ECE 333

Green Electric Energy

Lecture 3

The Grid, Generation Technologies, Energy Conservation

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Department of Electrical and Computer Engineering

Slides Credit Prof. Tim O'Connell

Announcements

- Reminder: HW1 is due Thursday, Jan. 30th beginning of class
- Today:
  - The Grid (1.4)
  - Generation Technologies (1.5)
  - Energy Conservation and Phasors
- Start reading Masters Sections 1.6, 3.1 and 3.2.

Electricity Hourly Prices: Jan. 27, 2014

ice Alert

Power Smart Pricing

Dear Timothy,

This is a High Price Alert from Power Smart Pricing.

Monday, January 27, hourly prices are at or above 9 cents per kilowatt hour (kWh) as shown in the list below:

Time	Price (cents/kWh)
6:00-7:00 AM	10.1
7:00-8:00 AM	10.9
8:00-9:00 AM	11.0
9:00-10:00 AM	11.5
10:00-11:00 AM	11.2
11:00-12:00 PM	11.3
12:00-1:00 PM	10.6
1:00-2:00 PM	10.6
2:00-3:00 PM	9.4
3:00-4:00 PM	11.0
4:00-5:00 PM	13.3
5:00-6:00 PM	19.4
6:00-7:00 PM	20.8
7:00-8:00 PM	18.5
8:00-9:00 PM	15.5
9:00-10:00 PM	12.4
10:00 - 11:00 PM	9.0

Electricity Hourly Prices: Jan. 28, 2014

Power Smart Pricing - High Price Alert

Power Smart Pricing

Dear Timothy,

This is a High Price Alert from Power Smart Pricing.

TUESDAY, January 28th, hourly prices are at or above 9 cents per kilowatt hour (kWh) all hours of the day.

Time	Price (cents/kWh)
12:00-1:00 AM	14.3
1:00-2:00 AM	10.1
2:00-3:00 AM	10.4
3:00-4:00 AM	11.3
4:00-5:00 AM	15.2
5:00-6:00 AM	22.6
6:00-7:00 AM	32.9
7:00-8:00 AM	33.9
8:00-9:00 AM	30.8
9:00-10:00 AM	29.3
10:00-11:00 AM	29.2
11:00-12:00 PM	27.9
12:00-1:00 PM	21.4
1:00-2:00 PM	19.6
2:00-3:00 PM	16.7
3:00-4:00 PM	20
4:00-5:00 PM	27
5:00-6:00 PM	33.4
6:00-7:00 PM	34.2
7:00-8:00 PM	28.8
8:00-9:00 PM	28.2
9:00-10:00 PM	24.7
10:00-11:00 PM	18.1

Explanation of High Prices

Power Smart Pricing - Extreme Cold Weather Update

Dear Timothy,

As you are aware, our region has been experiencing extremely cold and record breaking temperatures during the recent weeks. This is having an impact on the region's day-ahead electricity market.

Any sudden and significant cold snap can drive up demand for electricity, push up the cost of natural gas making it more expensive to operate natural gas fired power plants,cause power plant outages and require the use of expensive peaking generation that uses oil as its fuel. All of these factors can increase the market price of electricity. This particularly intense cold snap has produced record-breaking winter electricity demand, and day-ahead prices have been higher than what is typically seen during the winter.

But despite the occasional increase in prices during the winter, the average price for the entire season has typically remained relatively low. We anticipate lower rates in line with seasonal trends when temperatures return to normal.

Since joining Power Smart Pricing you have saved $433.62 overall, which is a 24.08% savings. Families on Power Smart Pricing have collectively saved $9.4 million dollars since the program began.

For more on seasonal price patterns and tips for managing electricity costs during the winter, visit the Power Smart Pricing website at www.powersmartpricing.org/tools/winter-tips/. Additionally, for a review of the tools available on Power Smart Pricing please feel free to join our webinar for new PSP Participants on Wednesday January 29th, 2013 at noon. Register here: https://www3.gotomeeting.com/register/885646430

Thank you for your continued participation in Ameren's Power Smart Pricing Program. If you have specific questions, please contact us at 877-655-6028 or email us at info@powersmartpricing.org.

Stay safe and warm,
The Power Smart Pricing Team

Electricity Infrastructure: The Grid

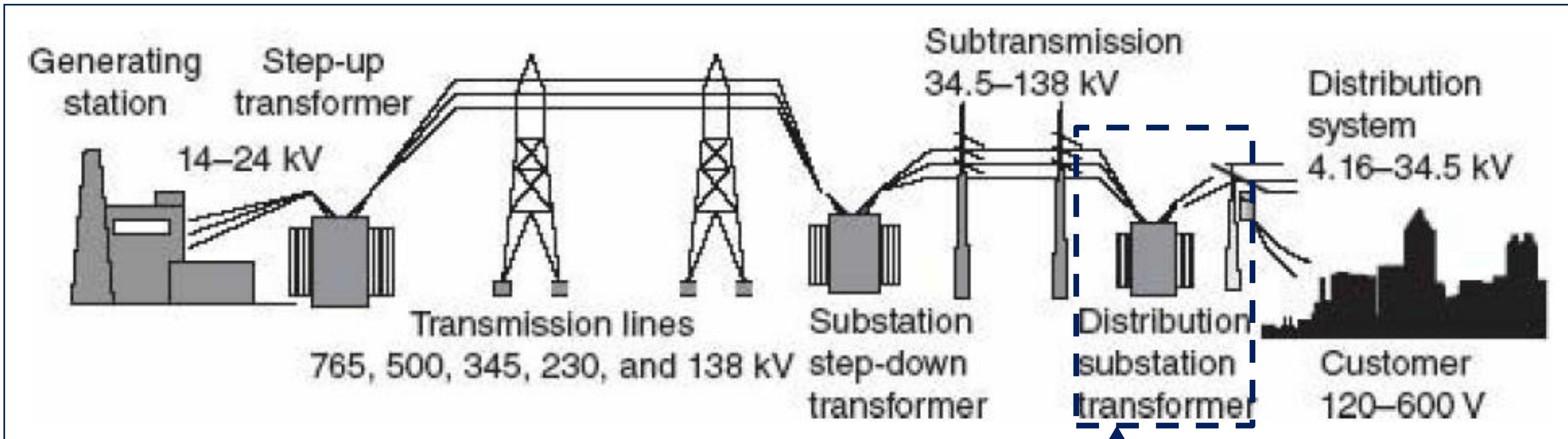


FIGURE 1.6 Simplified power generation, transmission, and distribution system.

Distribution substation (next chart)

