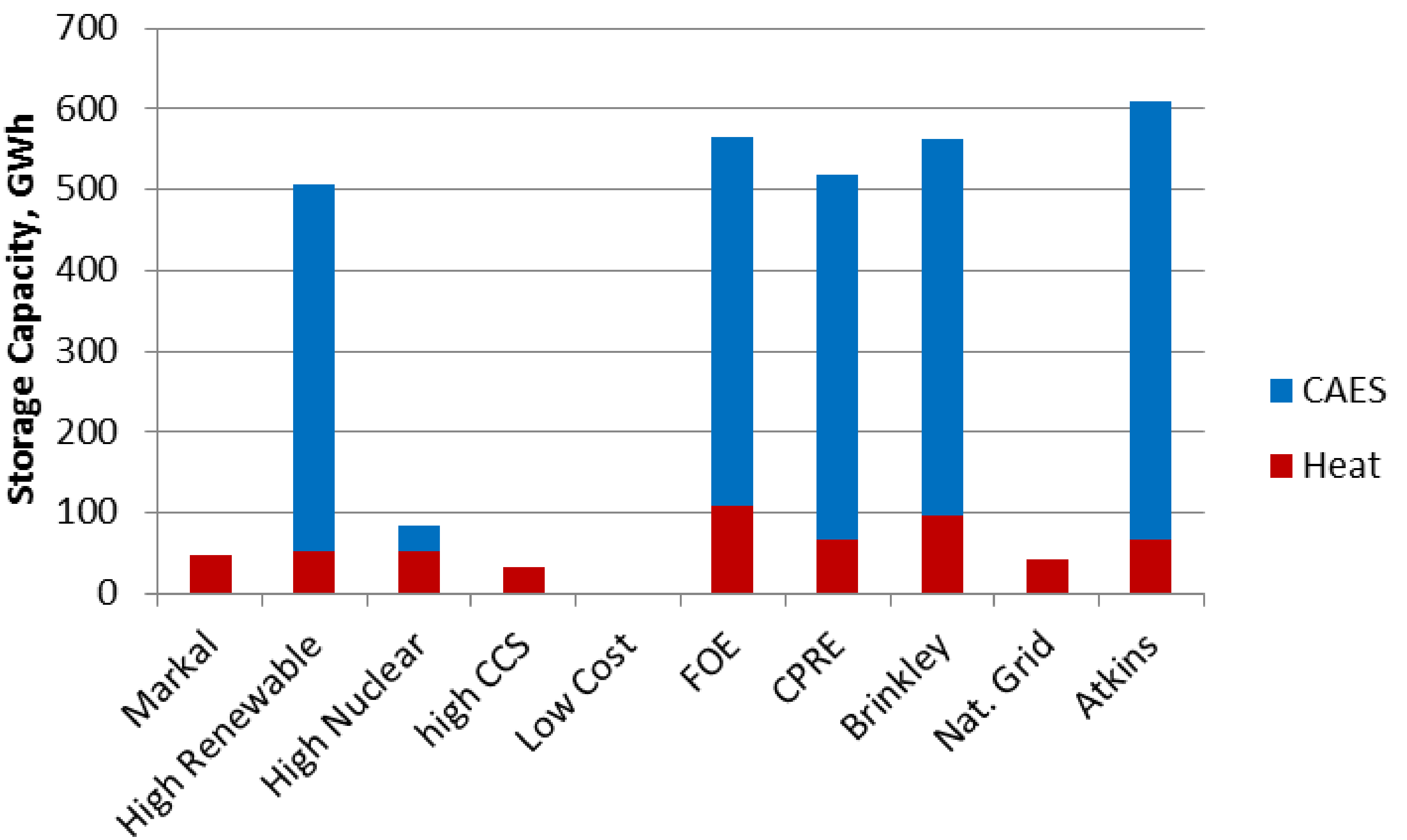
Optimum Solution is Multiple Stores Working Together



