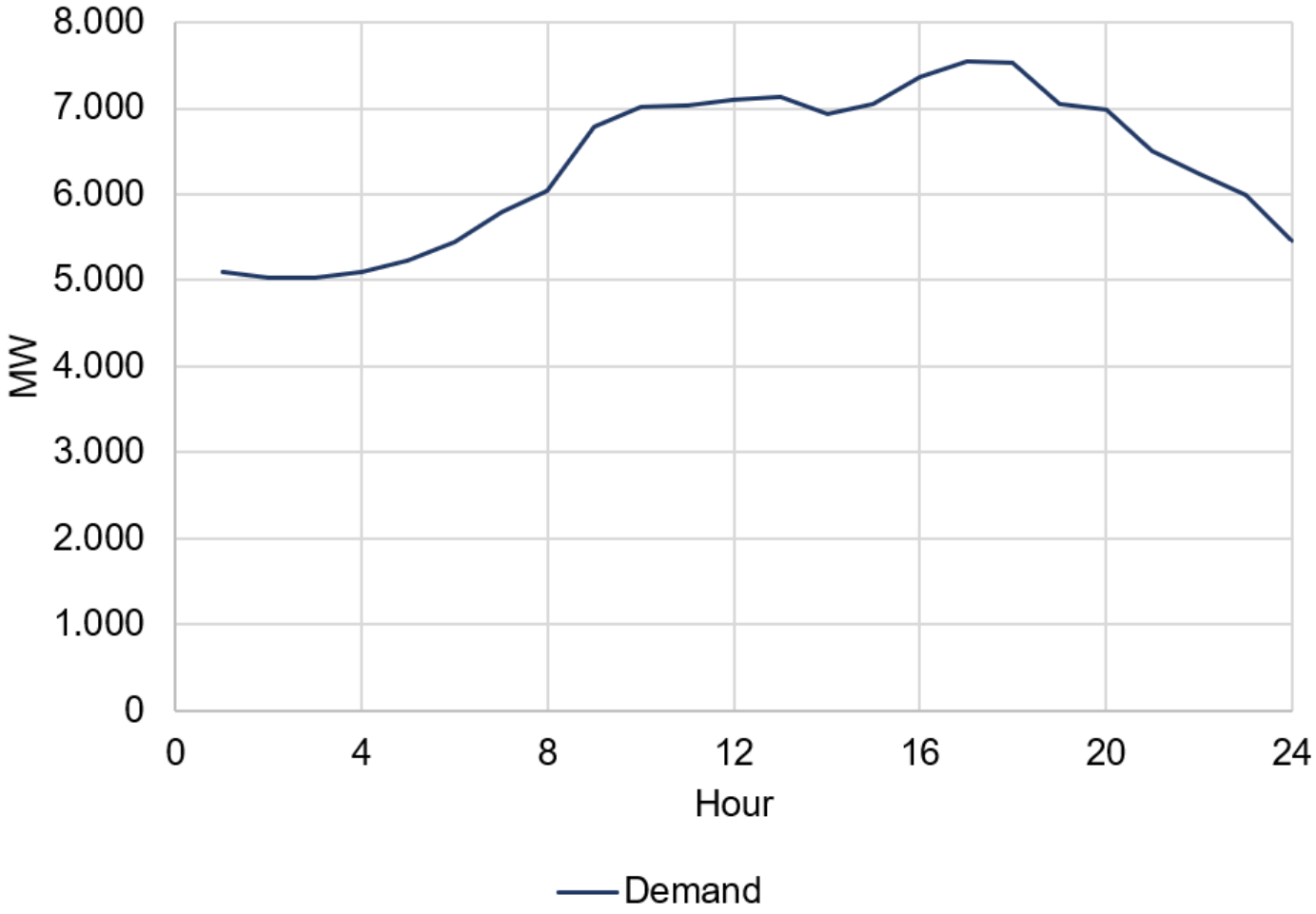
Renewable Energy

- Why wind and solar will not work

Søren Hansen

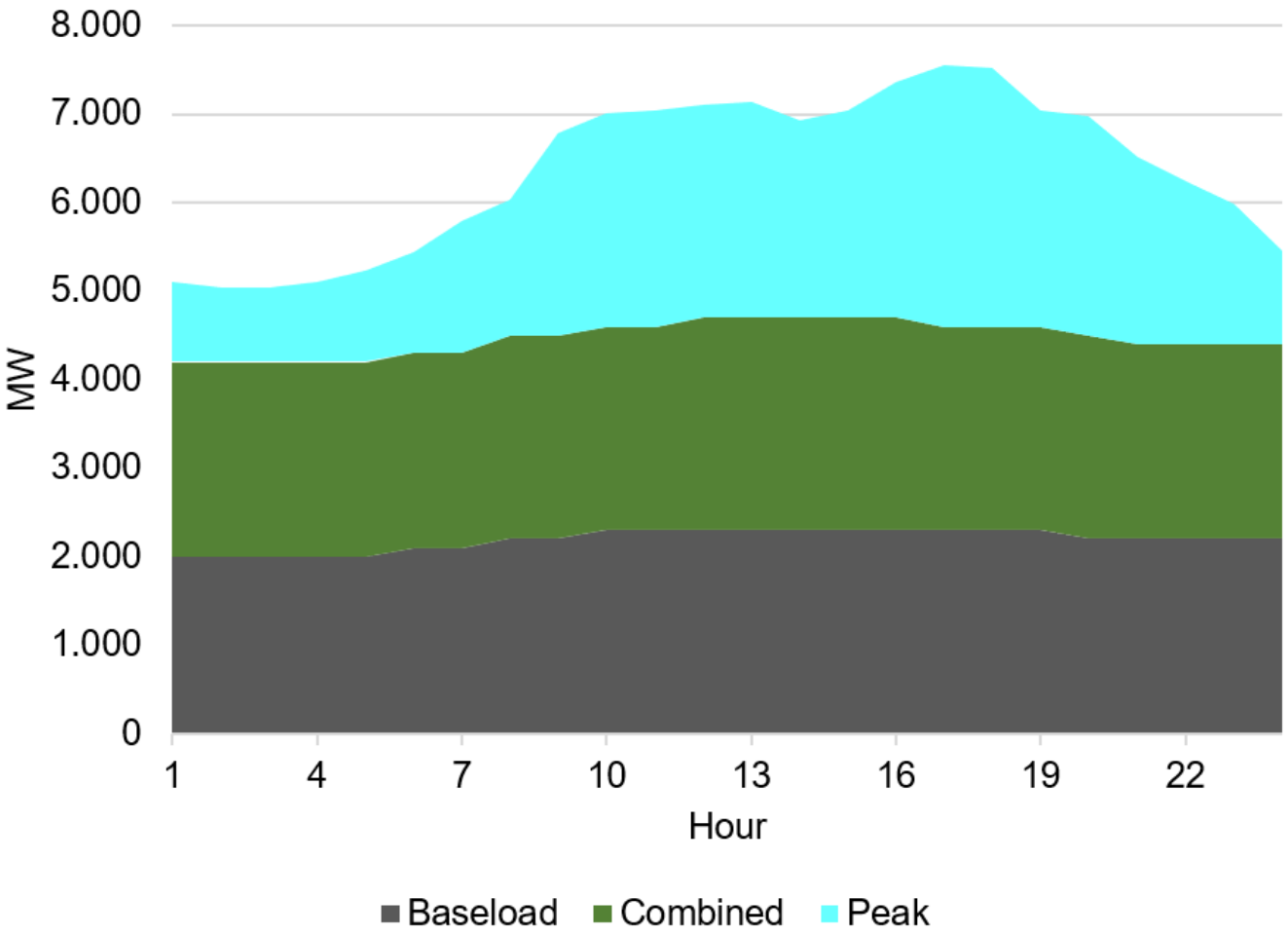
Power supply

- Demand in a typical day



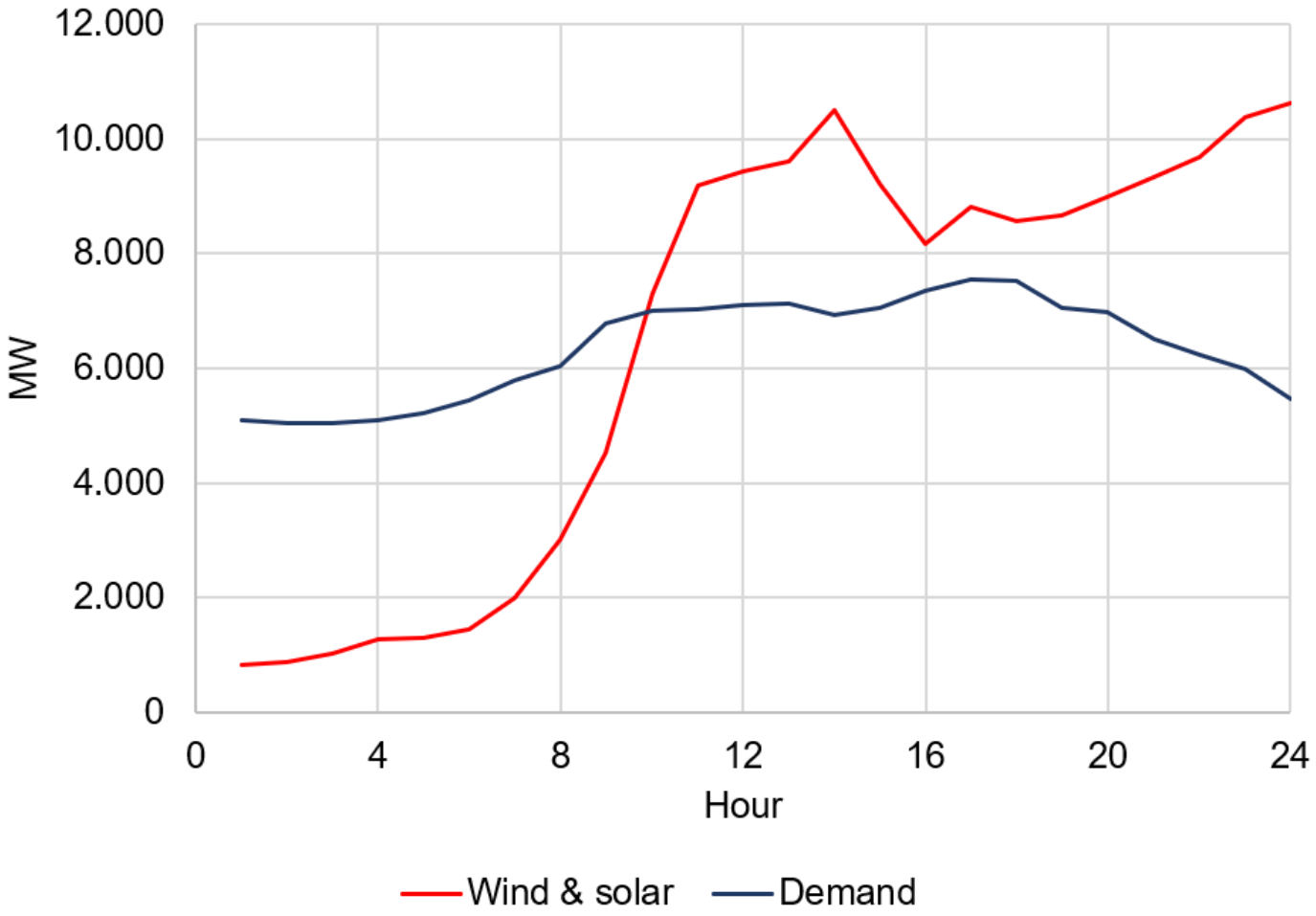
Power supply

- Traditional generation



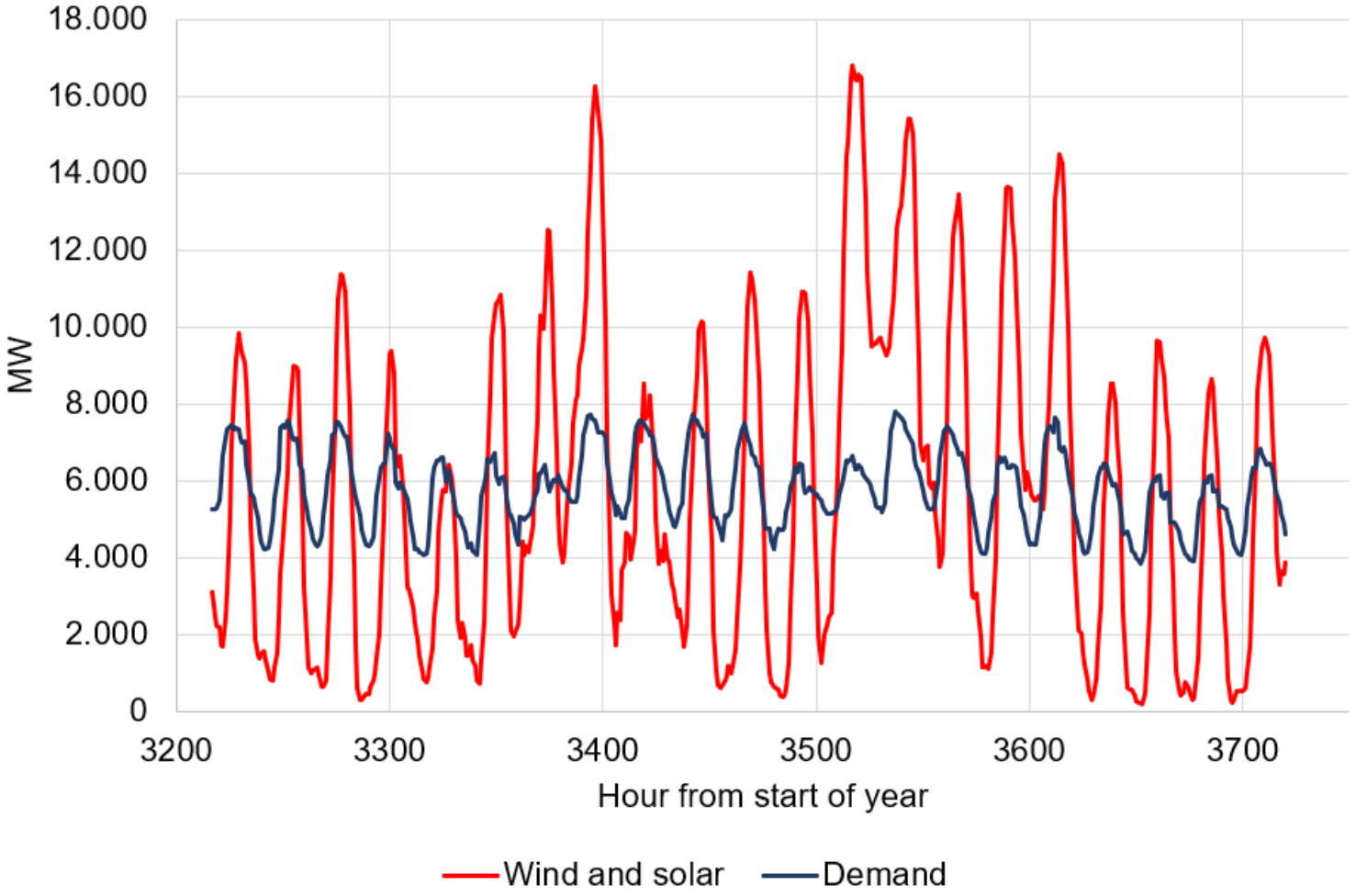
Power supply

- Output from wind and solar



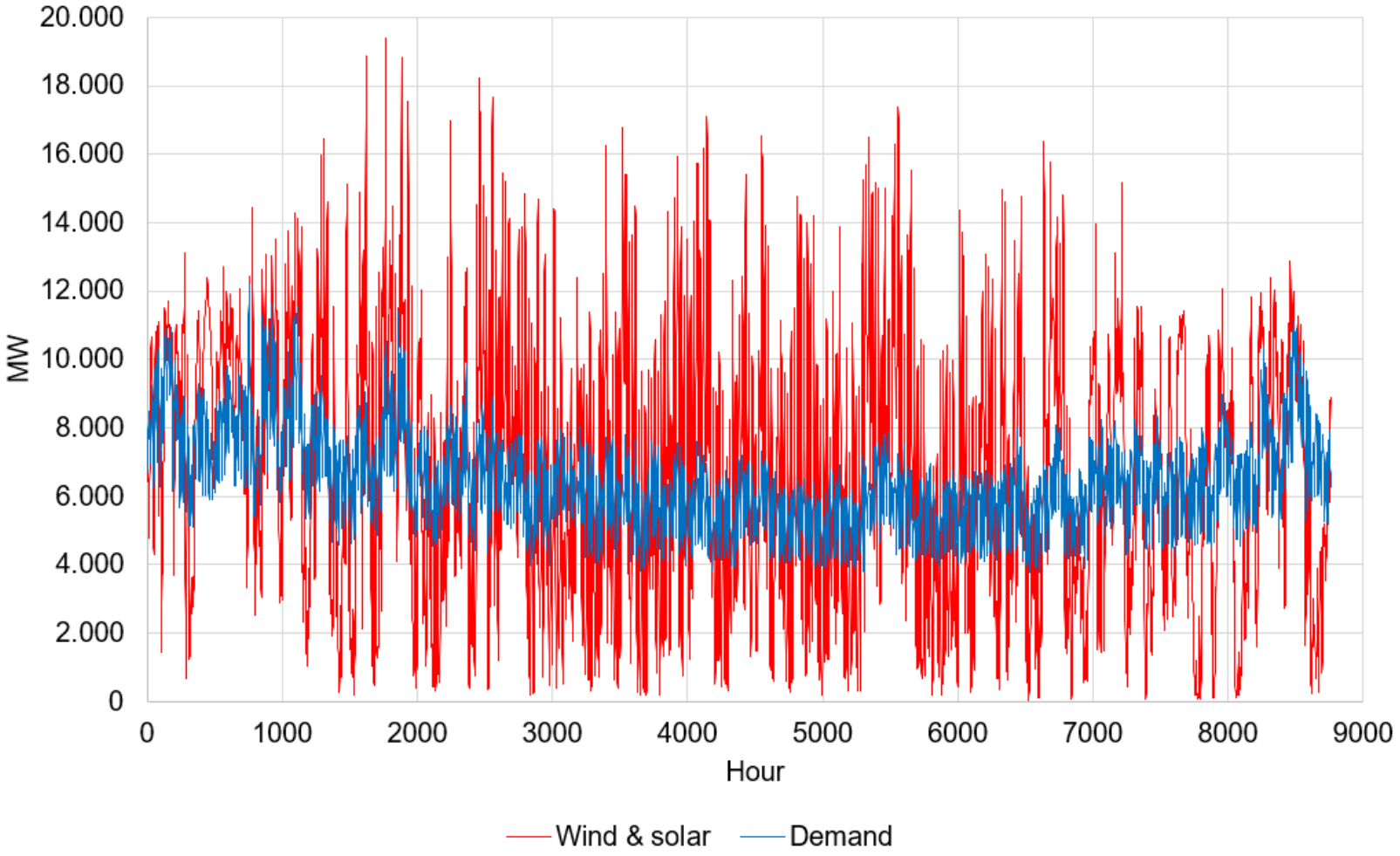