Electricity Infrastructure: The Grid

- A simple distribution station

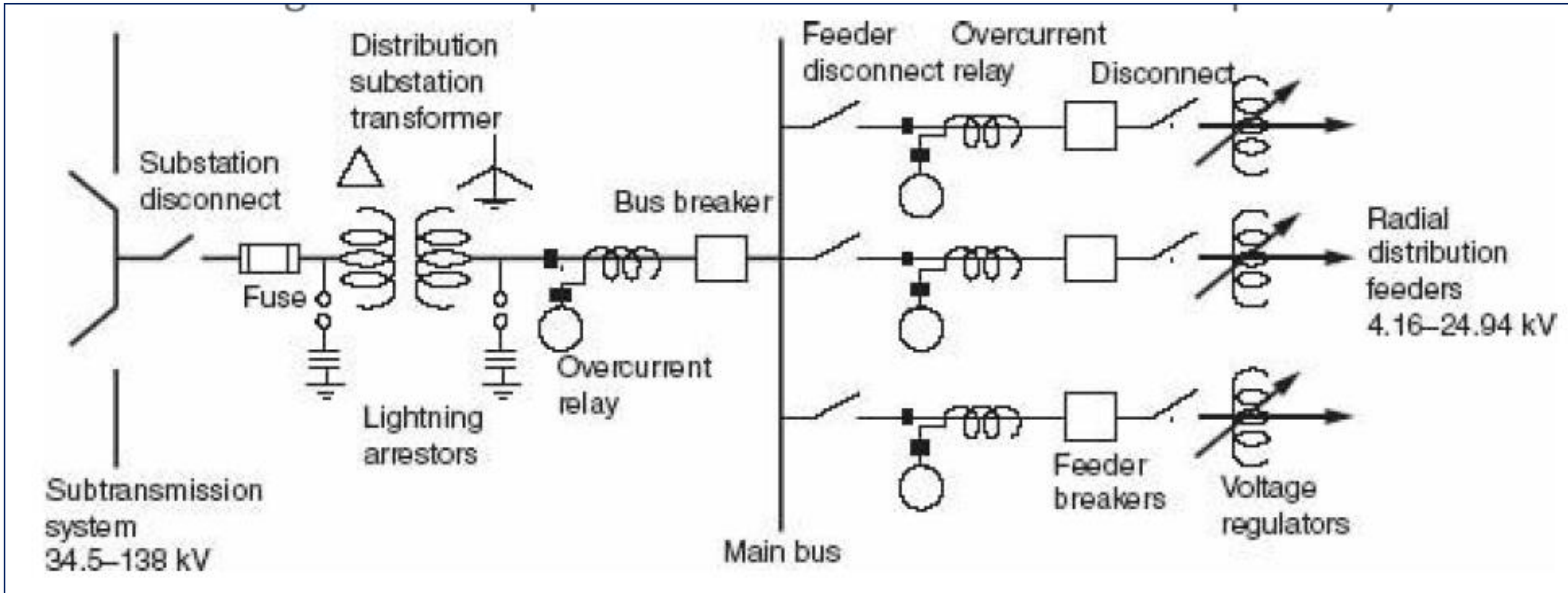


FIGURE 1.5 A simple distribution station. For simplification, this is drawn as a *one-line diagram*, which means a single conductor on the diagram corresponds to the three lines in a three-phase system.

North America Interconnections

North America Interconnections

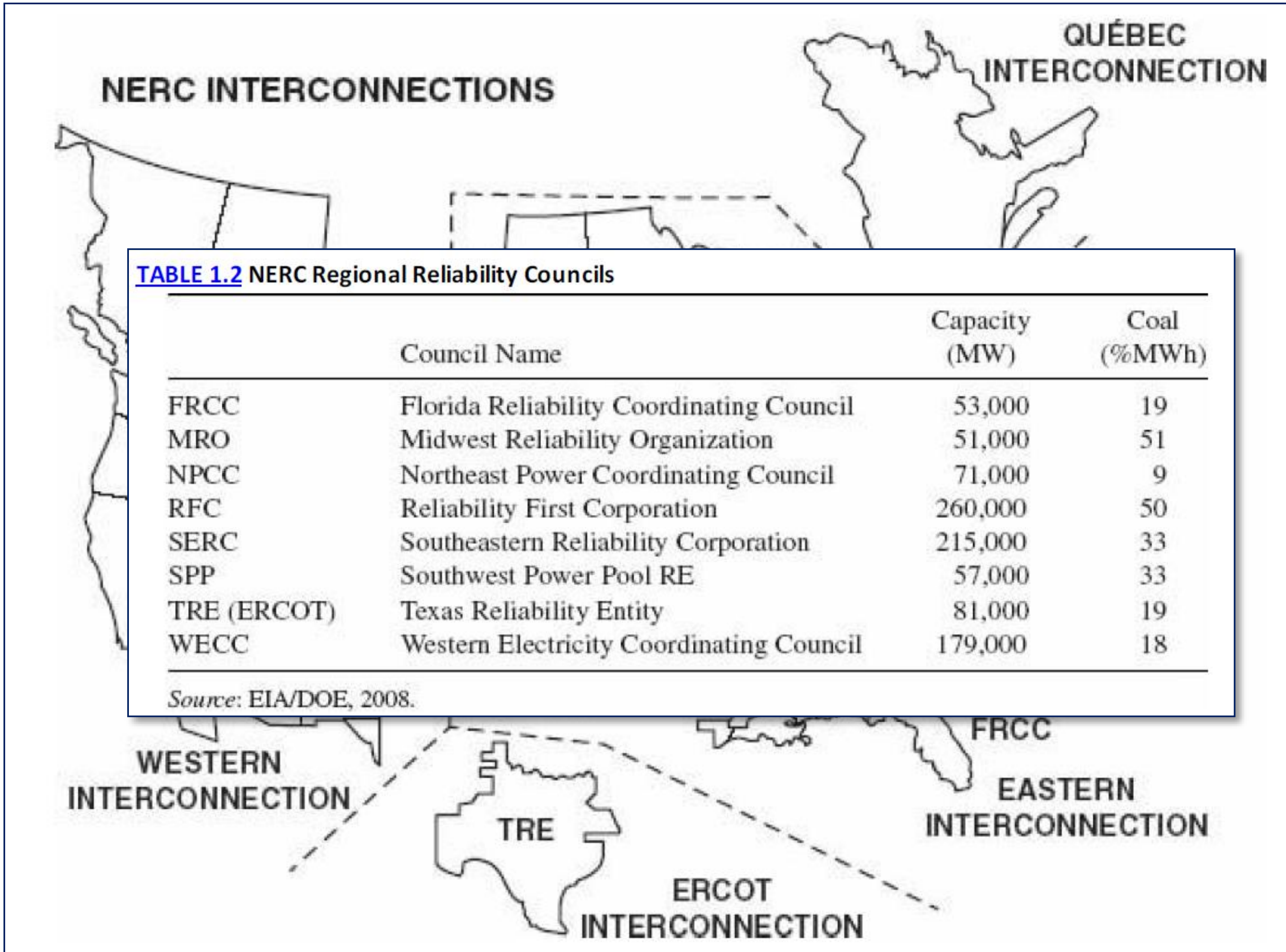
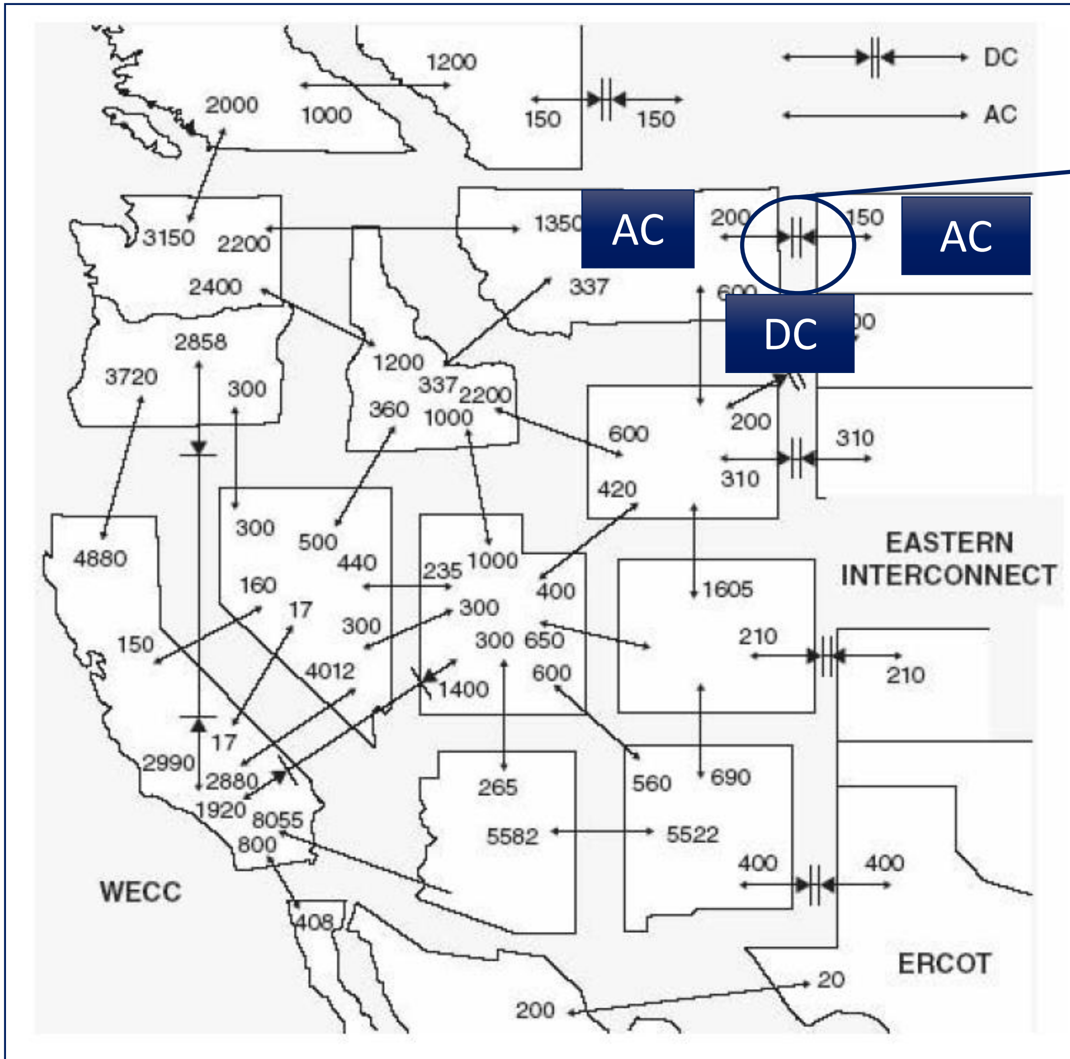


