Economics for Wholesale Electricity Markets

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The Language of Costs

Module 1

Objective

- Develop a common language for talking about costs
  - The big four:
    - Capital cost
    - Operation & Maintenance costs (cost of keeping the plant open)
    - Average cost (cost per MWh produced)
    - Variable (marginal) cost
- Show how costs depend on plant type and capacity utilization

The varieties of costs

- Total: fixed and variable
- Average costs
- Marginal costs
- Opportunity cost
- Levelized cost of energy
- Levelized cost of avoided energy
- Annual revenue requirement

Fixed cost [FC]

- Capital cost of *building and financing* a plant
  - Cost of construction (sometimes called '*overnight cost'*)
  - Payment to the owners of capital (interest rate)
  - Amortized loan amount over term of loan
- We will report this as a monthly cost
  - **Constant over the life of the plant**
  - In theory, this is the monthly rental price of capital
- We need to know three things
  - Amount of capital investment
  - Term of the loan
  - Interest rate: return on the investment (or interest paid on loan)

Fixed costs - example

- Payment = pmt(interest rate, term (months), overnight cost)
- Example:
  - Plant: 500 MW capacity
  - "Overnight" cost: $320,000,000
  - Term: 360 months (30 years)
  - Rate: 7% (annual)
- Monthly payment: $2,129,000
  - Includes capital and interest payments
  - Over the term of the loan

Fixed costs

- Ways of reporting capital costs
  - Monthly payment or fixed costs per unit generated
- Monthly payment for the capital (amortizing the loan) : $2,129,000
- This doesn’t change
  - No matter how much is produced
  - No matter what fraction of time the plant is run (capacity factor)
  - Whether or not the plant is open for business
- We will focus on *average fixed costs:*
  - Fixed cost per MWh generated over some period

Capacity factor (quick definition)

- What fraction of a plant's maximum capacity is achieved in practice?
  - For our 500 MW capacity plant
  - How does actual output compare to what the plant could generate if it ran at full capacity all the time (8760 hours per year)? → 4,380,000 MWh
  - Actual capacity factor is measured as a percentage
  - Each 1% of capacity is 87.6 hours of operation at 500 MW
  - Or 43,800 MWh of output per year
  - Monthly: 7.3 hours, 3,650 MWh

Average Fixed Costs [FC]

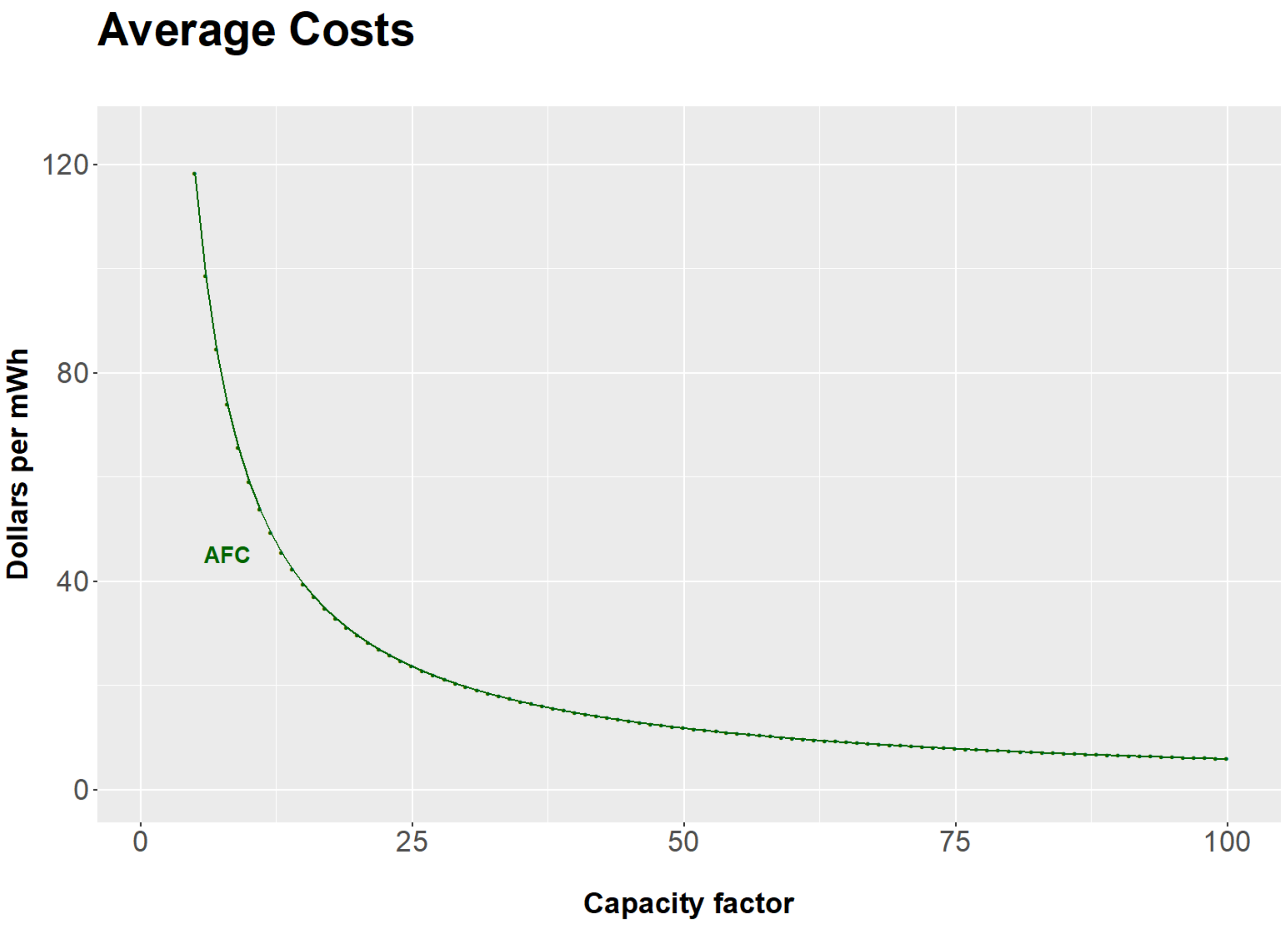
- AFC = monthly payment / monthly MWh generated
  - Where MWh per month = plant capacity (MW) * hours in month * capacity factor (cf)
- AFC falls as the capacity factor increases
  - Capital costs are spread over more MWh