Wind and solar on their own

- 3 week period



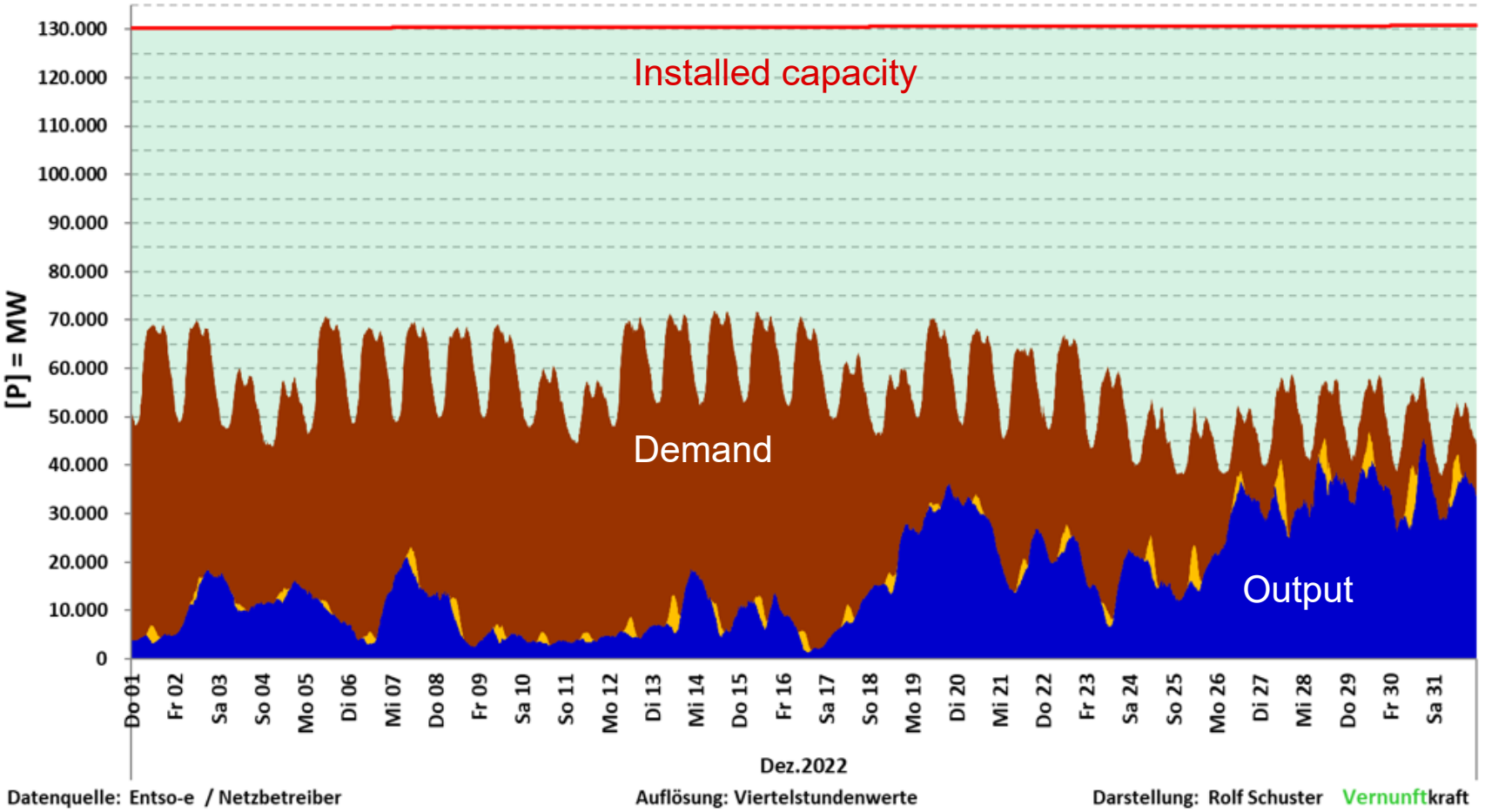
Wind and solar on their own

- The whole year



“Dunkelflauten”

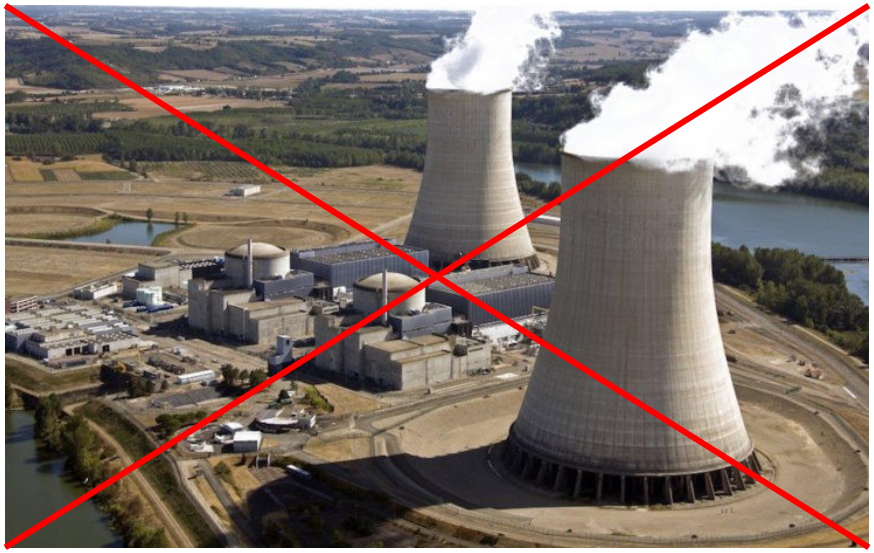
- Germany, Dec. 2022. Demand & output from wind & solar

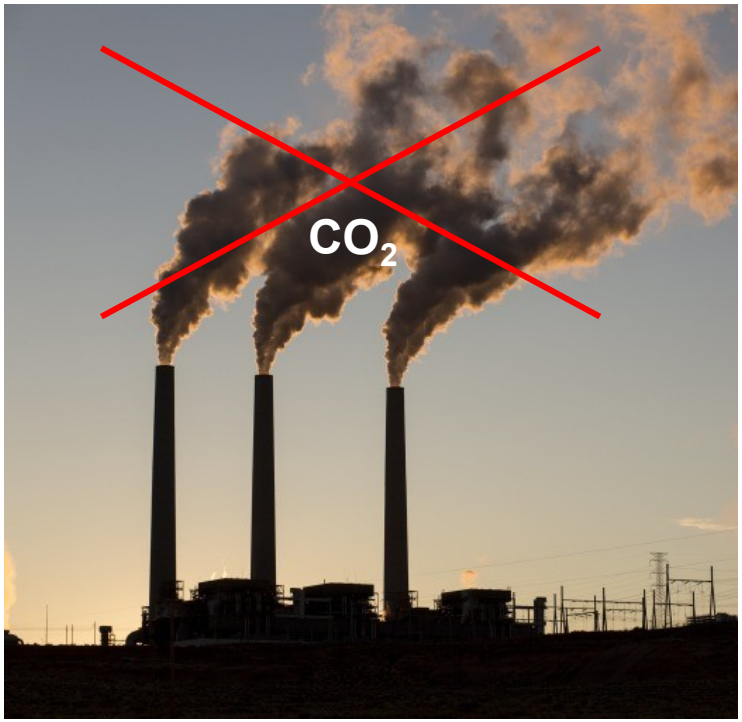


Source: Rolf Schuster, Vernunftkraft.de

Solar and wind as energy sources

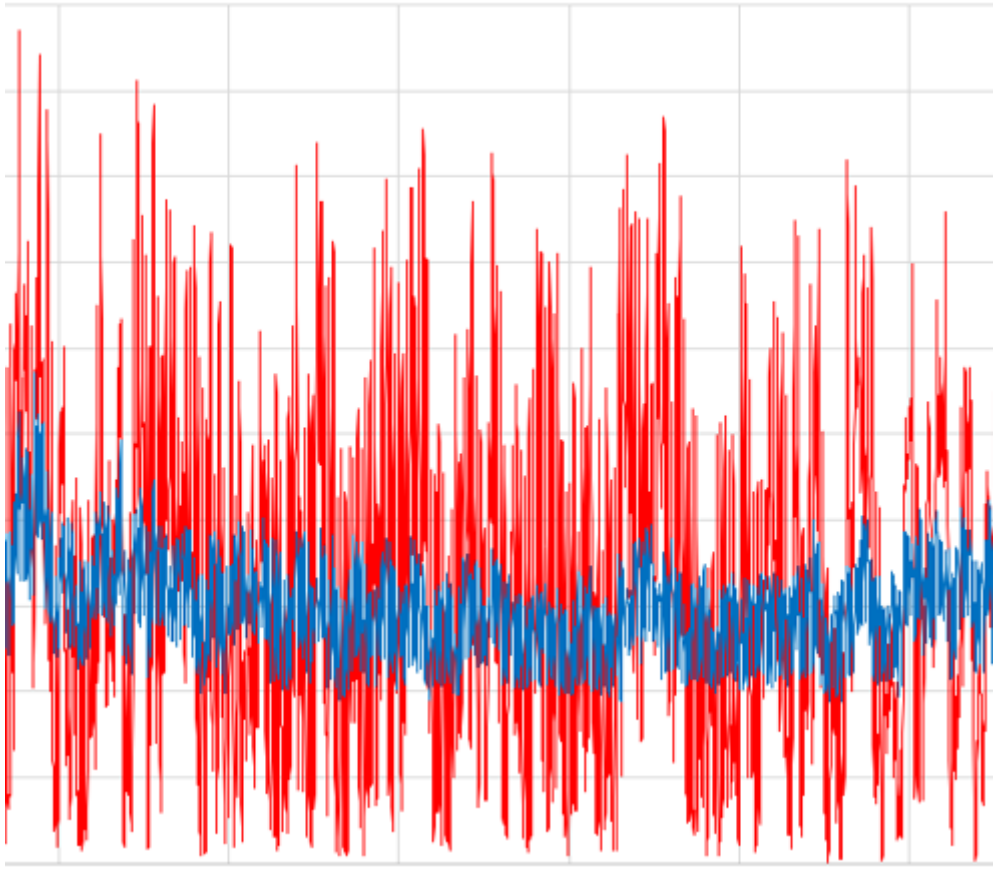
- How to do?