TABLE 1.2 NERC Regional Reliability Councils

	Council Name	Capacity (MW)	Coal (%MWh)
FRCC	Florida Reliability Coordinating Council	53,000	19
MRO	Midwest Reliability Organization	51,000	51
NPCC	Northeast Power Coordinating Council	71,000	9
RFC	Reliability First Corporation	260,000	50
SERC	Southeastern Reliability Corporation	215,000	33
SPP	Southwest Power Pool RE	57,000	33
TRE (ERCOT)	Texas Reliability Entity	81,000	19
WECC	Western Electricity Coordinating Council	179,000	18

Source: EIA/DOE, 2008.

WECC Interconnects



High Voltage DC interconnection

Good for matching frequency and phase.
Bi-directional.

Balancing Electricity Supply and Demand

- Power supply must always match demand at every moment.
- The rotational speed of generators at power plants is directly proportional to grid frequency (60 Hz in U.S.)
  - Supply = Demand: f = 60 Hz
  - Supply < Demand: f < 60 Hz
  - Supply > Demand: f > 60 Hz
- Generators have controls that adjust power to match the load in order to keep the frequency constant.

Balancing Electricity Supply and Demand

- P_{gen} = Torque*ω
- Automatic generator controls attempt to hold the frequency constant

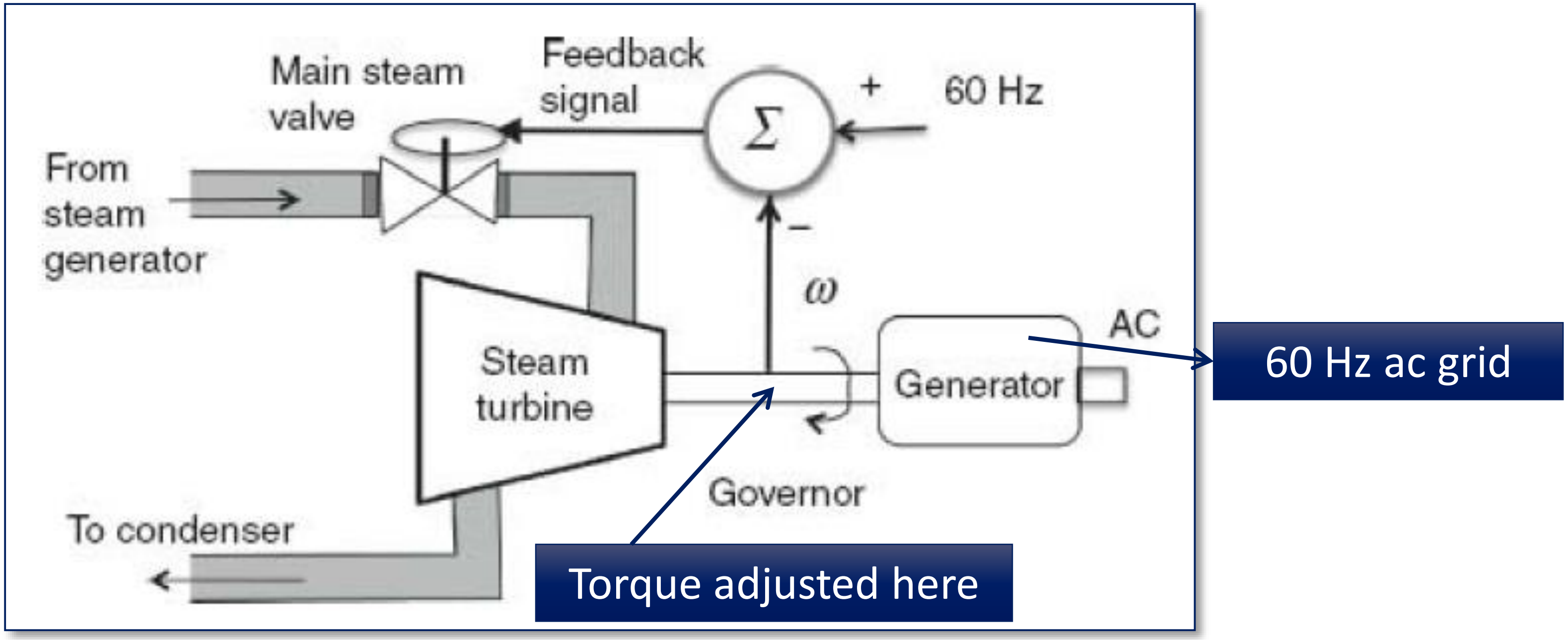
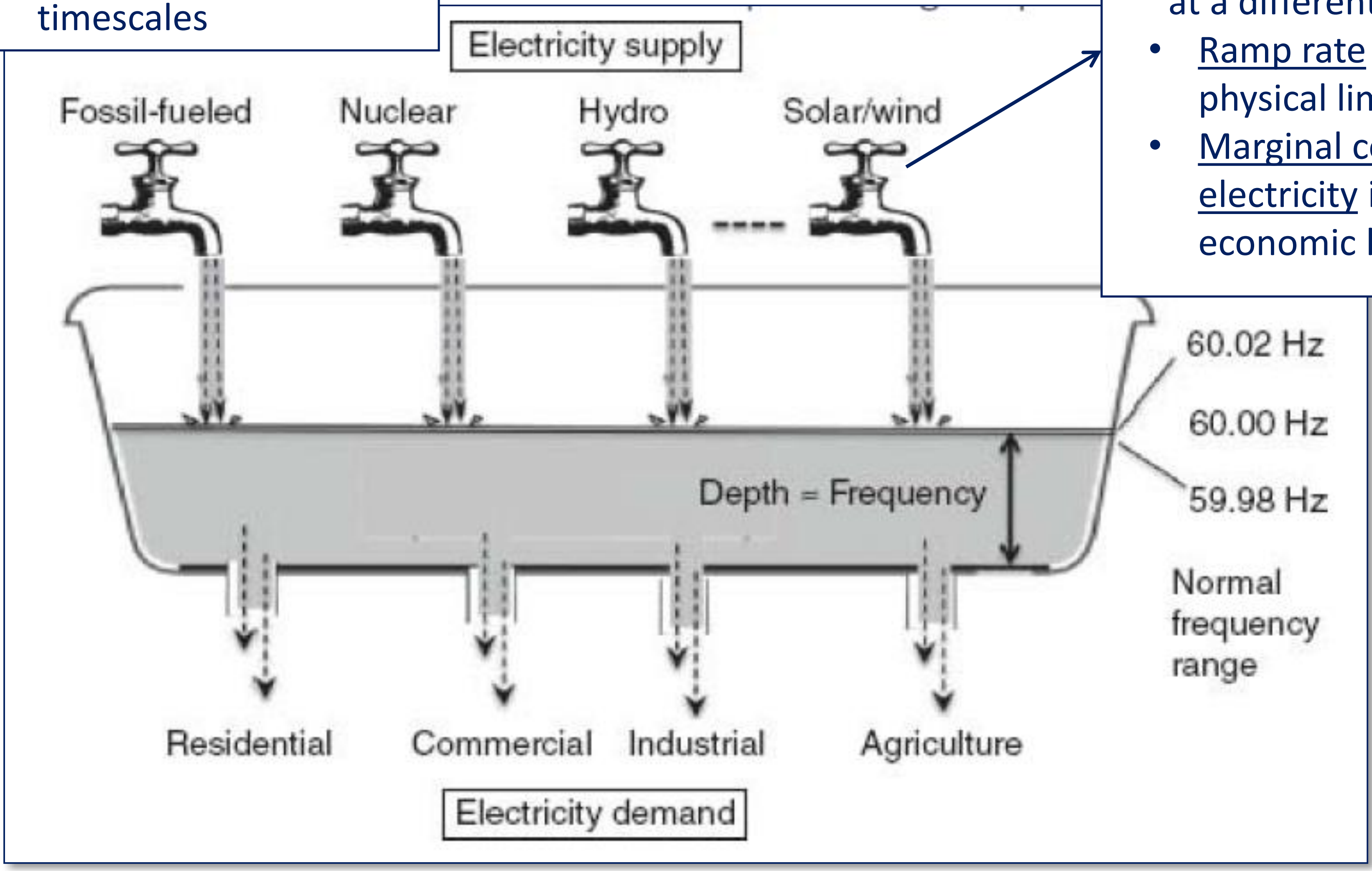