Average fixed costs: Example

- For our example 500 MW plant:
  - Fixed monthly finance payment: $2,129,000

- Monthly costs for a 730 hour month
  - 100% cf: $2,129,000/365,000 MWh = $5.83
  - 50% cf: $2,129,000/182,500 MWh = $11.7
  - 25% cf: $2,129,000/91,250 MWh = $23.3
  - Etc.

Average fixed cost



Operation and maintenance costs [O&M]

- Costs of keeping the plant in operating condition
  - Average monthly cost of staff, maintenance, security, etc.
- Must pay each month that plant is in service
- A plant may be taken out of service (mothballed)
  - But, it takes time and money to bring back online
  - And you must still pay a small part of O&M costs
- Key point: some O&M costs do not increase with output
  - They are “fixed” in the short run: say a month at a time
  - Other O&M costs may rise as more electricity is produced

Operation and maintenance costs [O&M]

- For simplicity, we divide up O&M costs into the fixed and variable components
  - The fixed part will go into fixed costs, and
  - The variable part will go into variable costs
- Note: if the plant is taken out of service, we do not pay O&M costs
- For today, we just ignore O&M costs as a separate category and focus on fixed and variable costs

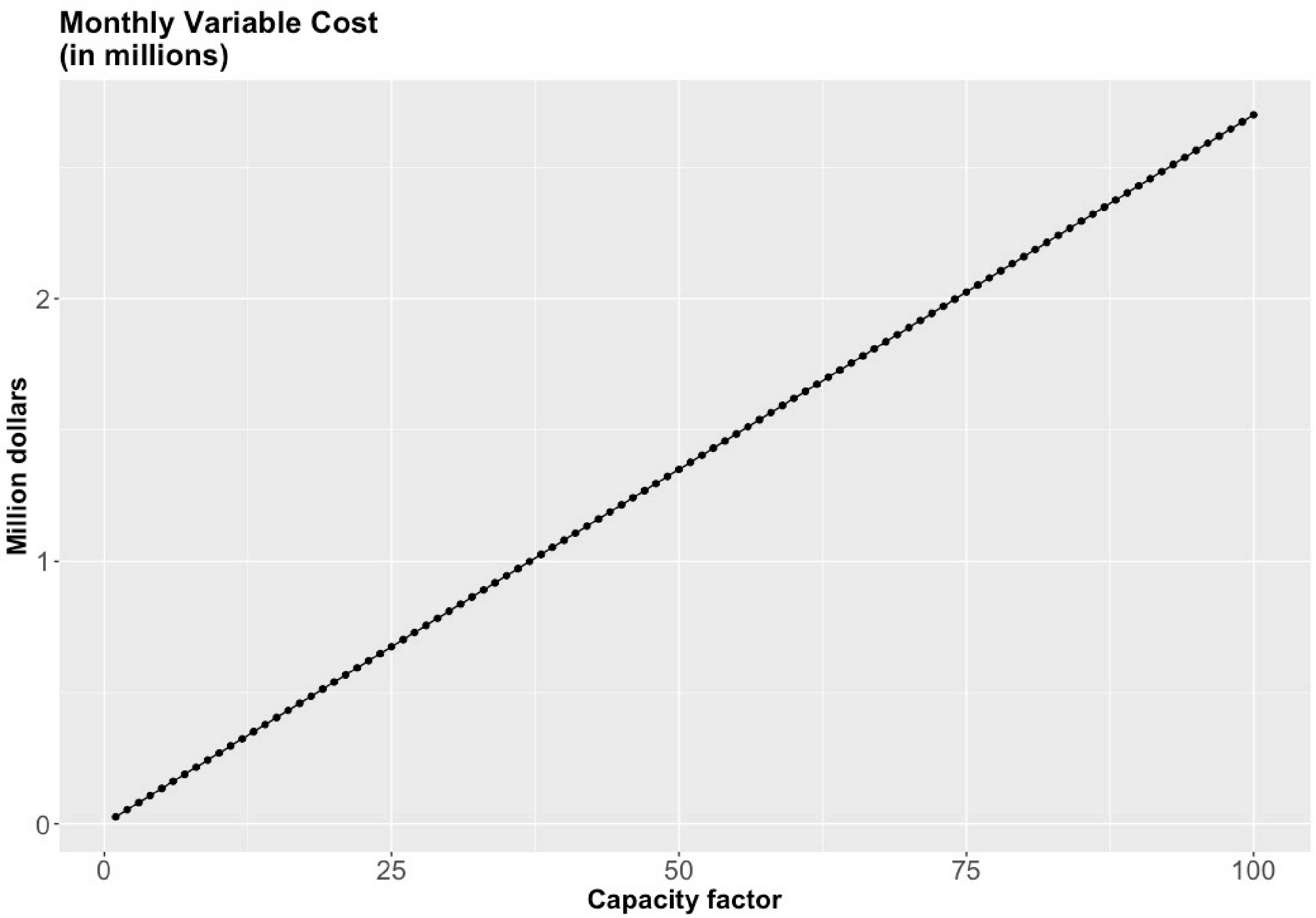
Variable costs [VC]