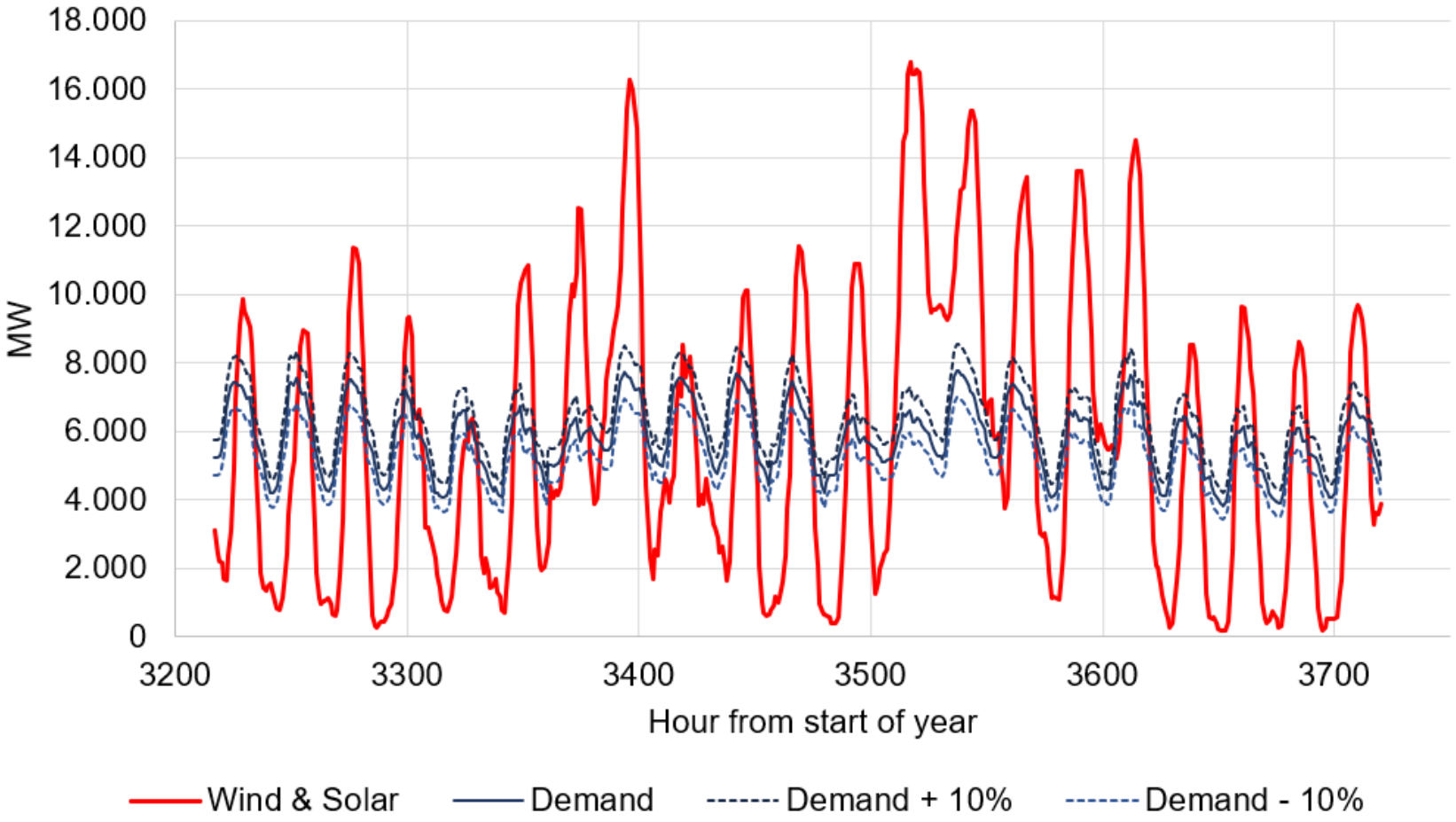


What to do?

- *Remedies proposed:*
- Demand flexibility
- Regional cooperation
- Biomass
- Energy storage

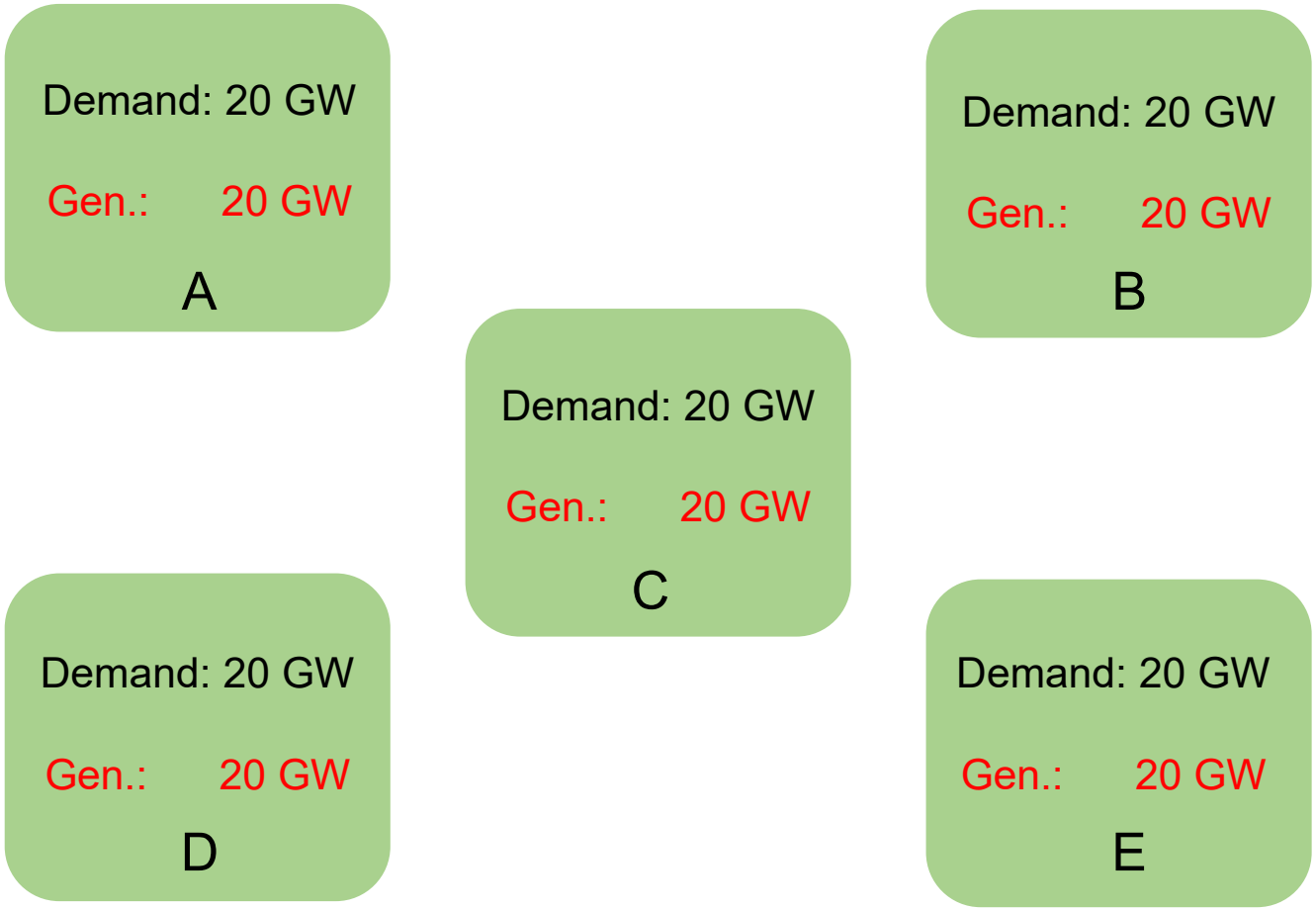


Demand flexibility



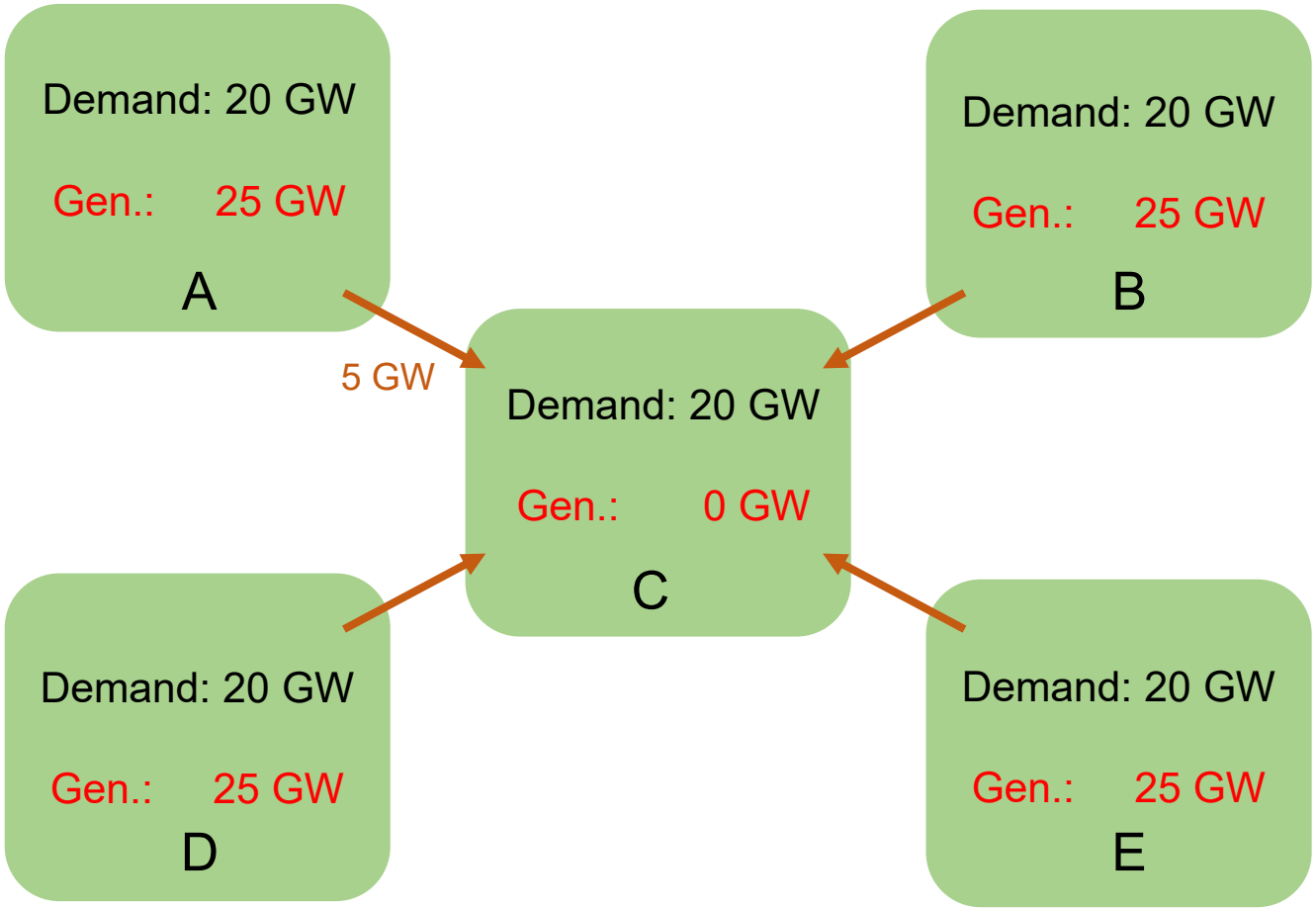
Regional cooperation

- 5 fictive regions:



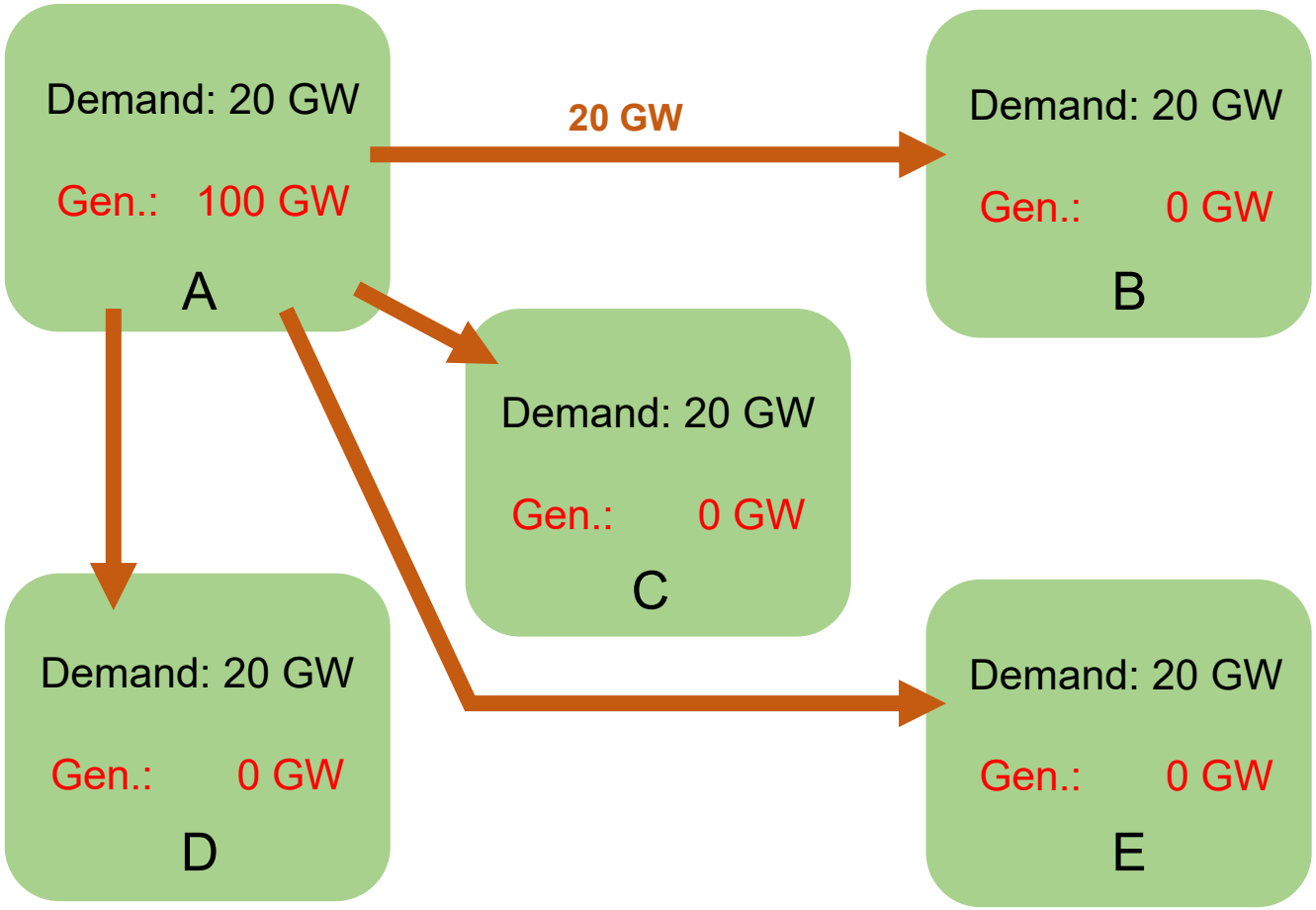
Regional cooperation

- 1 region's output = 0



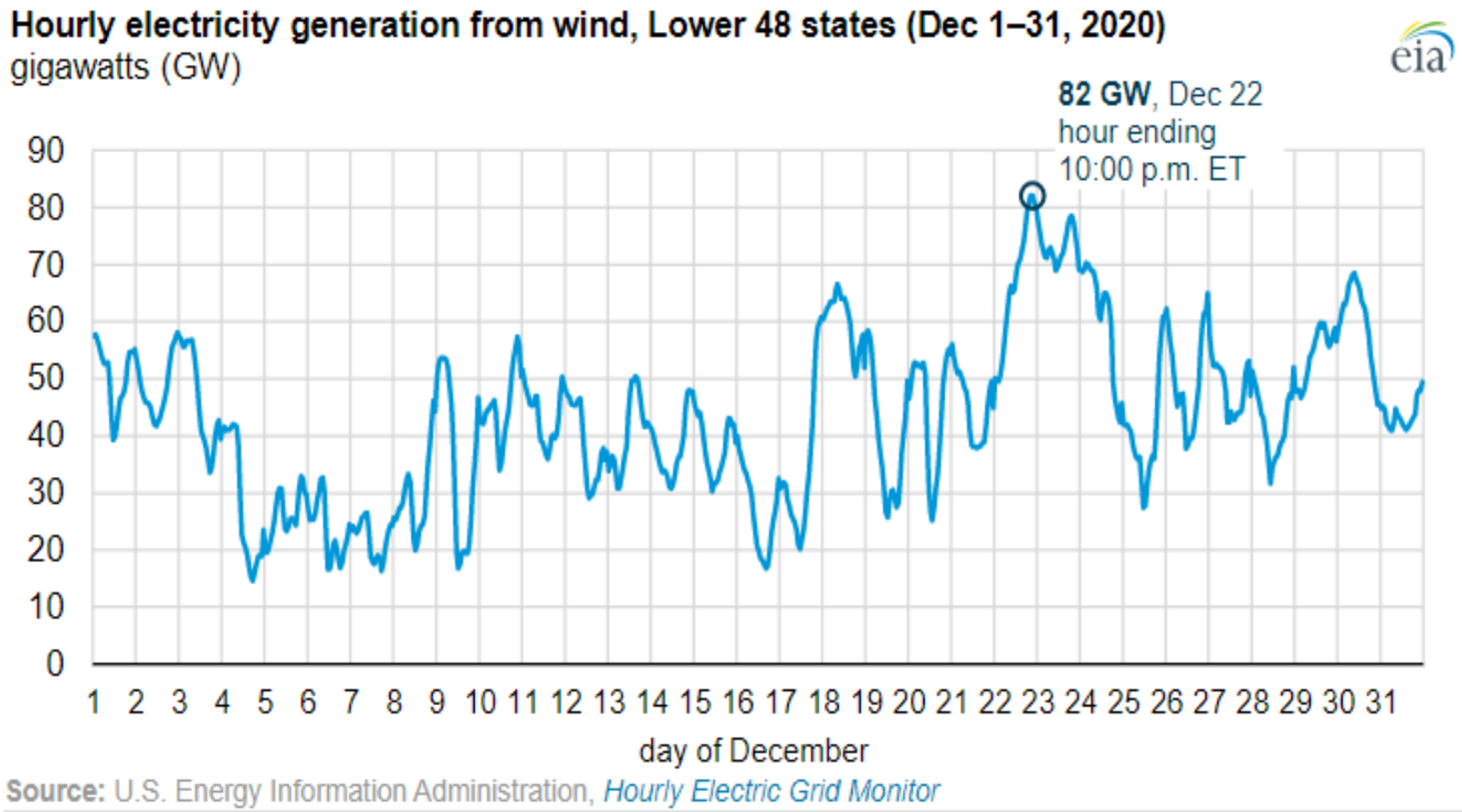
Regional cooperation

- 4 regions close to zero



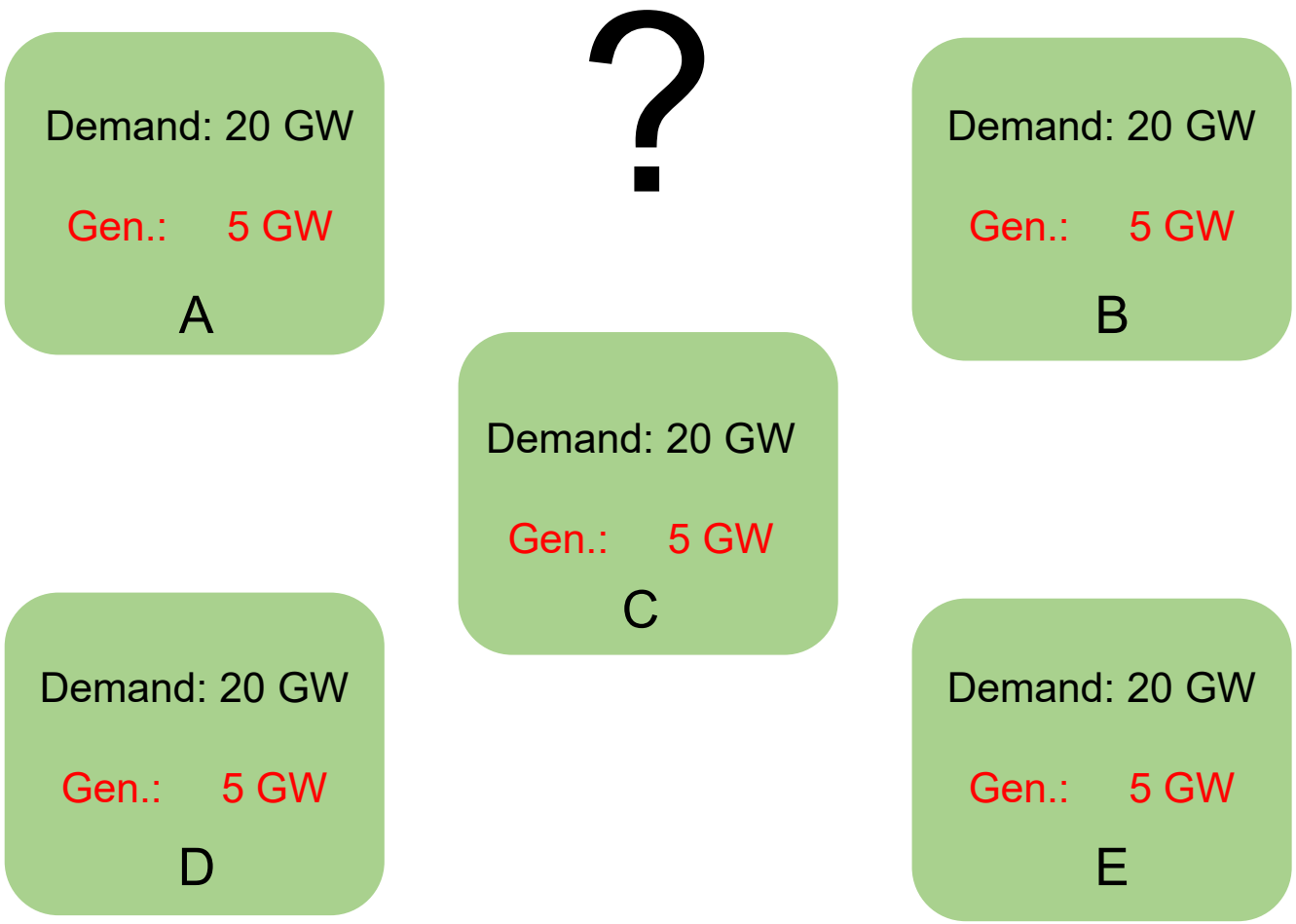
Regional cooperation

- USA Dec. 2020: Wind generation



Regional cooperation

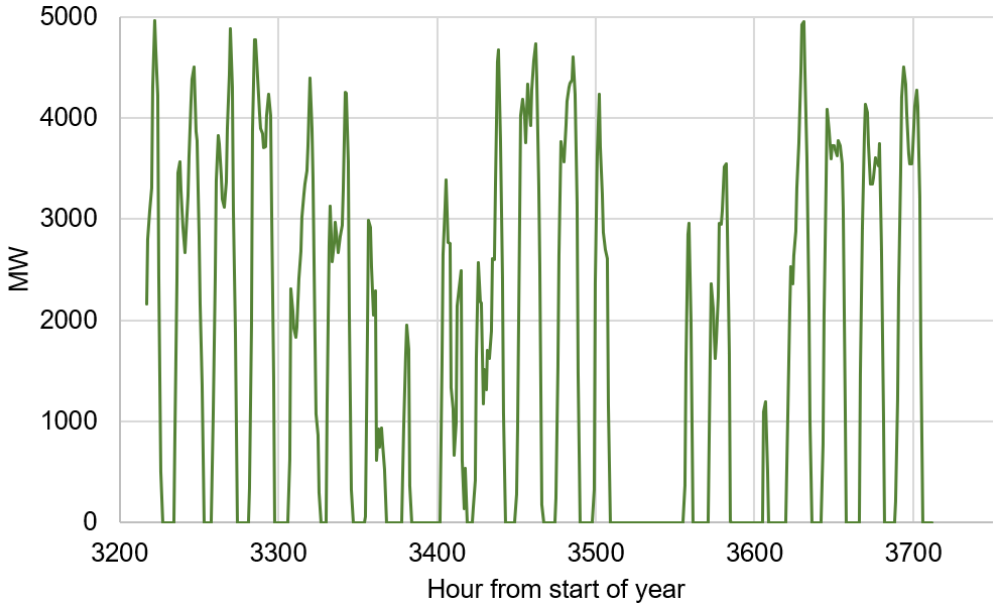
- Low output overall:



Biomass?

- Backup for wind and solar

Biomass	Yearly
Requirement, PJ	120
Req. per person, GJ	20
Globally available per person, GJ	10