FIGURE 1.9 Frequency is often automatically controlled with a governor that adjusts the torque from the turbine to the generator.

Bathtub Analogy

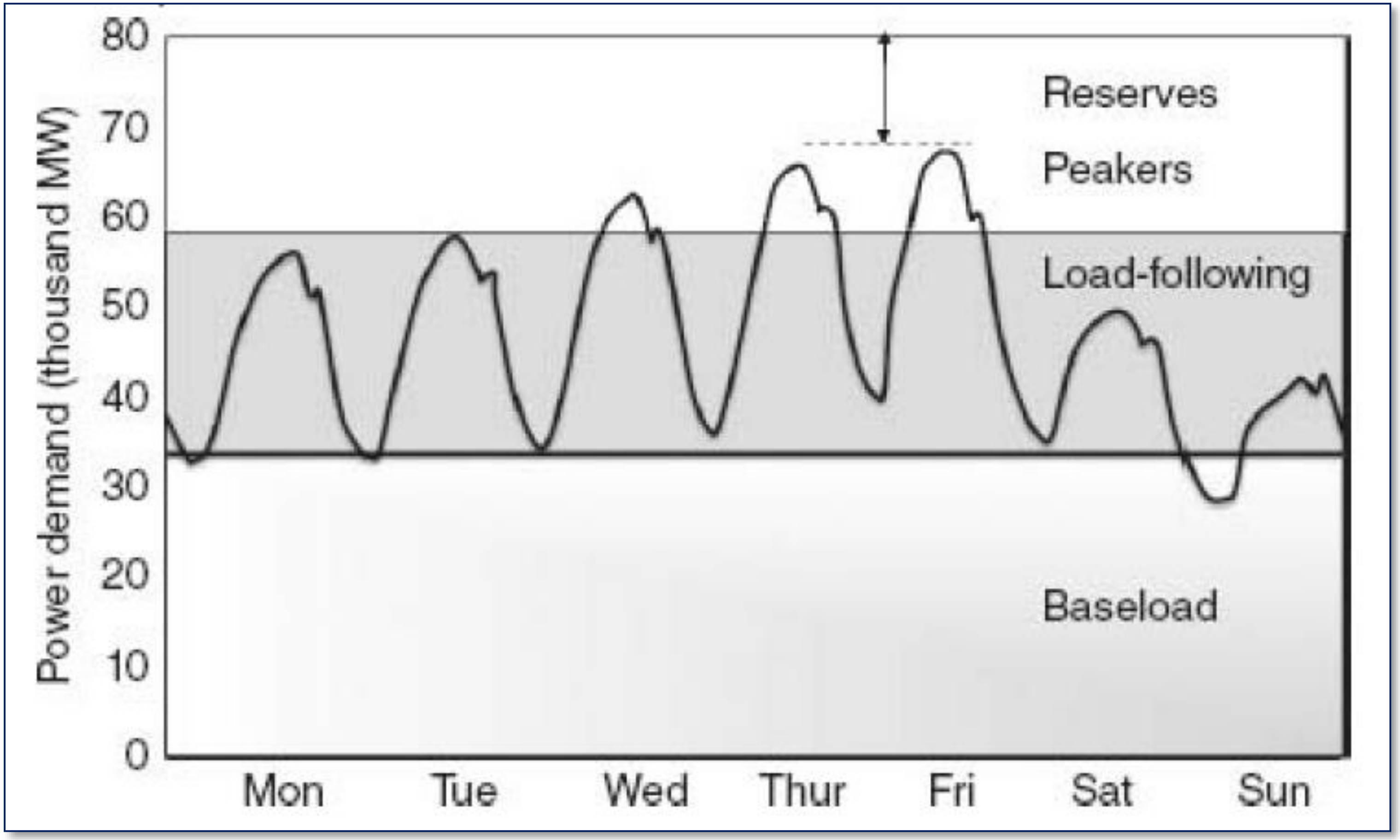
- Source/Load balancing occurs on many timescales

- Each nozzle responds at a different speed.
  - Ramp rate is a physical limitation
  - Marginal cost of electricity is an economic limitation