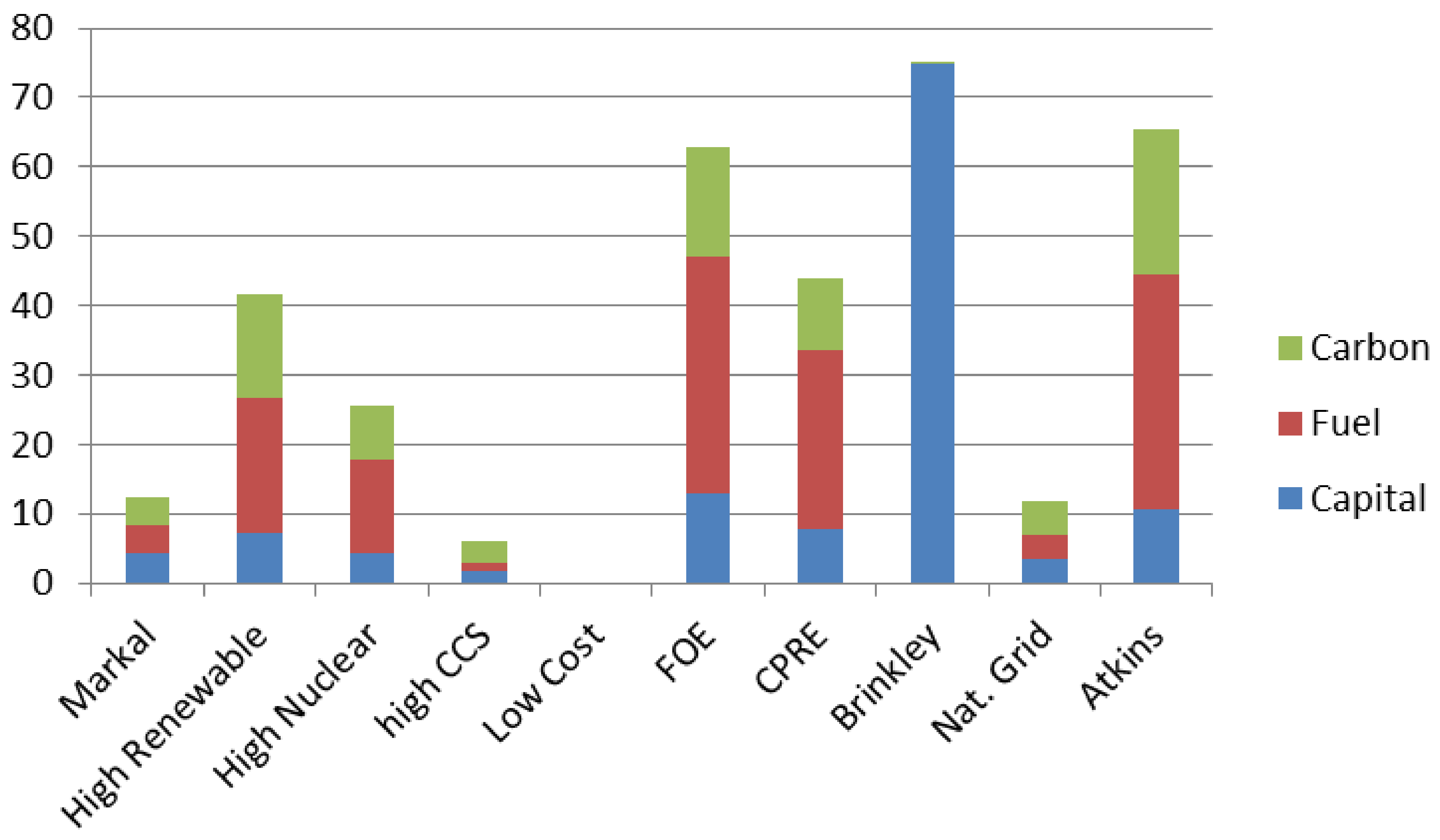
Optimum Storage Power



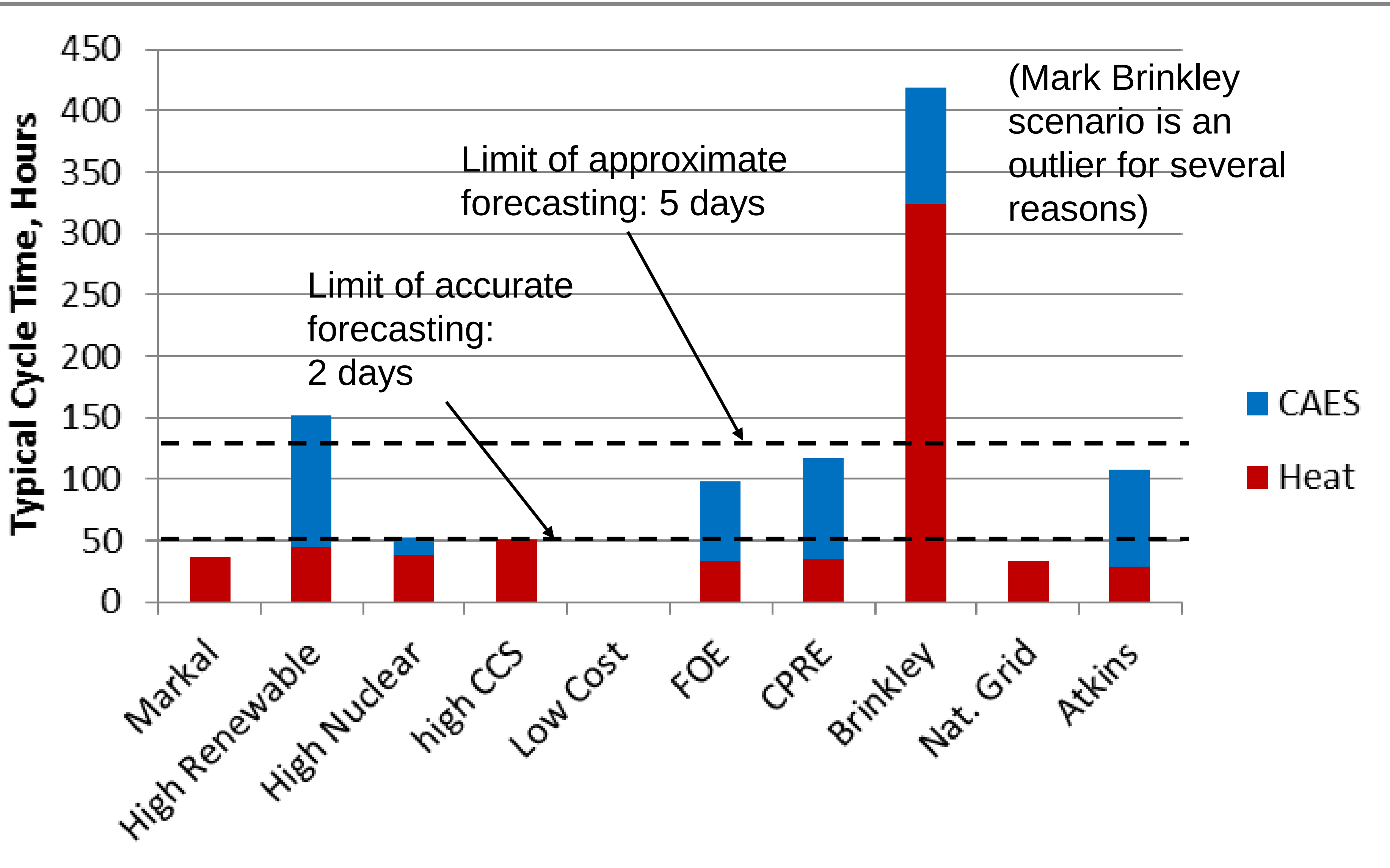
Optimum Storage Energy Capacity



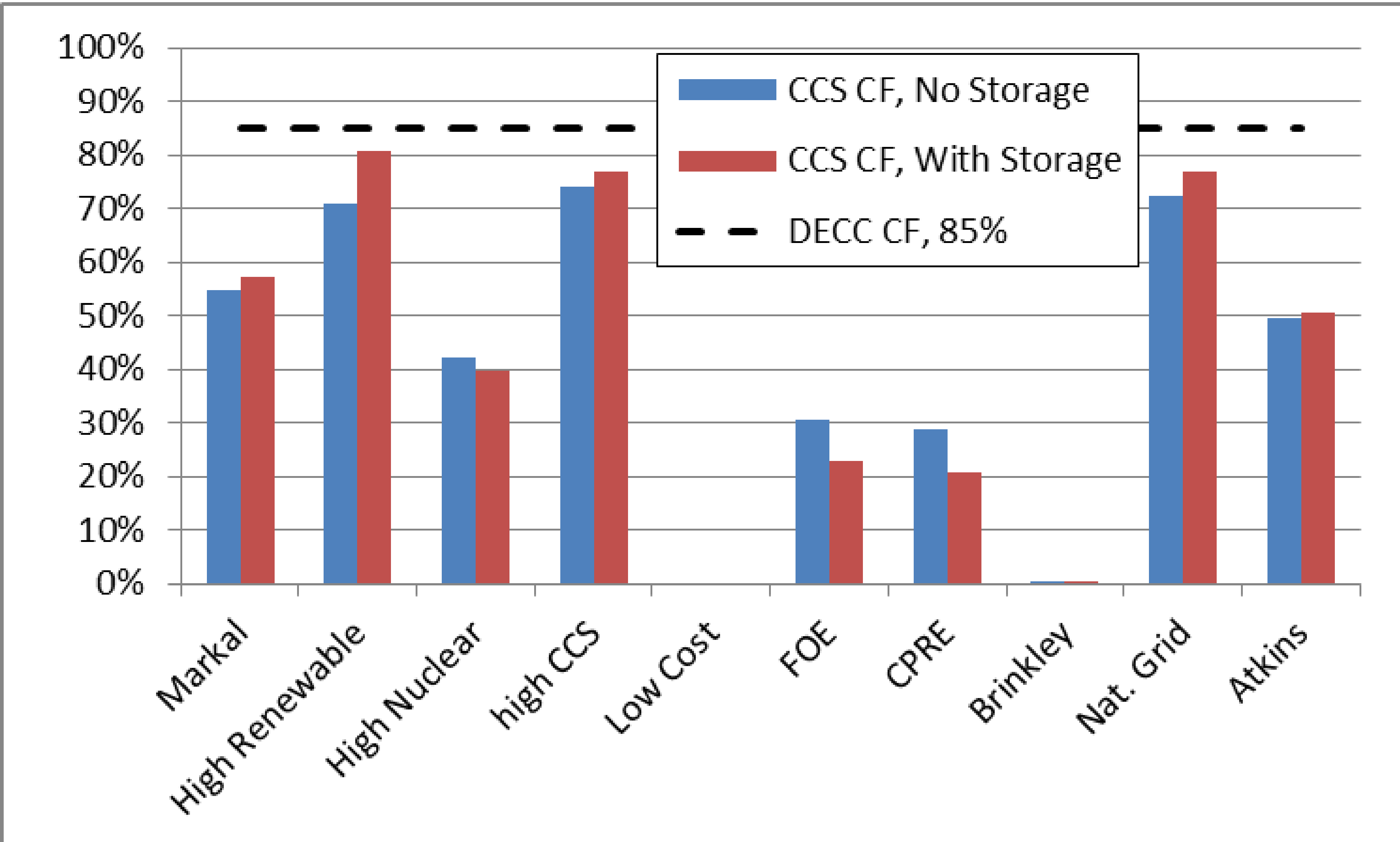
Components of Value of Energy Storage



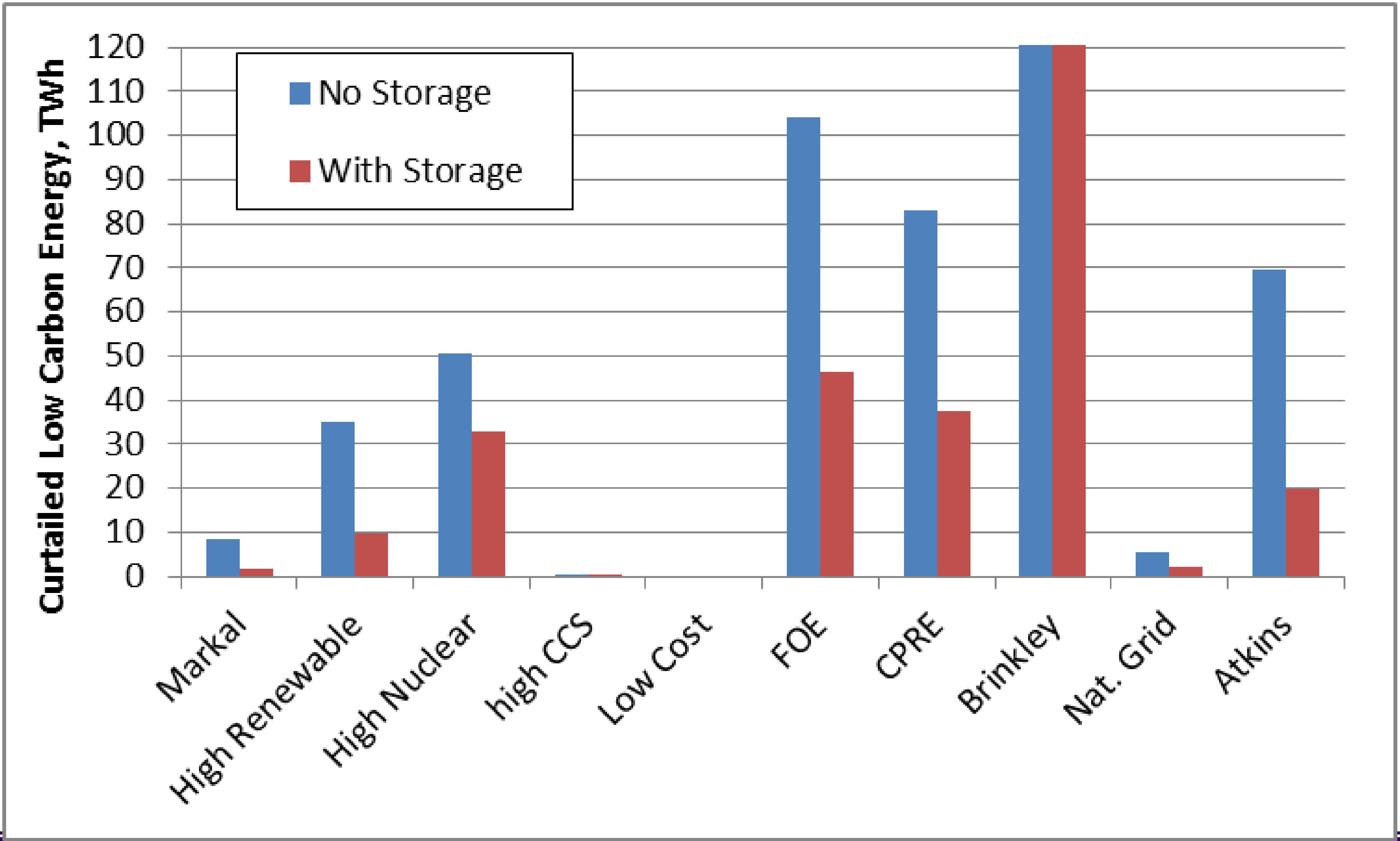
Energy Storage Cycle Time vs. Weather Predictability



Modest Improvement in Load Factor of CCS



Reduction in Curtailed Low Carbon Energy at Economically Optimum Level of Energy Storage



Conclusions – Part 1

- The need for energy storage is increasing
- The optimum ratio of GWh/GW (time constant) increases exponentially with power rating
- Strong law of diminishing returns with energy capacity, GWh
- The cost-effective technologies appear to be heat storage and Compressed Air (CAES). Flow batteries are another possibility.
- Storage is cost-effective for cycle times of **approximately** 2 to 5 days but no more:
  - Poor Economics of long-term storage
  - Inadequate long-term weather forecasts

Conclusions – Part 2

- Energy storage can substantially reduce the following parameters but it is not economically feasible to build enough storage to eliminate them:
  - Curtailed low-carbon energy
  - High carbon peaking generating plant
- Energy storage can increase the utilisation factor of fossil-fuelled plant with CCS, but it is not economically feasible to use storage to bring it up to the levels anticipated in the DECC 2050 Calculator Model

Next Steps

- Forecasting Errors – How the optimum size, despatch algorithm and value of storage change with imperfect forecasting
- Extend FESA to a European model – the optimum role of storage alongside interconnectors
- Demand response – where (in timescale) does DR finish and storage begin?
- Alternative supply scenarios – more electricity generation mixes, e.g. from ETI, Shell, UKERC