Storage of electricity

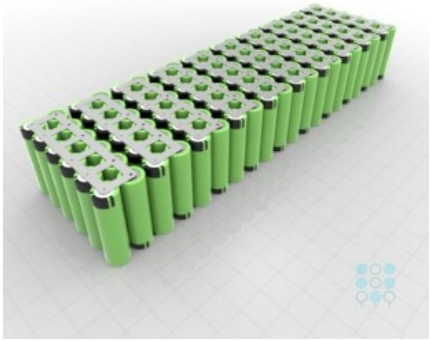
- Batteries
- Hydrogen
- Power to X

Batteries as back up

- Electricity stored directly
- Small losses in handling

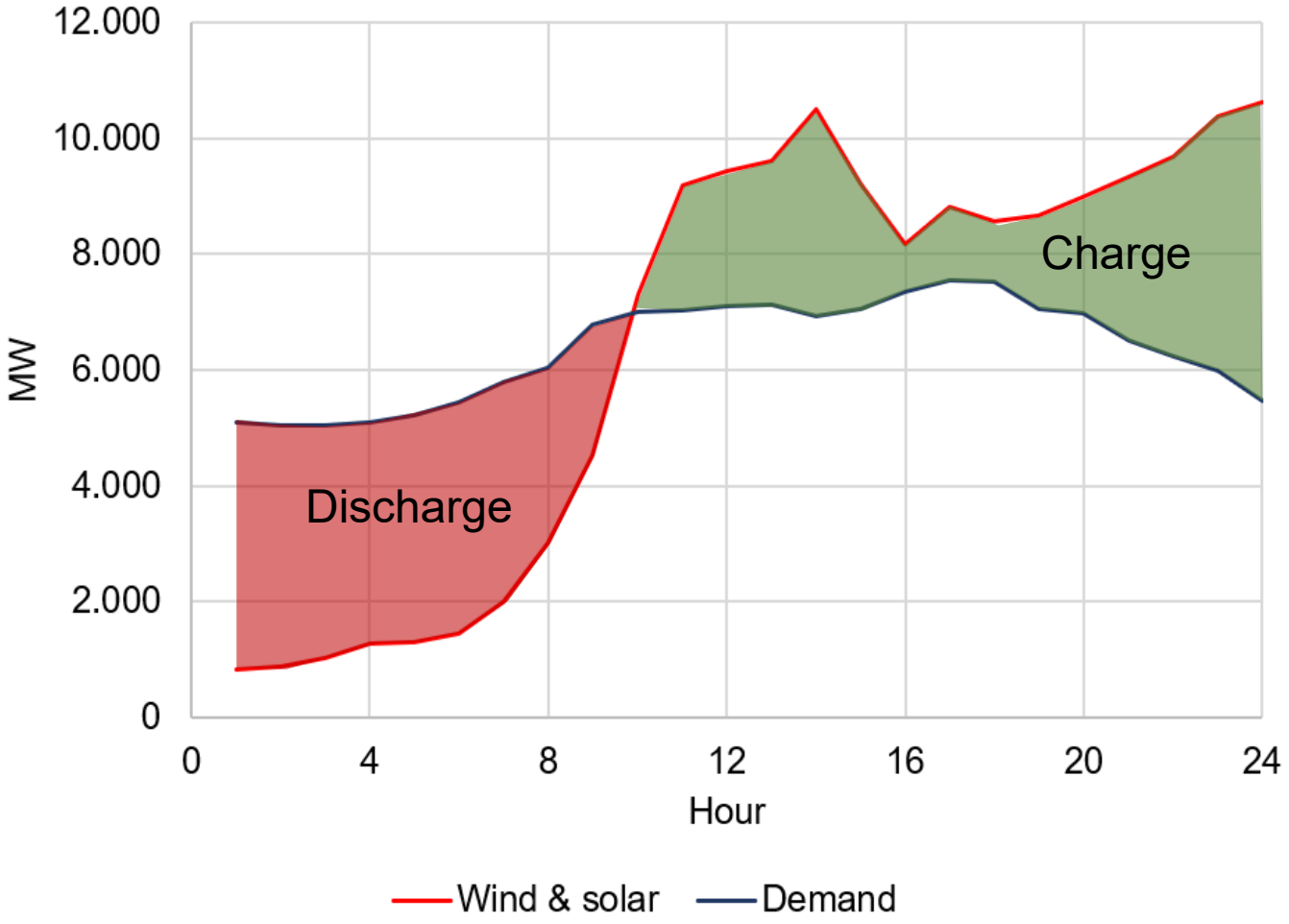
Batteries

- Car battery, 60 kWh:
  - 6000 cells



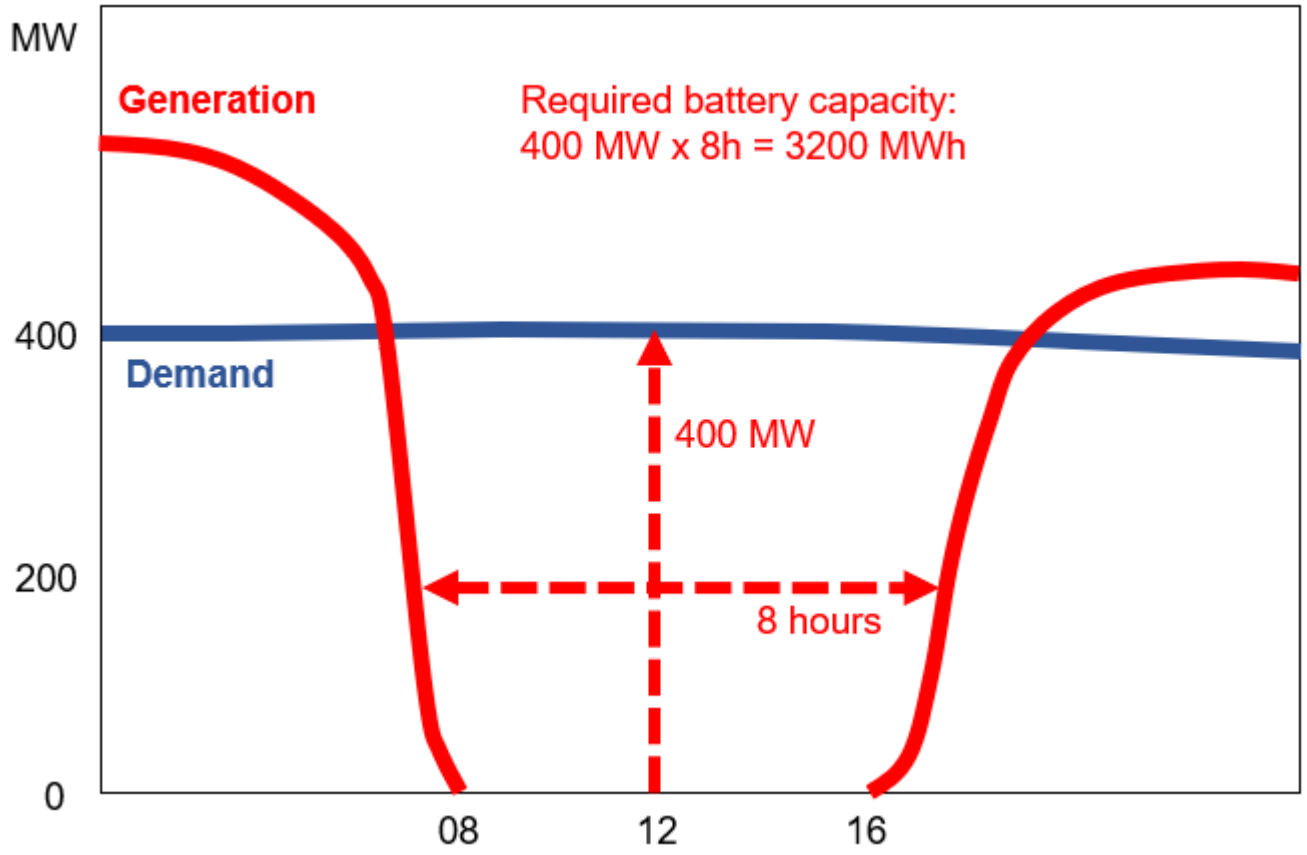
Power generation

- Production from wind and solar



Batteries

- MW - power
- MWh - energy



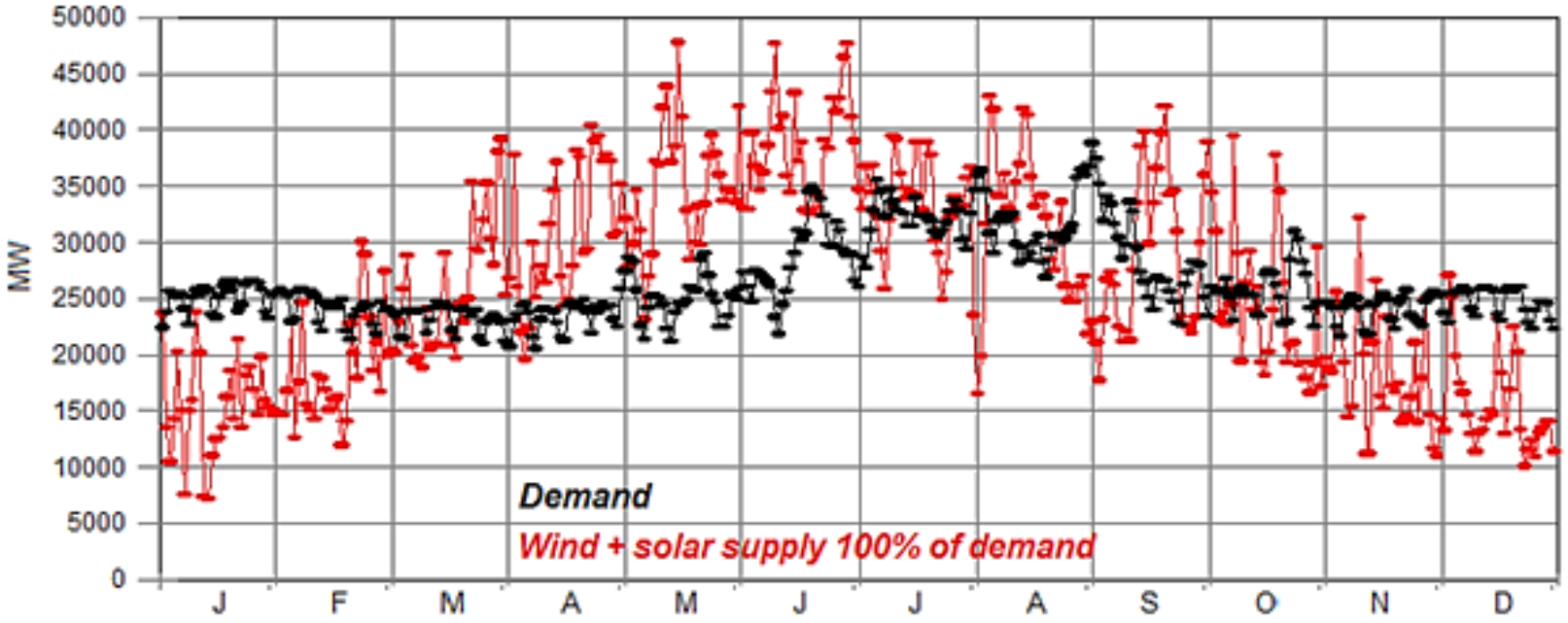
Grid-scale batteries

- Largest in the World:

		MW	MWh
Moss Landing	Capacity	400	1600
California, demand	Average power	30.000	
	Demand/hour		30.000
Coverage, Moss L.		1.3 %	3.2 minutes

Batteries

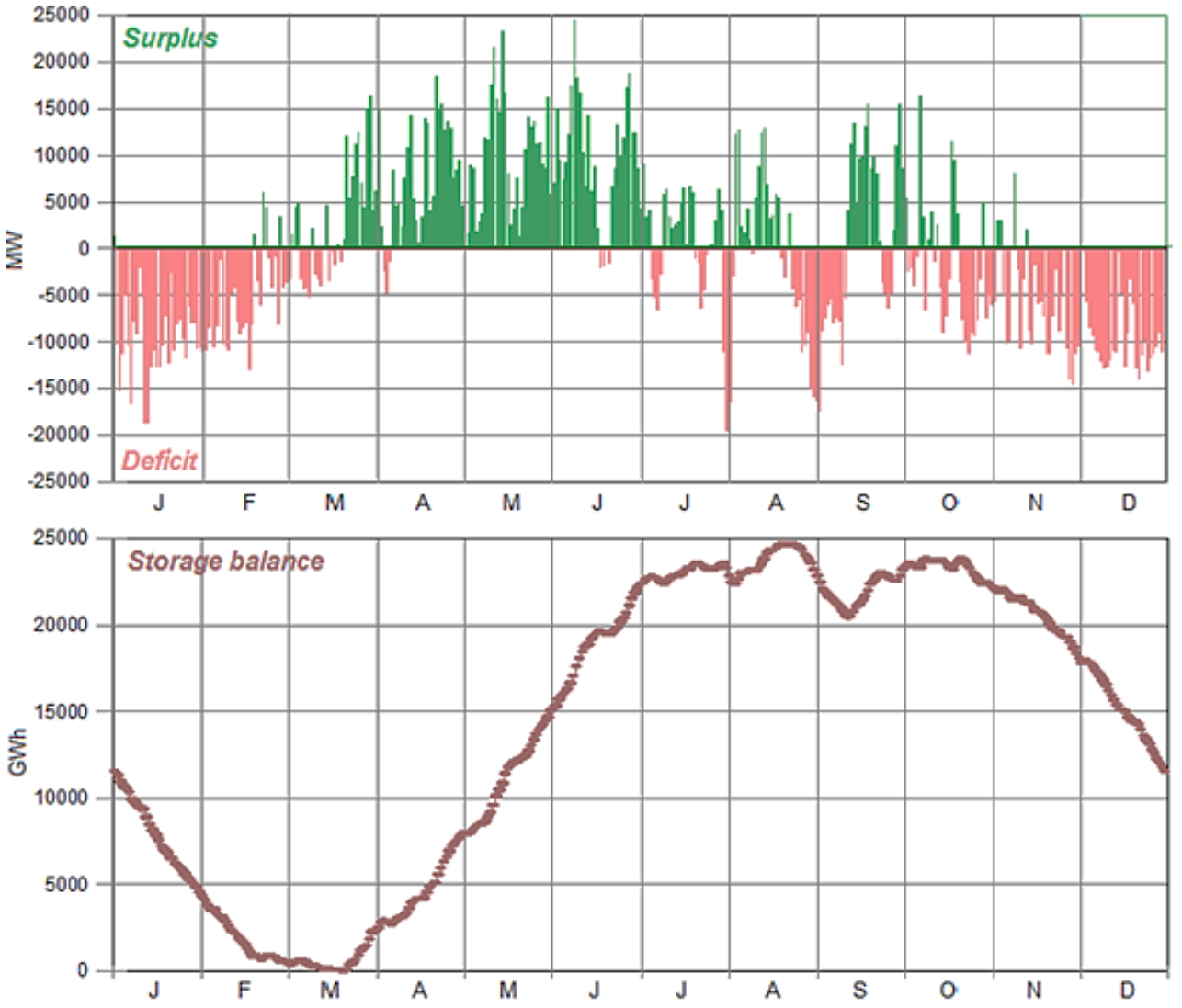
- California



Source: The Manhattan Contrarian

Battery back up

- Required capacity, California:



Batteries, costs

- Grid-scale projects, costs:

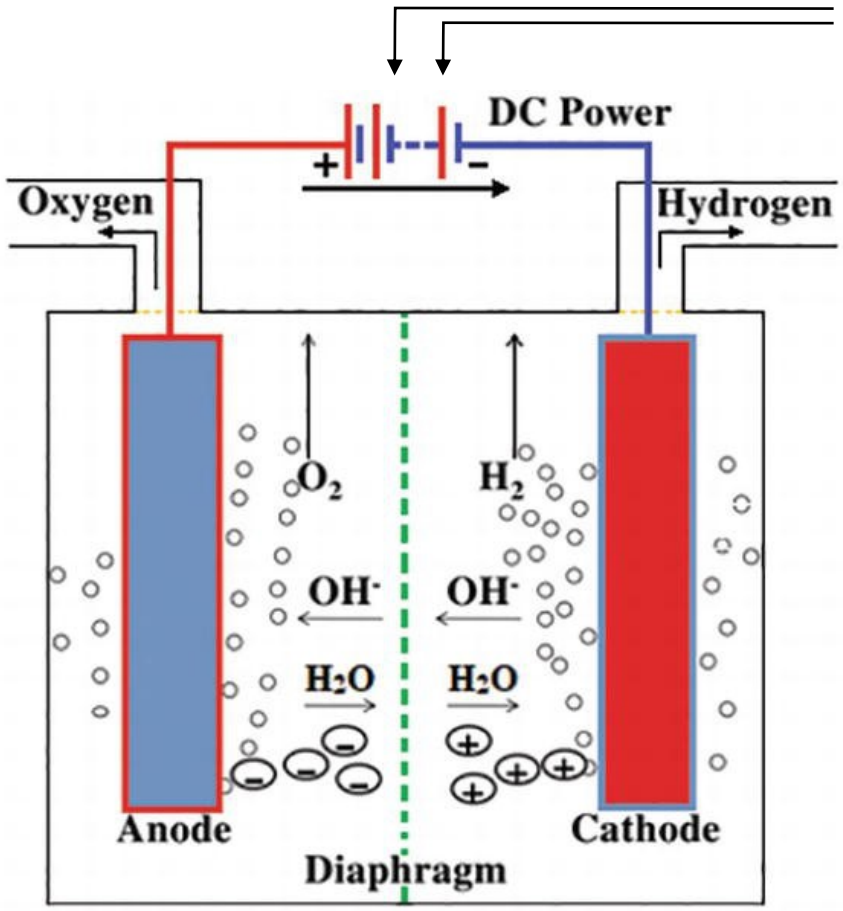
Period	US$/kWh
2013-2018	1500
2022	600

- Lithium ion battery, grid scale (California):

Storage cost	US$
Per kWh	600
Size required	25 billion kWh
Total investment	15 trillion US$
California GDP	3.7 trillion US$

Hydrogen

- H_2
- Produced by electrolysis

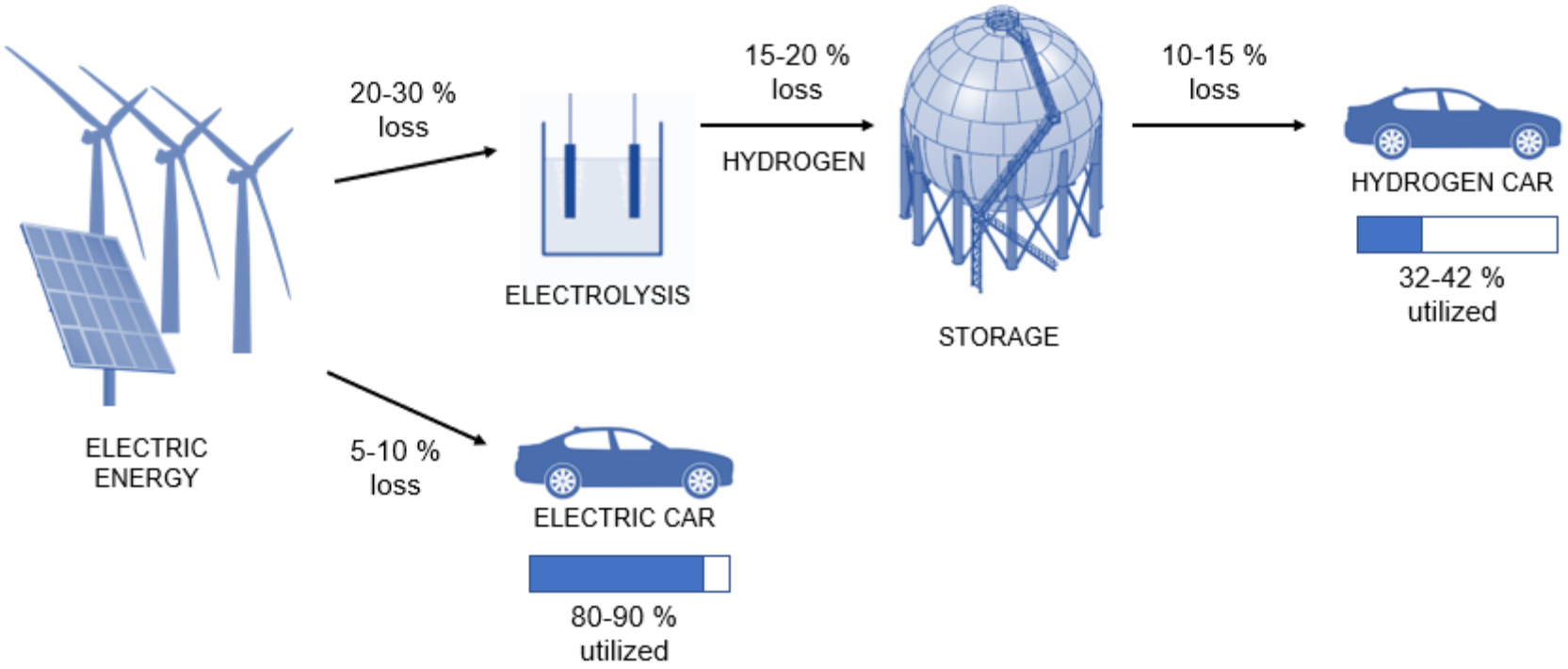


Hydrogen

- Car, range: 600 km

Fuel tank	Gasoline	Hydrogen
Pressure, bar	1	700
Volume, liters	40	150
Weight of fuel, kg	28	5
Total weight, kg	40	87