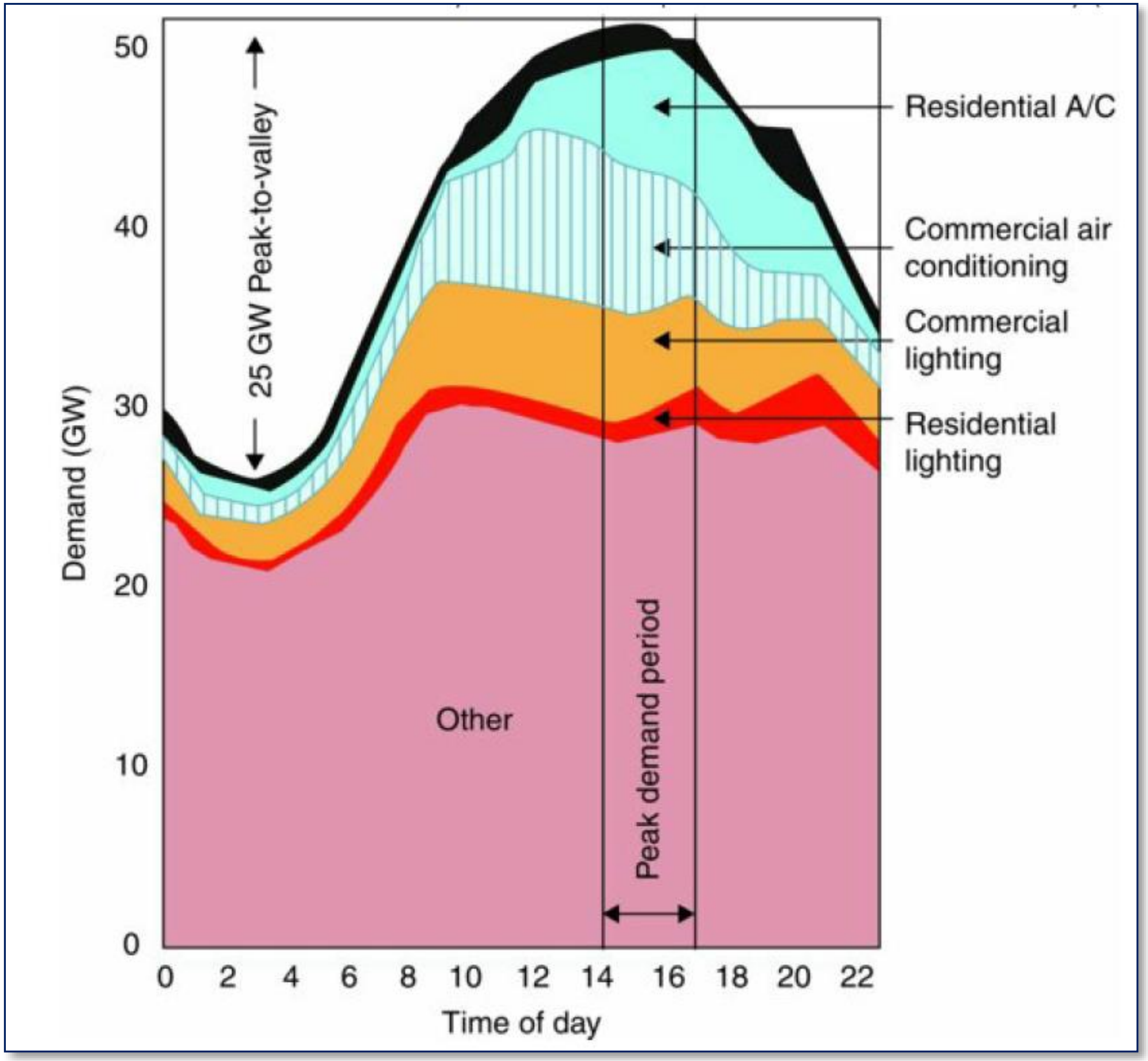


Baseload, Intermediate and Peaking Plants

Example of hour-by-hour, day-by-day power demand



Example: Daily Variation for California



Peak summer day in 1999

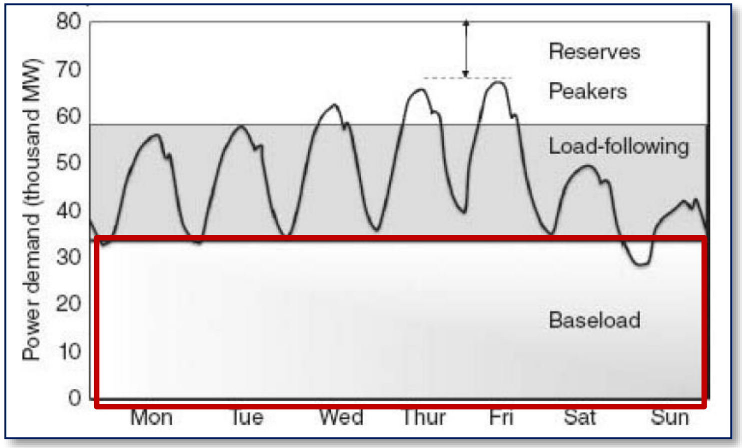
Lighting and A/C are the main cause of the peak during the day.

Baseload Plants

- Run continuously at full power
- Expensive to build, cheap to run*
- Expensive to shut down
- Very slow ramp rate (cannot meet minute-by-minute or even hour-by-hour load variations)
- Examples: Nuclear, large coal-fired steam

1065 MW

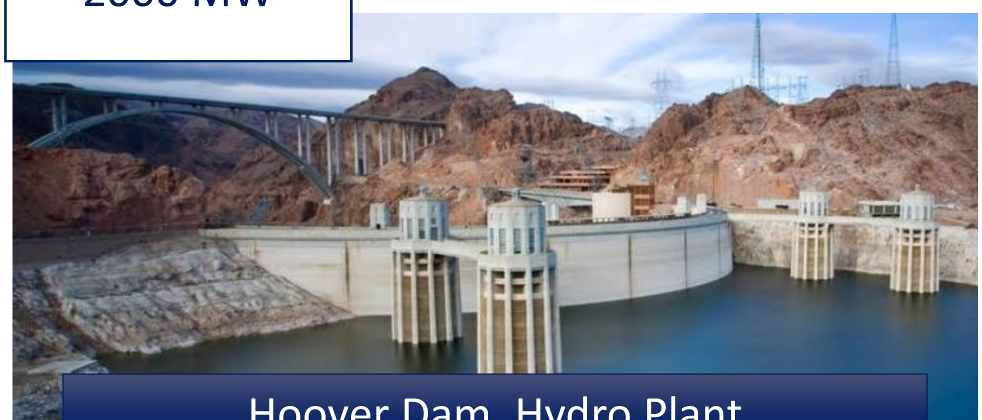
Clinton, IL nuclear plant.



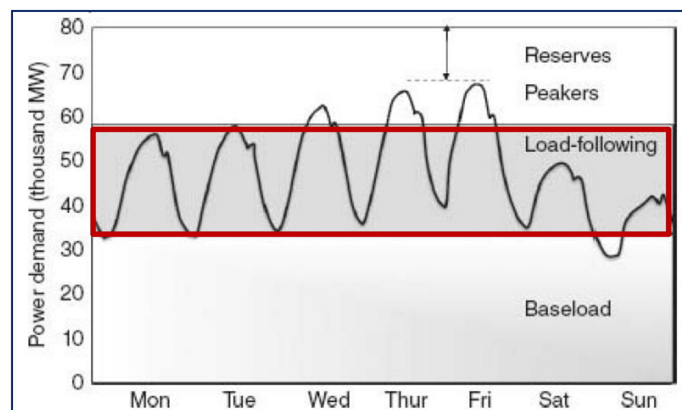
Load Following / Intermediate Plants

- Average ramp rate
  - Can track predictable daily load variations
- Run at whatever power level is needed to match grid variations
- Examples: Most fossil-fueled plants, large hydroelectric plants
  - Solar and wind could fit in here, but in a different way since source power is variable.

2000 MW



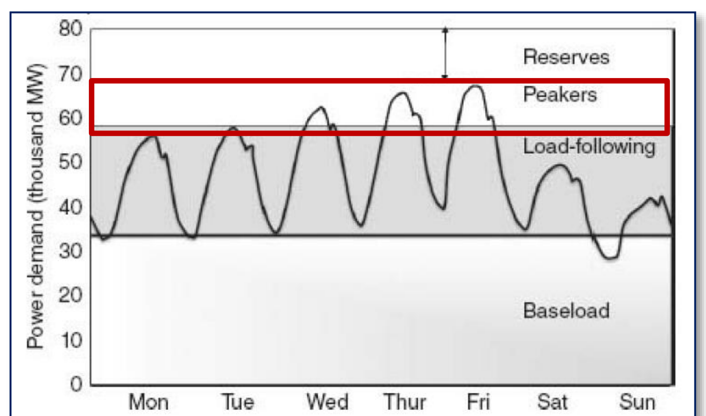
Hoover Dam, Hydro Plant



Peaker Plants

- Cheap to build, expensive to operate
- Small power ratings
- Used to meet highest peak demands
- On for only tens of hours per year
- Fast ramp rate: can meet minute-by-minute power variations
- Example: Typically these are gas turbines (GTs)