- *How do total production costs vary with the amount of electricity generated?*
  - More fuel is required; fuel is the lion's share of variable cost
- Monthly variable cost = monthly fuel bill
- The monthly fuel bill will depend on:
  - How much the plant is run, *the capacity factor*
  - The fuel needed to generate a MWh, *heat rate (mmBtu/MWh)*
  - The price of fuel
- Monthly fuel cost = fuel price * heat rate * monthly output
  - Heat rate varies with the type of plant ***and*** the *cf* of the plant
  - For today: assume that heat rate is constant for a given plant

Variable Cost

- Back to our example 500 MW plant
- Fixed cost:
  - Fixed monthly finance payment: $2,129,000
- Variable cost
  - Fuel price: $2.50/million Btu
  - Heat rate: 9 million Btu/MWh
  - Fuel cost per MWh: $2.50 * 9 = $22.5/MWh

Total Monthly Variable Cost
(with constant heat rate)



Average cost measures [AC]

- Average fixed cost: AFC = total fixed cost/MWh
- Average variable cost: AVC = total variable costs/MWh
- Average total cost: ATC = (fixed cost + variable costs)/MWh
  - So ATC = AFC + AVC

Average Variable Cost

- For simplicity: we assume a constant heat rate
- Given this assumption, average variable cost is constant
- *In real power plants, the heat rate is not constant, so the average variable costs will vary with the capacity factor*

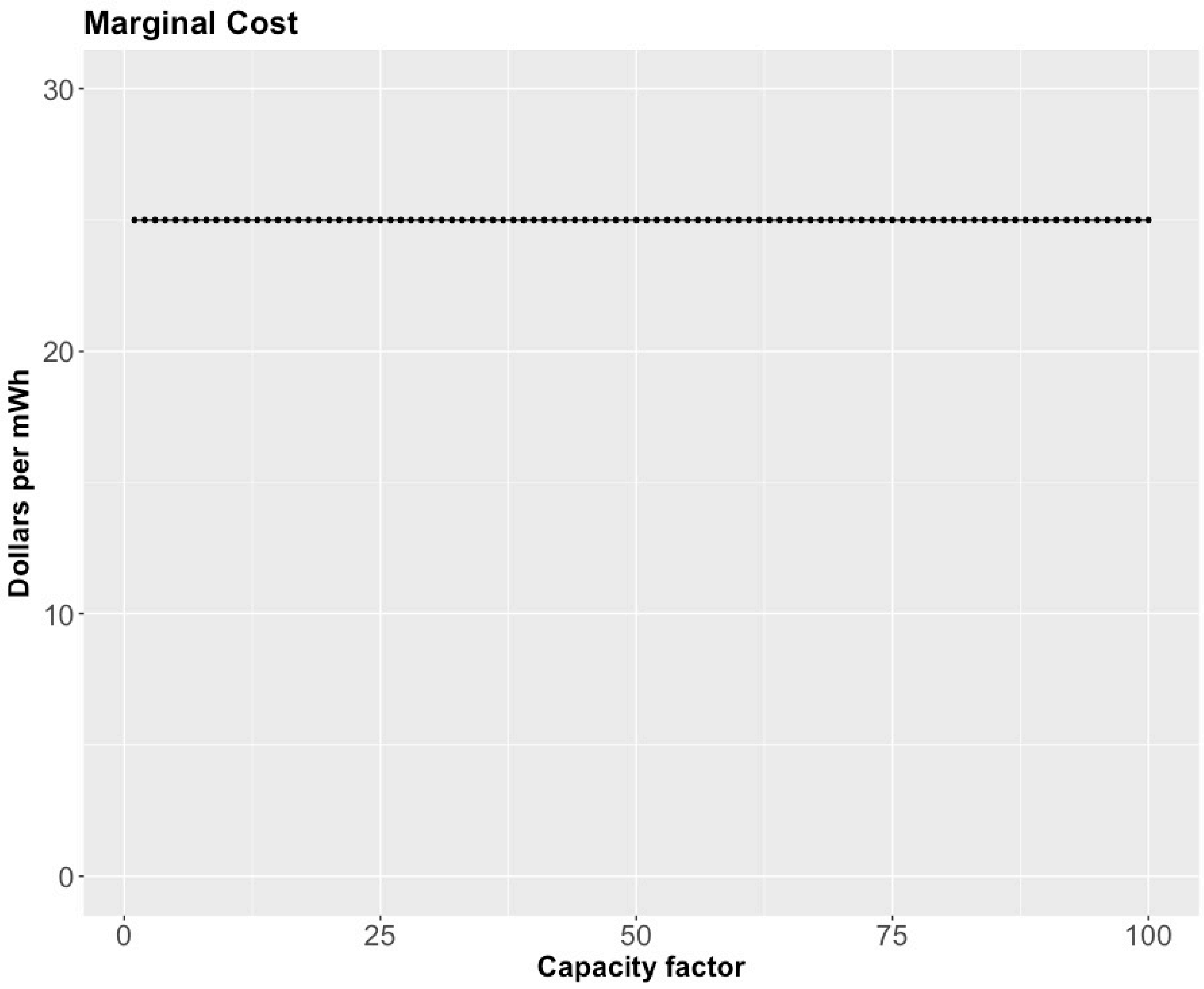
Marginal cost [MC]