Hydrogen – loss of energy



Hydrogen - safety

- Leakages
- Explosion risk

Power to X

- Many possibilities

Hydrogen, H_2

+ CO_2

Gasoline, C_xH_y

Methanol, CH_3OH

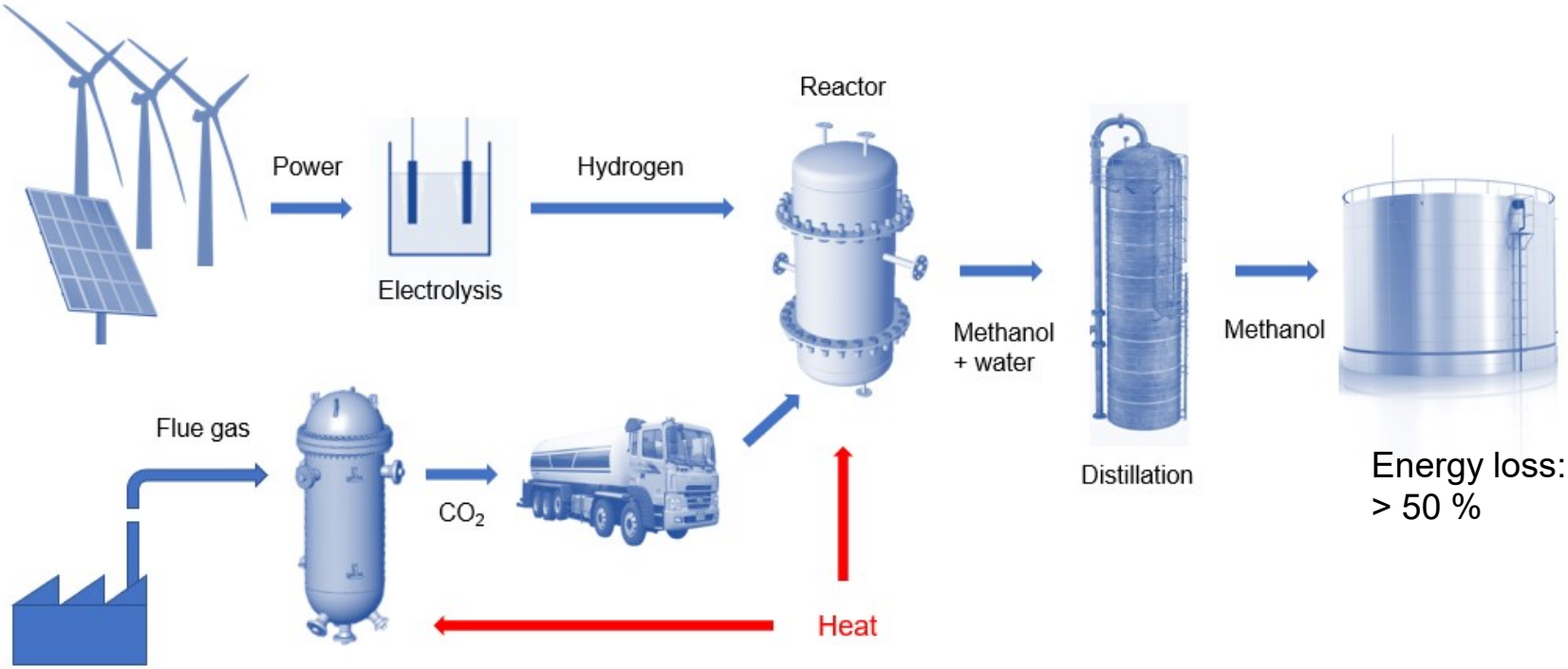
Methane gas, CH_4

+ Nitrogen, N_2

Ammonia, NH_3

Power to X

- Methanol production



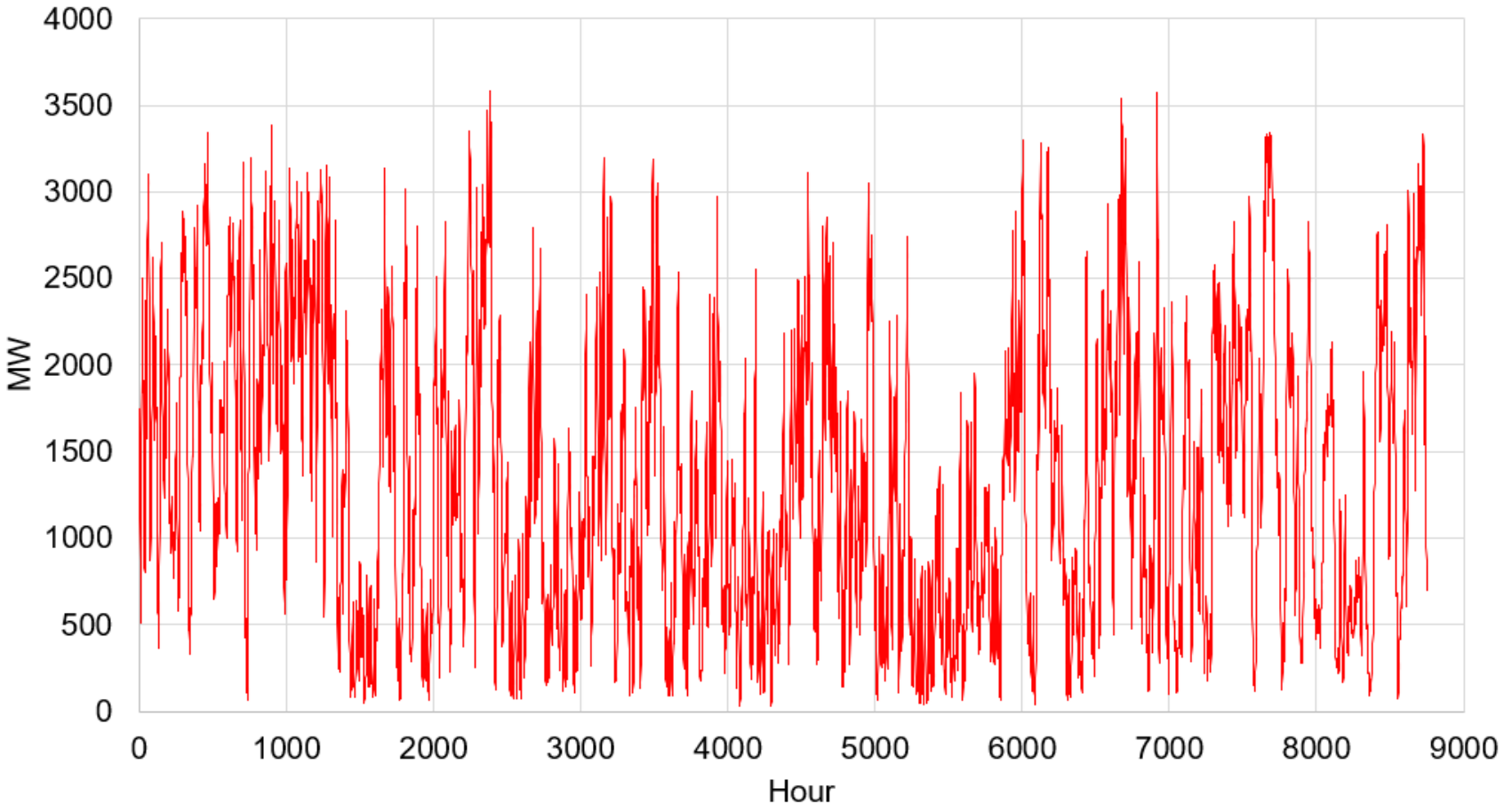
Power to X

- Proposed plant in Denmark

- Electrolysis:
  - Max 2 GW
- Avg. consumption:
  - 1.2 GW
- Power supply:
  - 3 GW wind
  - 1 GW solar
- Production/year:
  - 1 million tons of fuel