Lausward, Germany. From phys.org



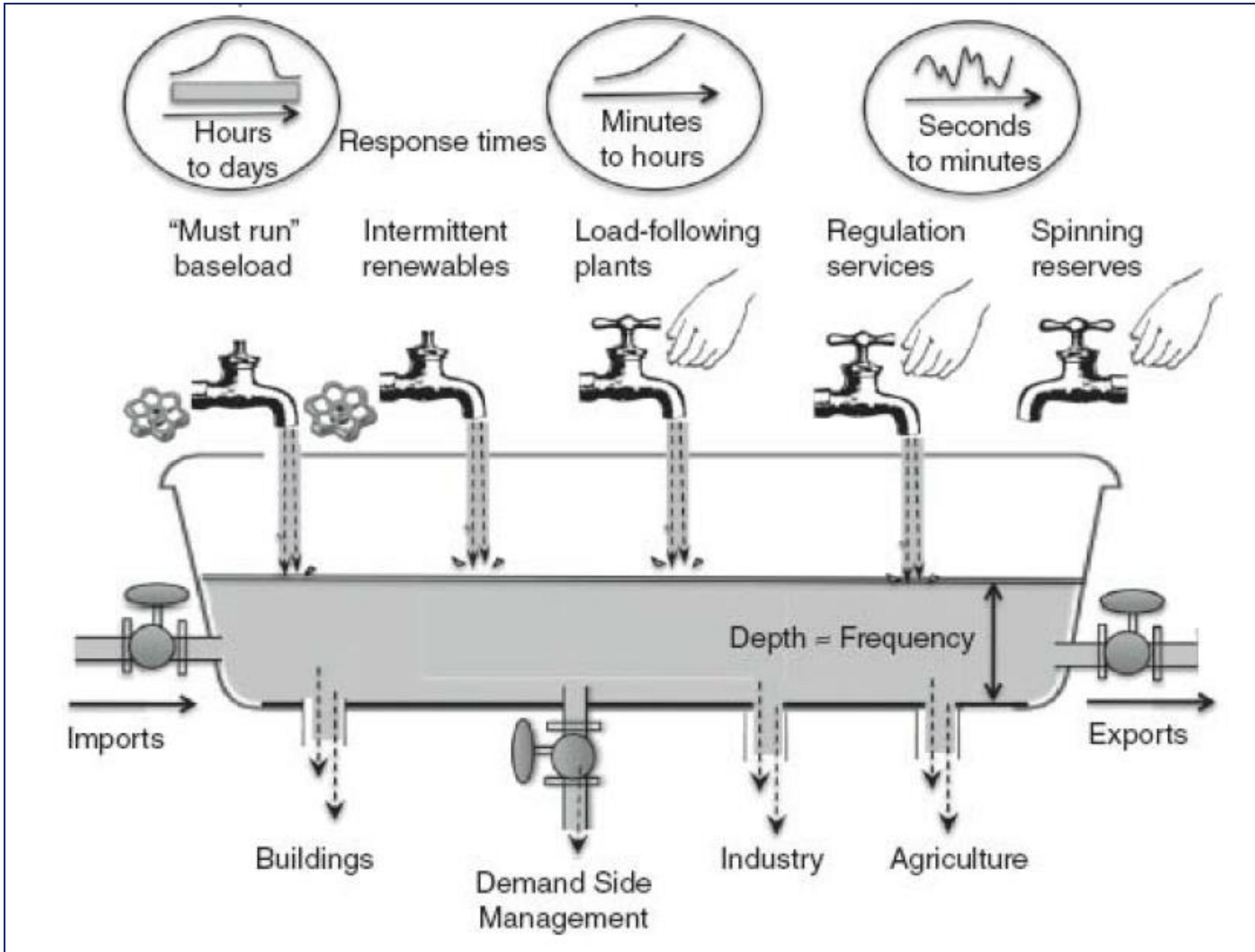
Additional Methods for Balancing Electricity Supply and Demand

- Regulation Services
  - Small, extremely high ramp rate
  - Track second-by-second demand changes
  - Provide frequency regulation
- Spinning Reserve
  - Generator spins all the time, but only produces power when needed.
- "Demand-Side Management"
  - Varying customer load automatically
    - Smart appliances, for example
  - This is a "Smart Grid" concept

Clothes dryer with a demand response switch to reduce peak

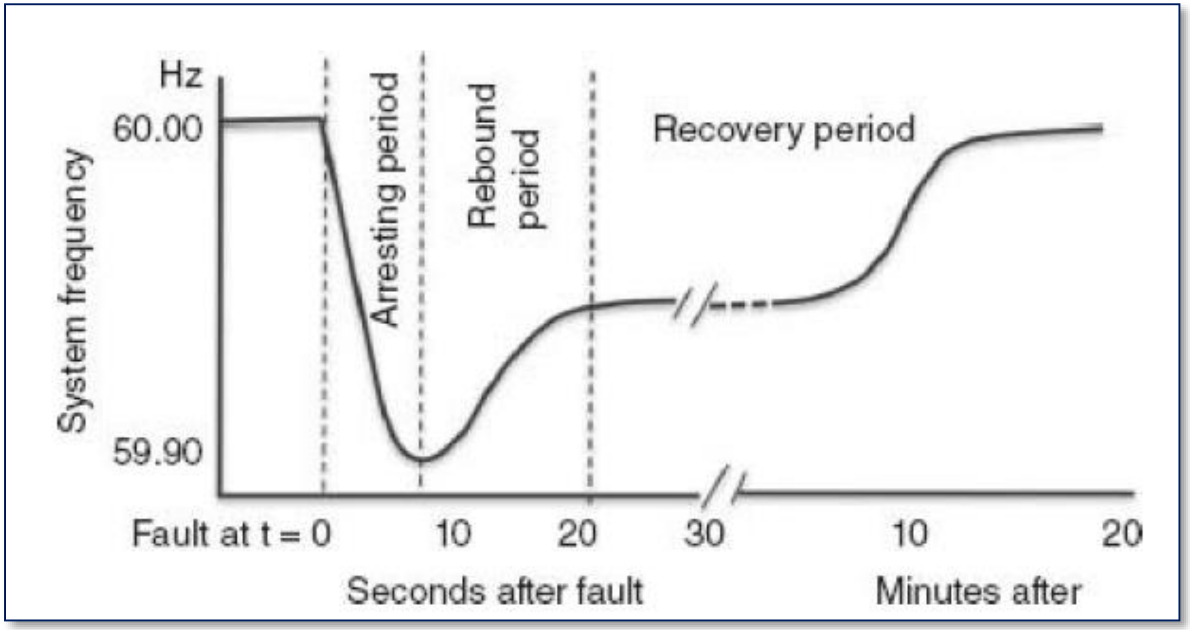
From Wikipedia: Demand Response

Advanced Bathtub Analogy



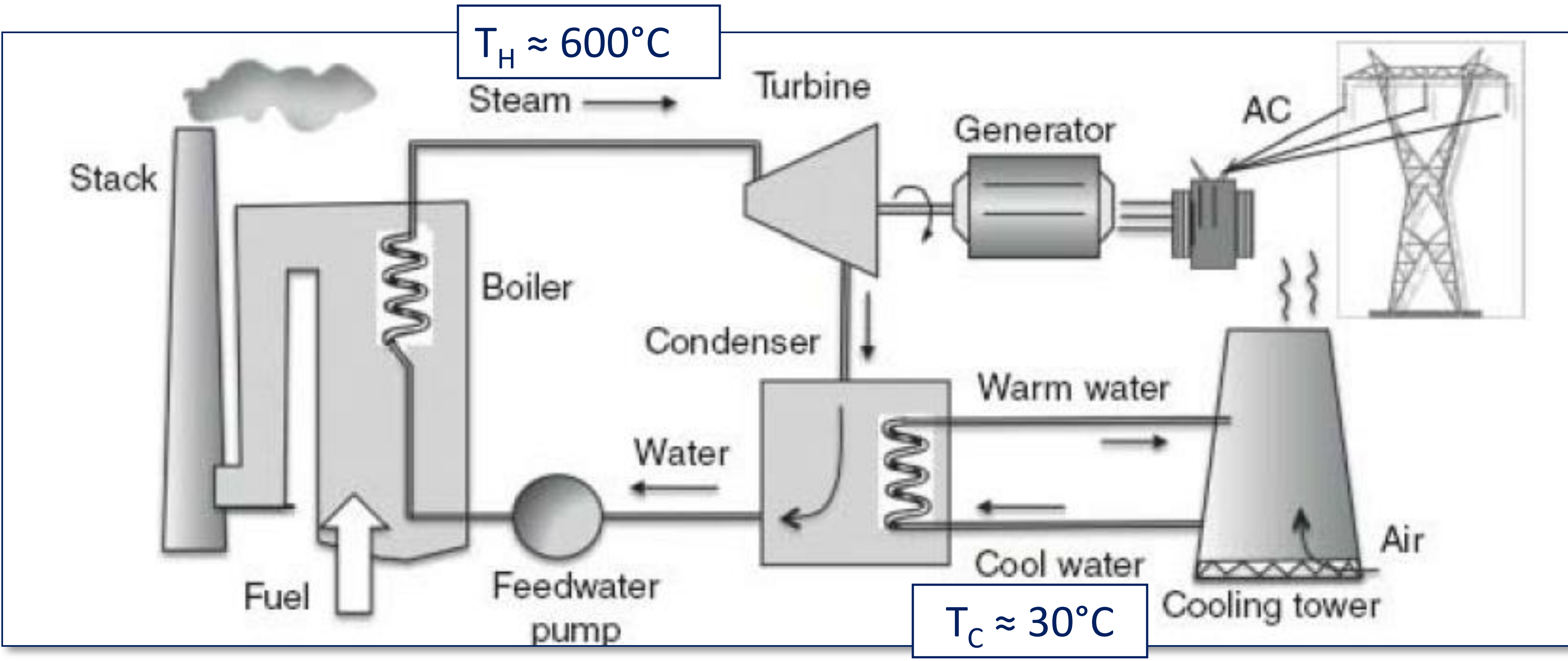
Grid Stability

- Causes of blackouts:
  - Faults: trees on lines, birds, squirrels, ice, etc.
  - Too much load
    - Grid at capacity, then a fault occurs
    - Hot summer days: lines sag, hit trees, too much load to recover
  - Generator failure