- What if I generate one additional MWh of electricity?
  - Cost of one more MWh ← **marginal cost**
  - The marginal cost may depend on how hard the plant is running
    - Heat rates may fall until the plant reaches minimum efficient output
    - As the plant approaches full capacity, heat rates may rise again
  - For simplicity, we have assumed the heat rate does not change
    - If this is true, MC and average VC will be the same (a special case)
    - The fuel cost to generate one more MWh

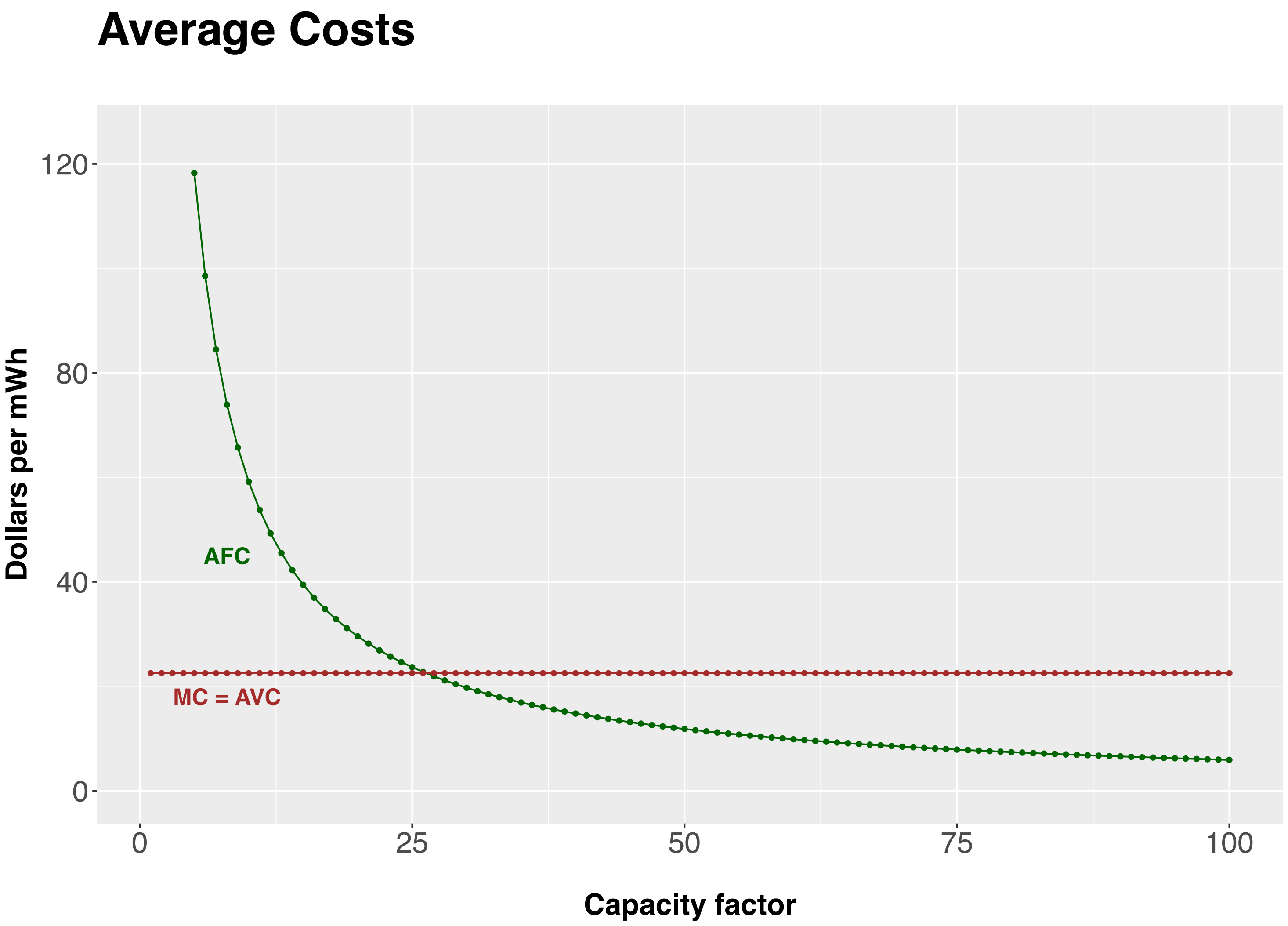
Marginal Cost

- Given a constant heat rate, MC is the same for each additional MWh generated
  - Think of it being constant over the reasonable operating range for a type of plant

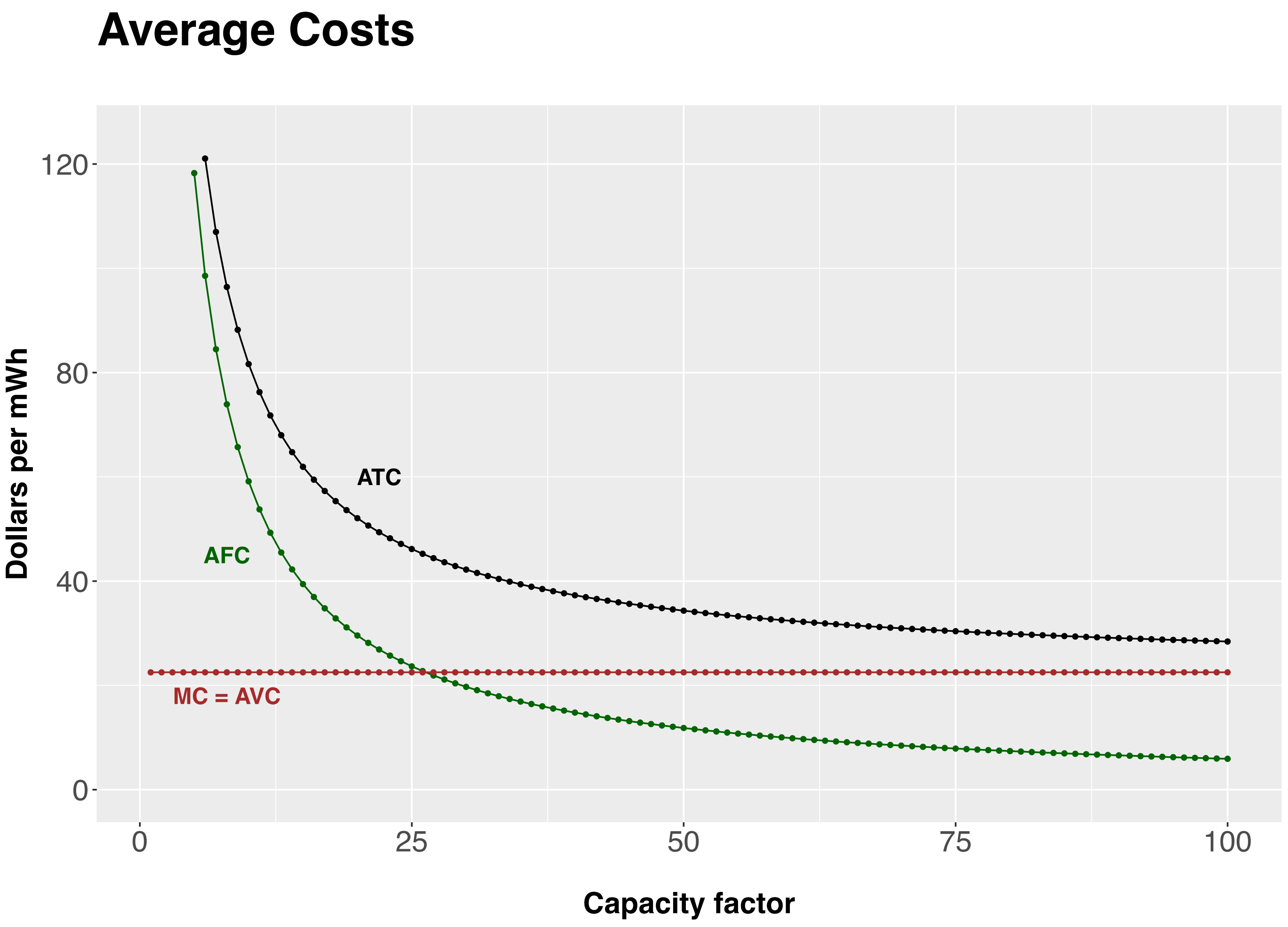
- As we shall see, MC varies greatly for different kinds of plants