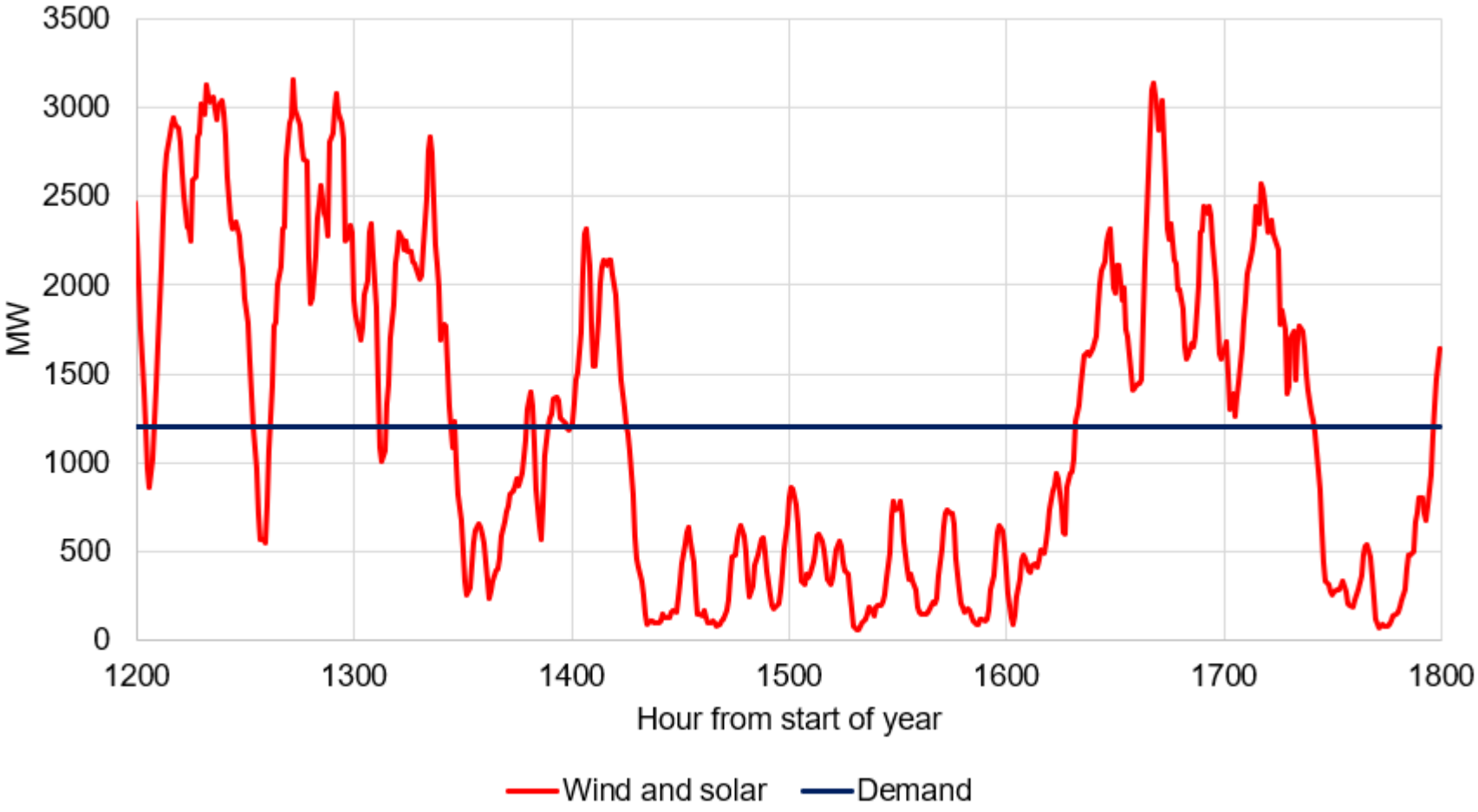
Plant proposal

- Power supply from wind and solar

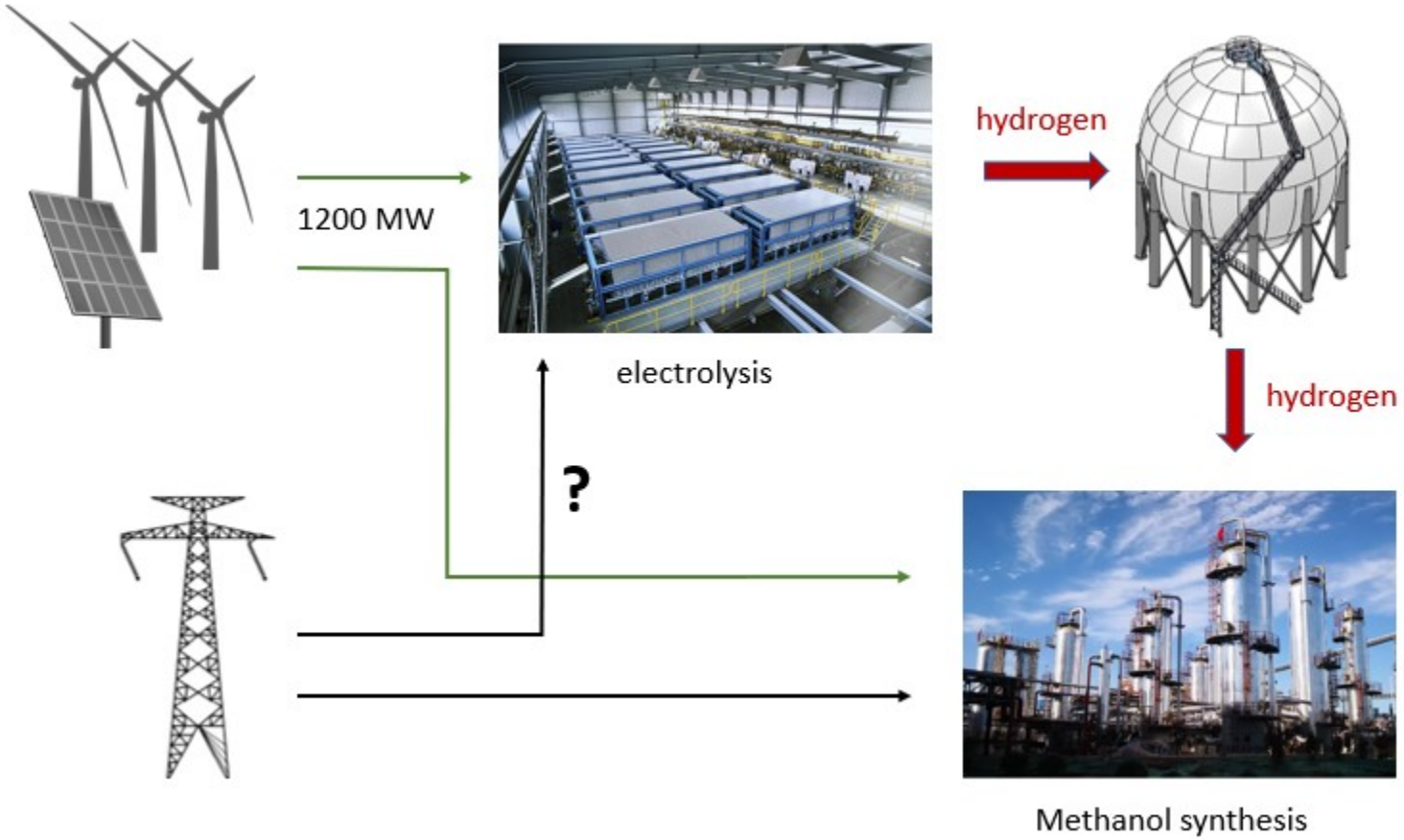


Plant proposal

- Power supply from wind and solar
  - 25 days, February-March

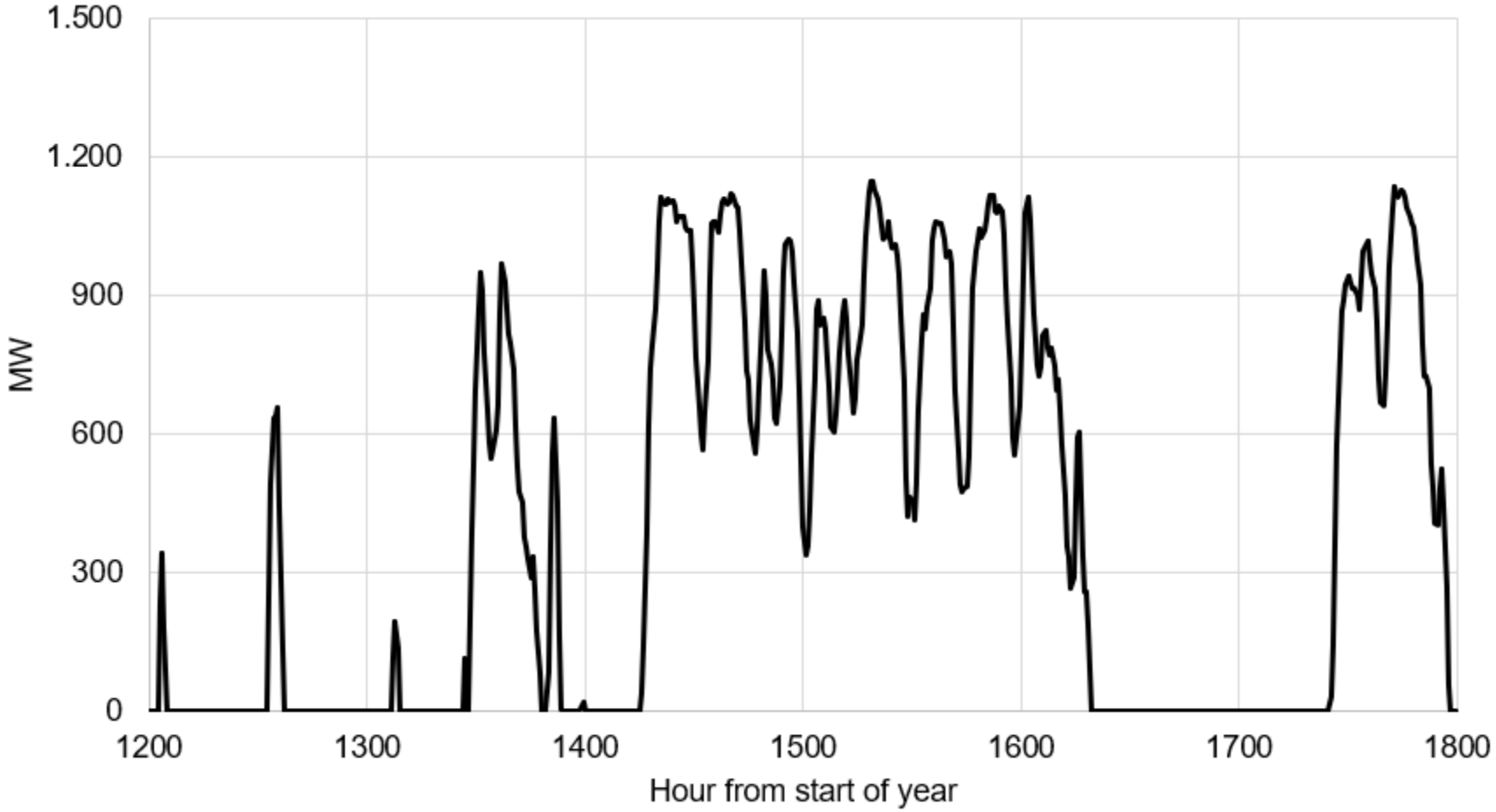


Plant proposal



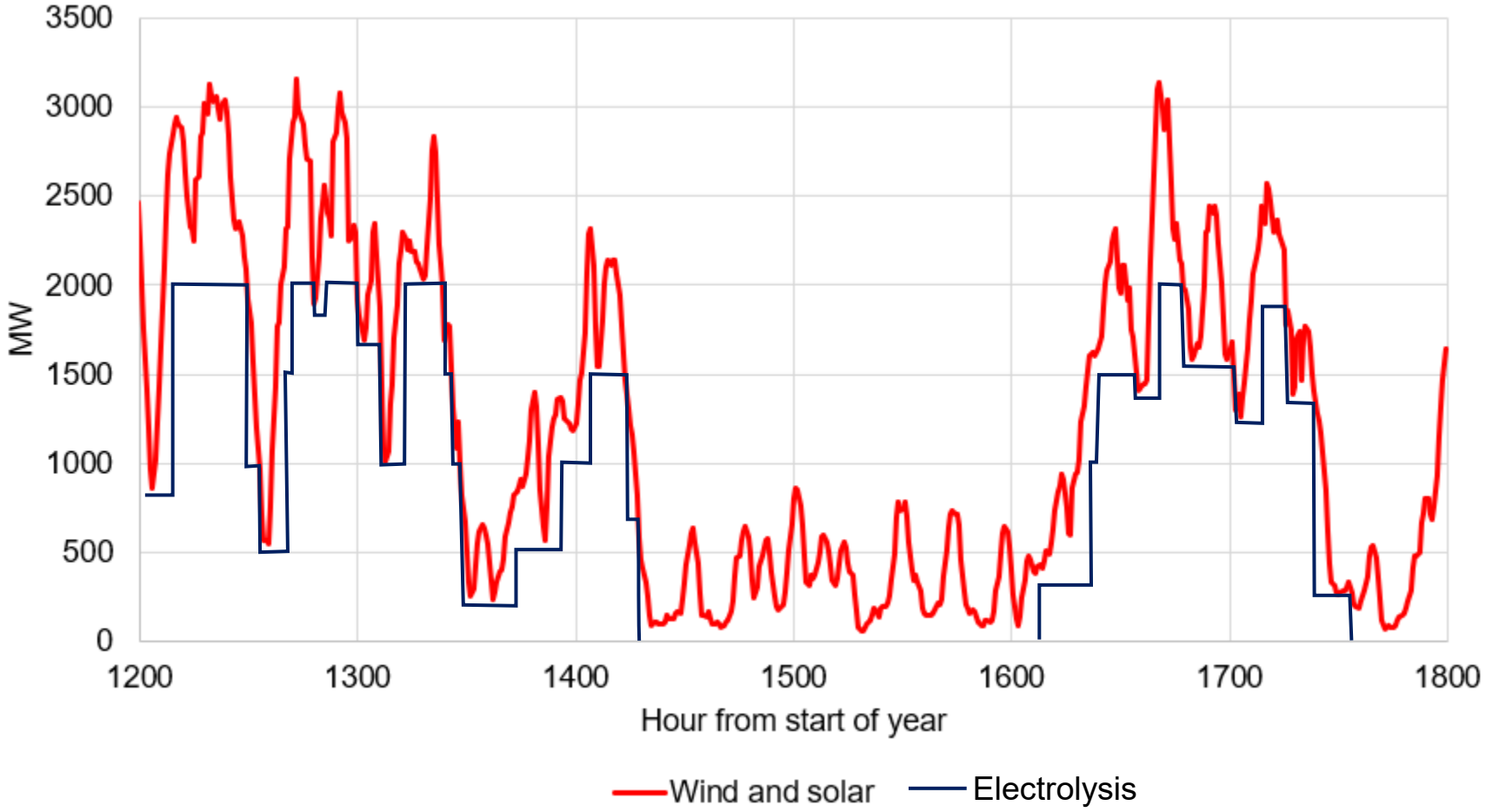
Plant proposal

- Need for outside supplies at constant consumption



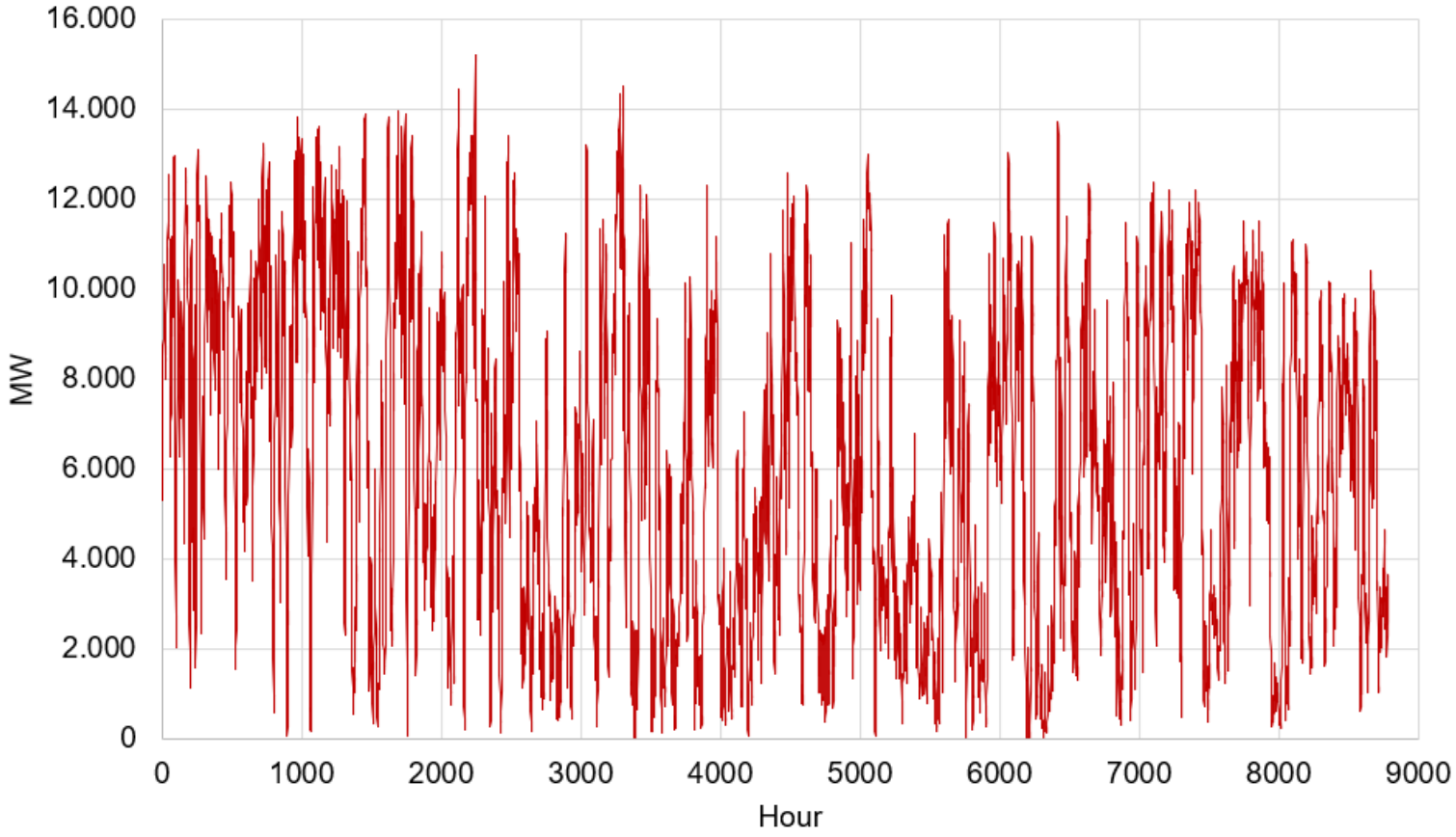
Plant proposal

- Electrolysis with fluctuating demand?