Basic Steam Power Plants

Rankine Cycle: Working fluid (water) changes phase from gas to liquid and back again



Modern Coal-Fired Steam Power Plants

- Provide about 40% of U.S. electricity
- Usually large units that operate well with fairly fixed loads
  - Run more or less continuously
- In general, high capital costs, low operating costs
- Responsible for a significant portion of CO_2, sulfur oxide (SOx), mercury, nitrogen oxides (NOx)
- Pollution controls have been in place since the 1960's
  - 40% of the cost of a new plant
  - Use 5% of the generated electricity

Modern Coal-Fired Steam Power Plant

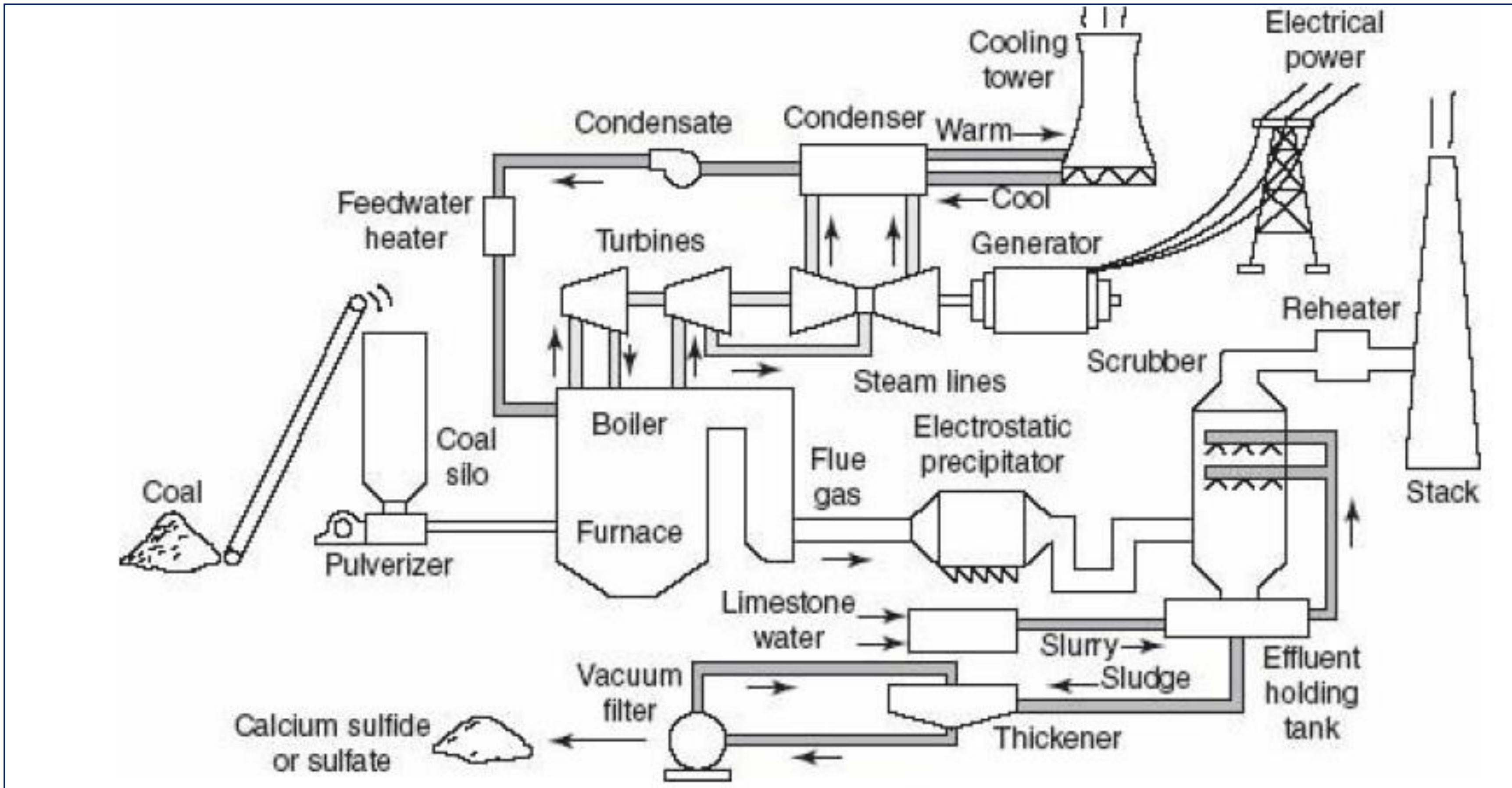
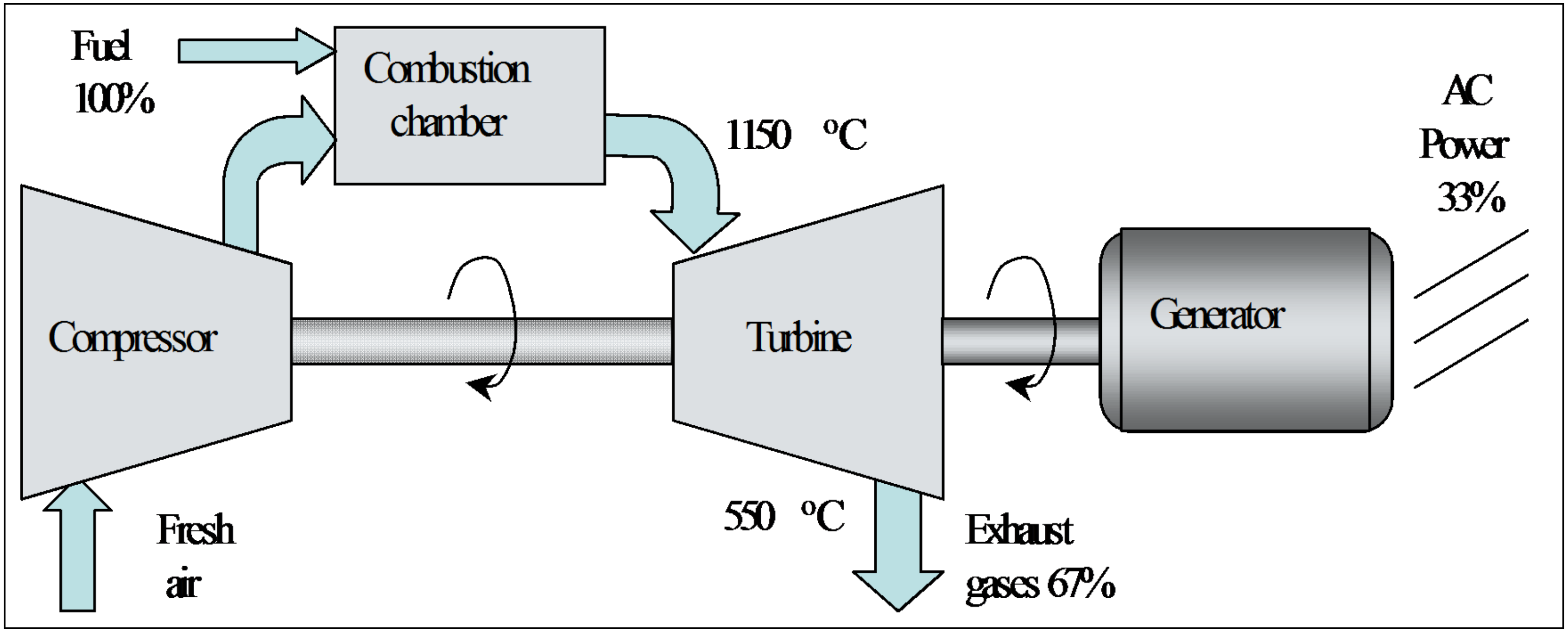


FIGURE 1.21 Typical coal-fired power plant using an electrostatic precipitator for particulate control and a limestone-based SO_2 scrubber.