Average Fixed Cost and Marginal Cost

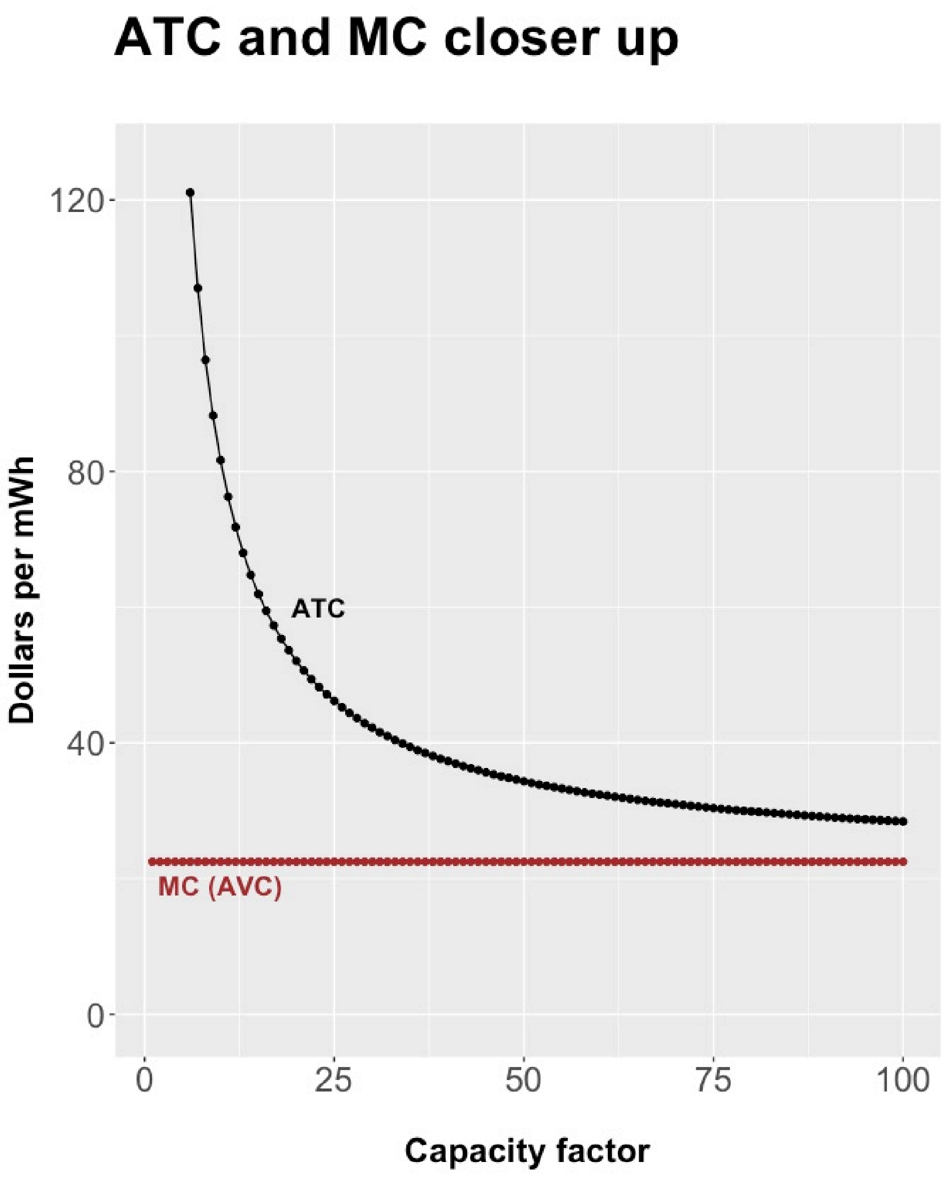


Average Total Cost



More on ATC and AVC (MC)

- In our example, ATC is falling, while MC (AVC) is constant
- Also, note that AVC (MC) is everywhere below ATC



Opportunity cost: the good cost

- Anything you own (or have control over) might have value to someone else
  - They would be willing to pay you for it
  - If you use what you have, you give up the money from selling it
  - This is *opportunity cost*: what you can get for your asset if you don't use it
- Suppose you win a car in a raffle
  - The raffle ticket cost $1.
  - Even if you already have a car, this second car is worth much more than $1 to you because you can sell it.
  - The possible sale price is the *opportunity cost* of keeping the car
- May you have high opportunity costs in life!