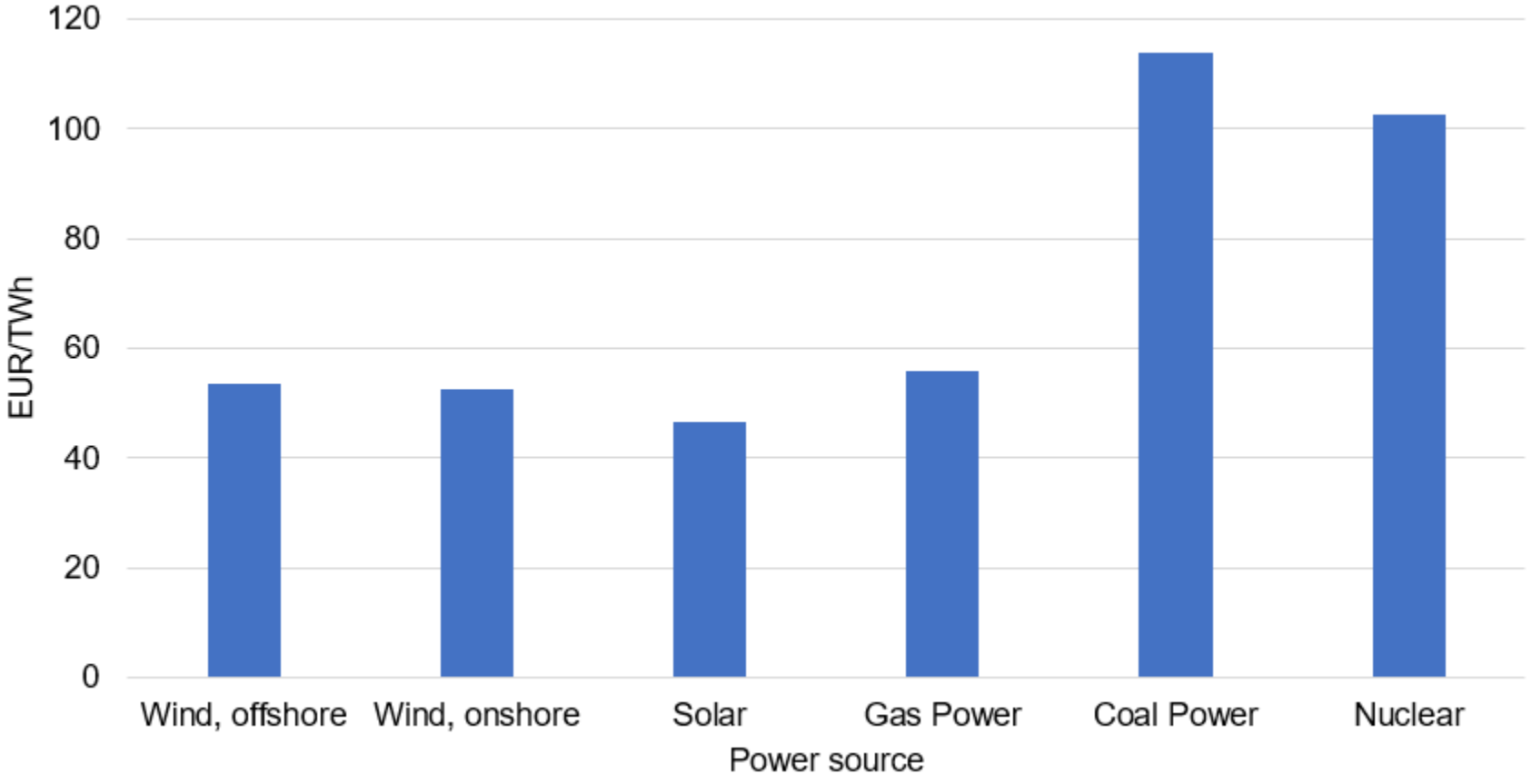
Power to X

- Key element in back up of wind and solar
- But how?



Cost of energy

- LCOE – Levelized Cost of Energy
- What we normally see



Cost of energy

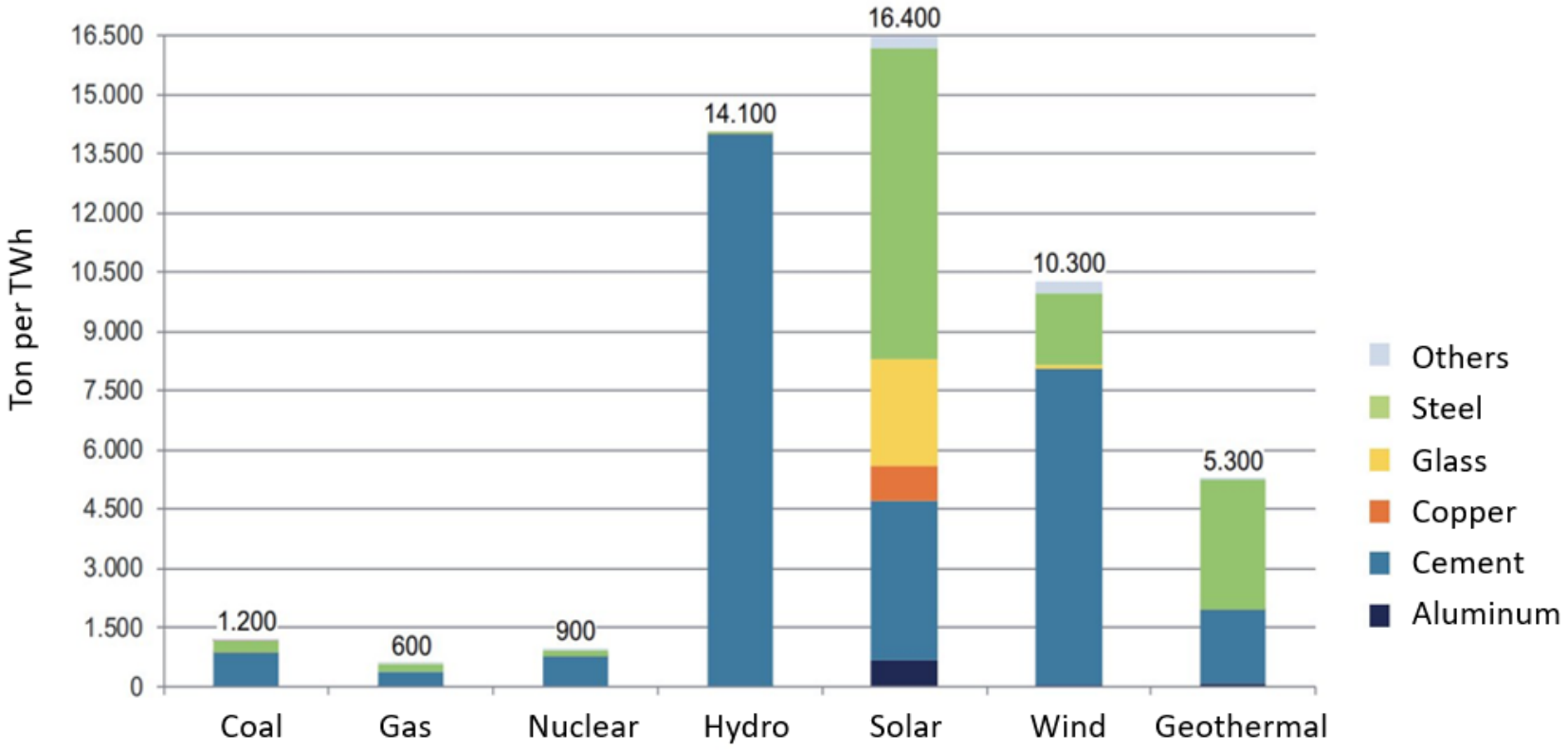
- FCOE – Full Cost of Energy

Direct costs	Investment	LCOE
	Fuel	
	Operation	
Cost of complete solution	Transmission	
	Storage	
	Backup	
Indirect costs	Environmental	
	Decommissioning	
	Land use	
No money involved	Material input	
	eROI - Energy balance	
	Lifetime	

Source: Schernikau & Smith

Cost of energy

- FCOE – Material input

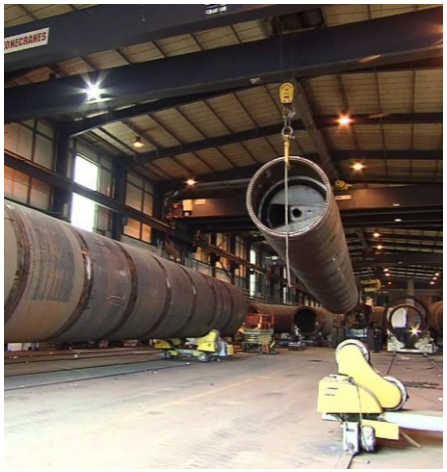


Cost of energy

- eROI – Energy Return on Investment
- Roman Empire, eROE = 2

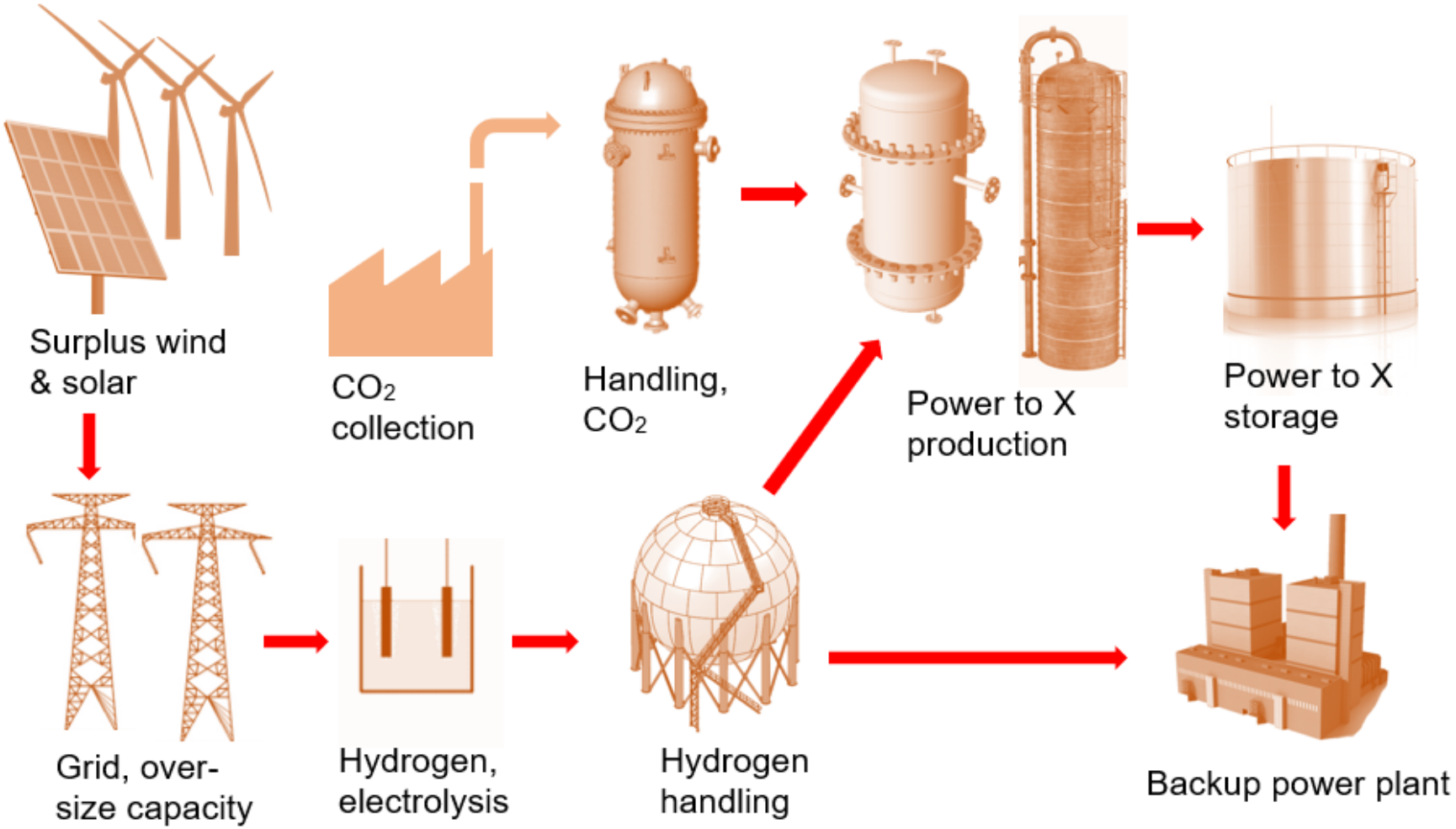
Energy used for manufacture

- Activities, all powered by fossil fuels

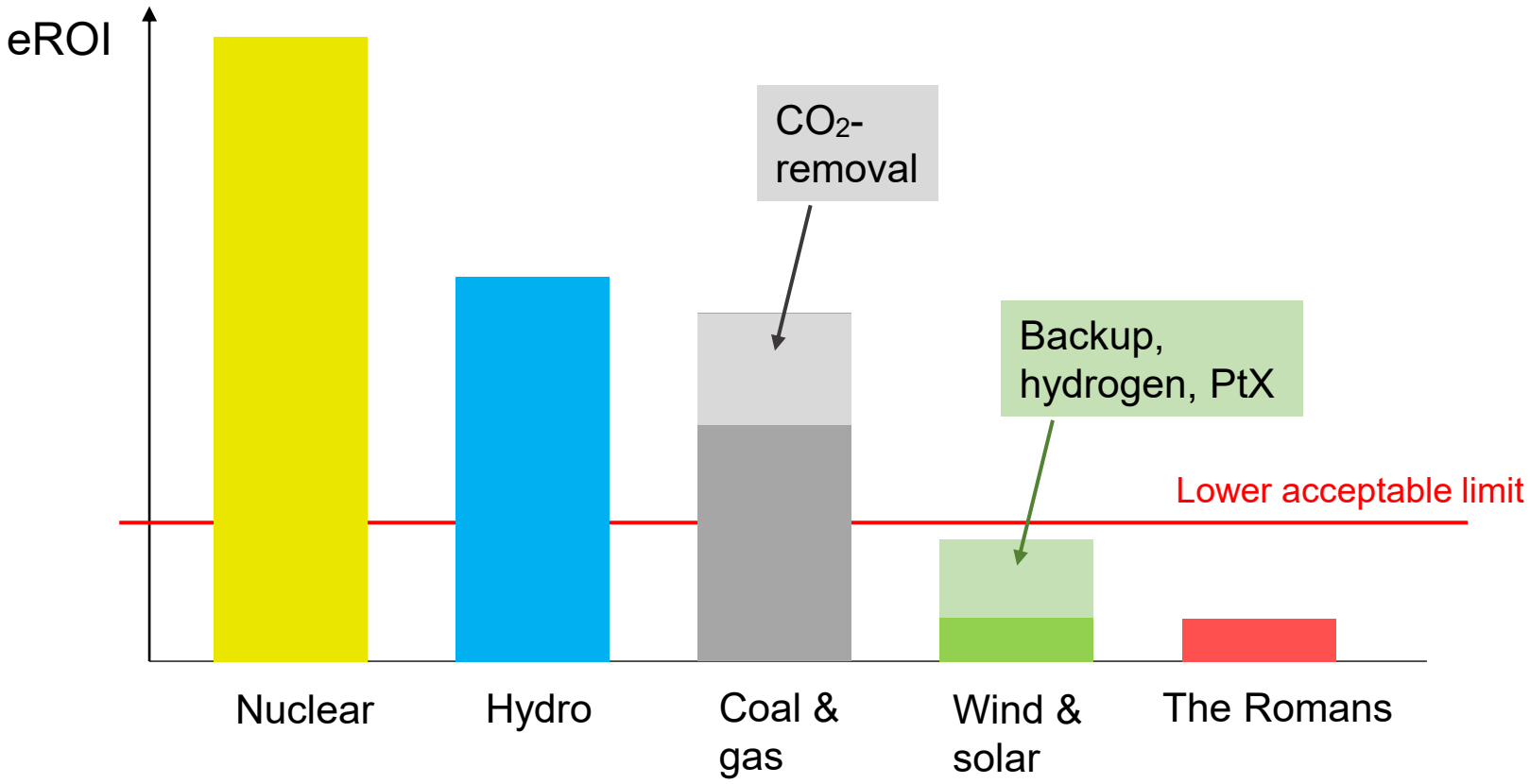


Equipment involved

- Elements of a wind/solar-based energy supply



Energy return on Investment



Source: Schernikau & Smith

Conclusion

- Future role of energy technologies

Solar and wind — Very limited

Biomass — Limited

Hydro — As much as possible

Fossil fuels — Large, for many years

Nuclear — The future #1