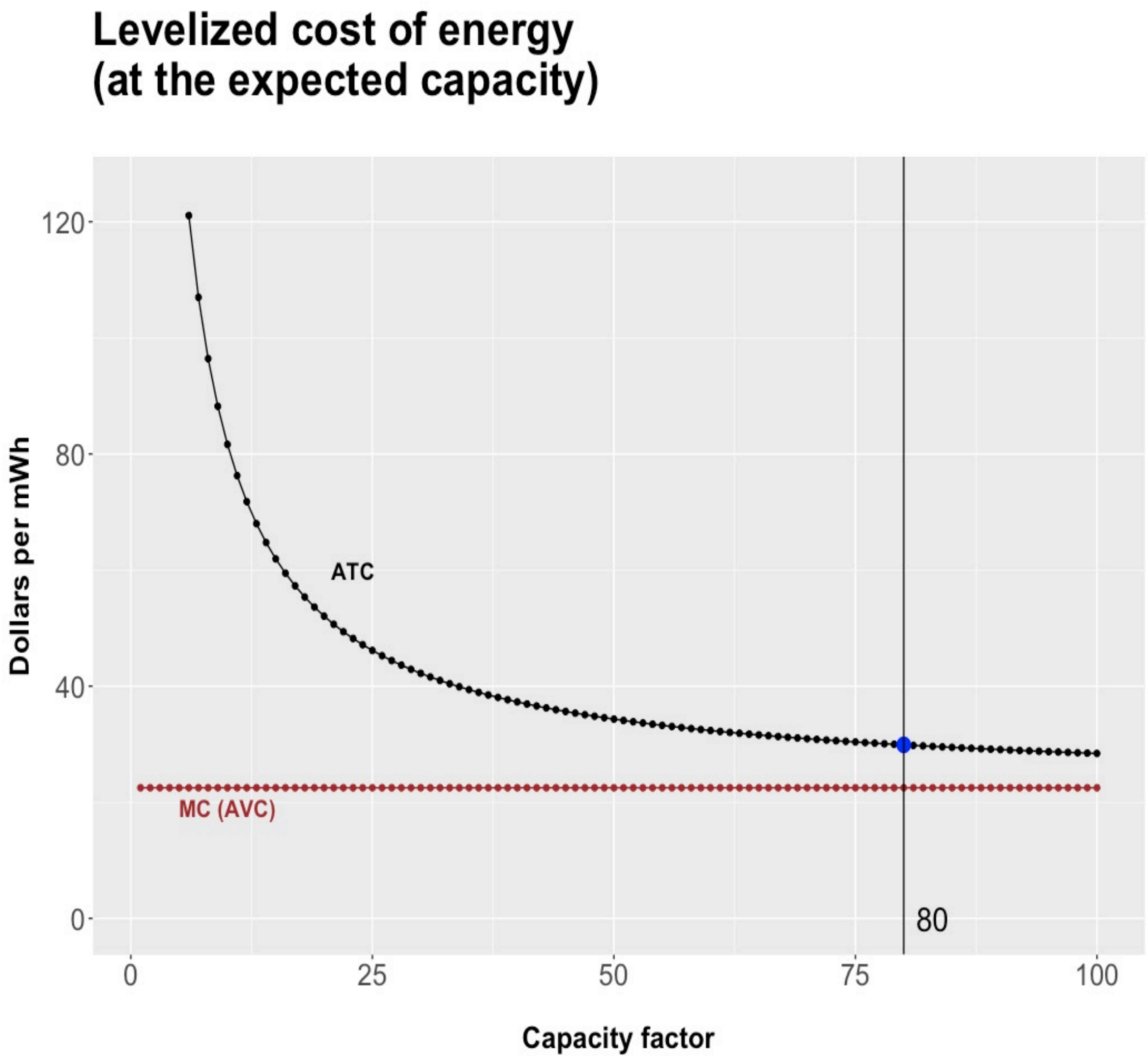
Levelized cost of energy [LCOE]

- Definition: The average cost per MWh (in discounted real dollars) of building and operating a generating plant over an assumed financial life and duty cycle.
  - Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed capacity utilization rate over the plant lifetime

- LCOE = Levelized fixed costs + levelized variable costs
- Average (capital + O&M + variable) costs *at a given capacity factor*
  - ❖ **Key point:** Since capital costs are fixed for the term of the loan, if O&M and fuel prices are likely to stay constant in inflation adjusted terms, then LCOE is equivalent to today's ATC.

LCOE for a new plant

- We want to know average total cost for this plant over its lifetime
  - Assume fuel prices are constant after adjusting for inflation
  - The cost of financing is fixed
  - The plant is expected to run at 80% capacity
  - LCOE is the ATC at the expected capacity factor
  - The "**long run** marginal cost"



Levelized avoided cost of energy [LACE]

- What costs are avoided by building this plant?
- What it would cost to generate the electricity that is displaced by a new generation project.
  - W*hat can you avoid doing if you build this new generation*
  - If you are displacing an expensive alternative, the levelized avoided costs are higher and the project is relatively more attractive than if you were displacing an inexpensive alternative.
- If LACE > LCOE, then the project is relatively attractive from Society’s point of view.

Annual Revenue Requirement (another view of long-term costs)

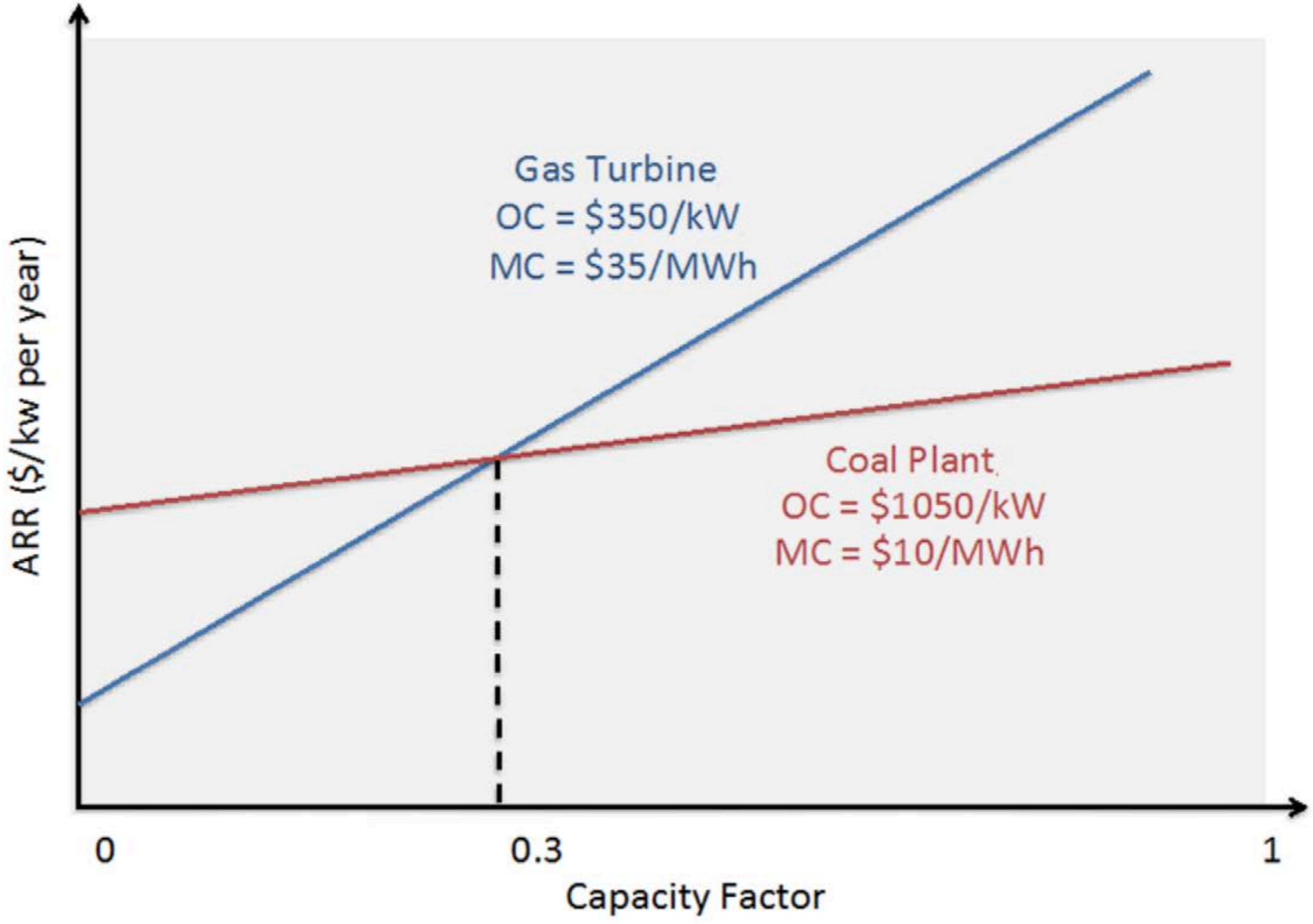
- Annual Revenue Requirement (ARR) for a power plant shows the annual average cost of a unit of power generation capacity.
  - It represents the amount of revenue (per unit of capacity) that a power plant must earn to break even
- ARR = Annual payment per MW capacity + variable costs
  - Remember, variable cost depends on the capacity factor

ARR calculation

- Fixed cost part:
  - (Monthly payment * 12) / MW of capacity
  - $25,548,000/ 500 = $51,096
- Variable cost part:
  - Fuel cost per hour * hours per year * capacity factor
  - $11,250 * 8,760 * cf = $98,550,000 * cf

- ARR(cf) = $51,096 + ($98,550,000 * cf)
  - Ex: For cf = 10%,   ARR(0.10) = $51,096 + $9,855,000 = $9,906,096

Annual Revenue Requirements compared



Assumptions: r = 0.1, T=40 years for coal, 20 years for gas