Basic Combustion Gas Turbine (GT)

Brayton Cycle: Working fluid is always a gas (no phase change)



- Most common fuel is natural gas

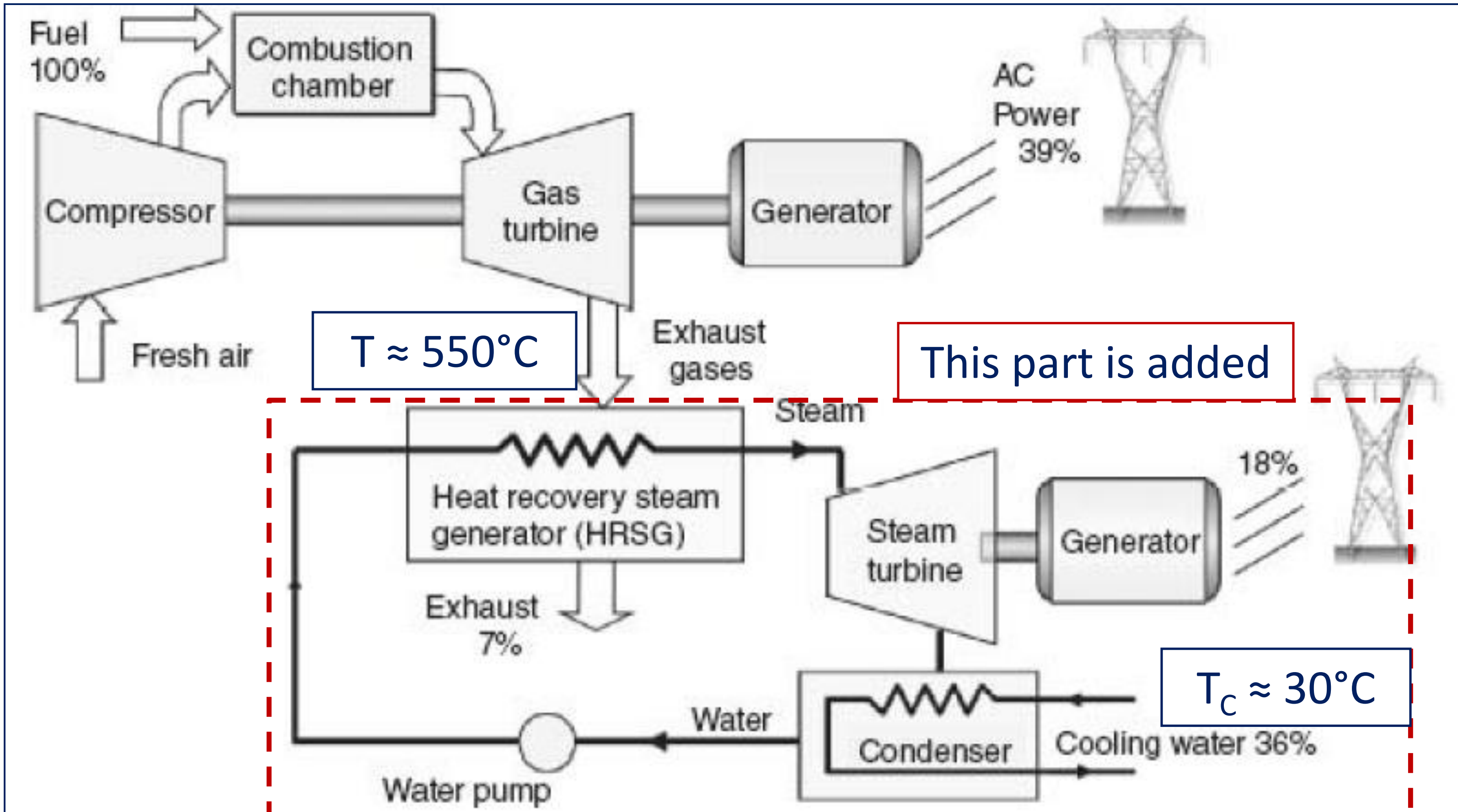
Basic Combustion Gas Turbine (GT)

- Typically smaller than steam plants
- Modern *aeroderivative* gas turbines draw on technology developed for aerospace generators
- Can be run intermittently due to ease of adjustment
- Low capital costs
- Traditionally, high operating costs, but recent trends have been pushing natural gas costs down
- Typical efficiency around 30-40%

Gas Turbine

Source: Masters

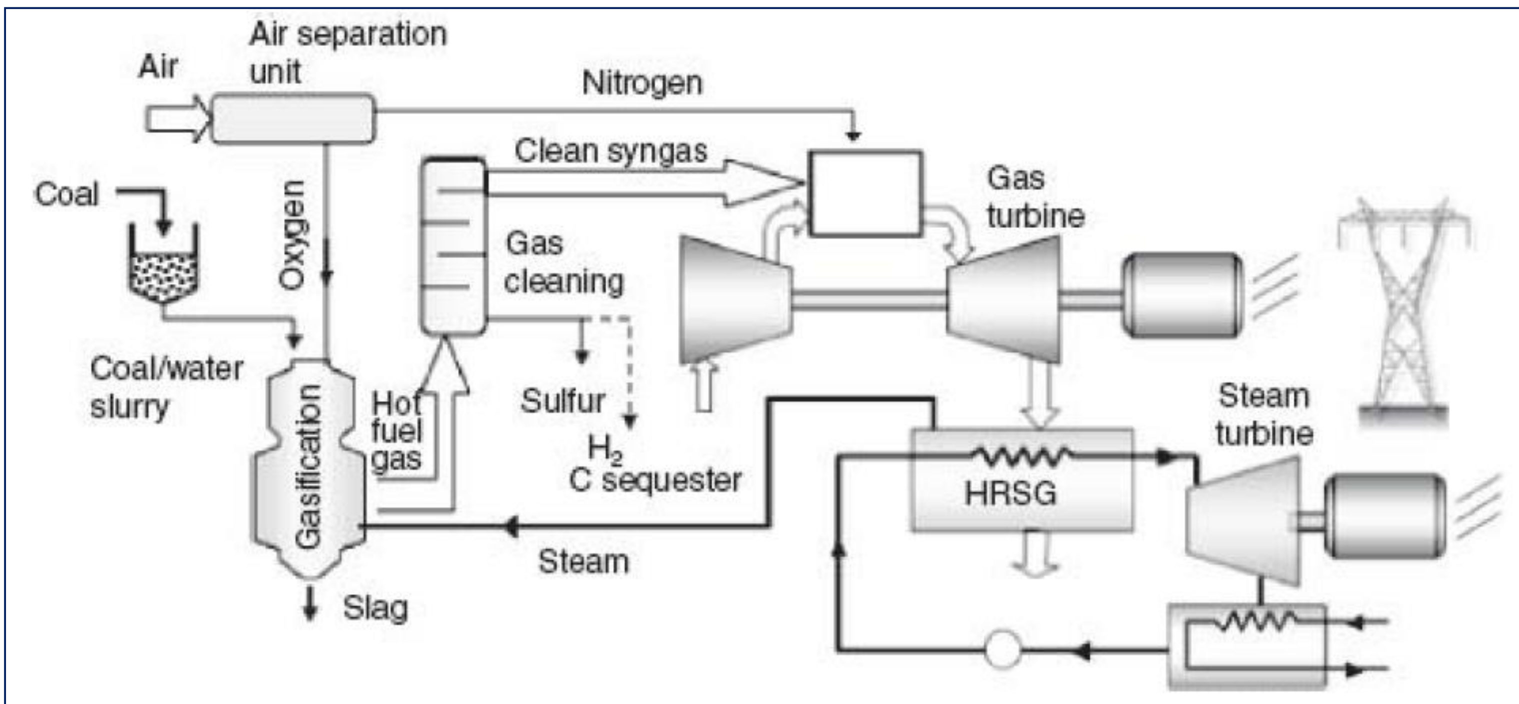
Combined Cycle Power Plants



Efficiencies of up to 60% can be achieved, with even higher values when the steam is used for heating.

Integrated Gasification, Combined-Cycle Power Plant (IGCC)

- Like a Gas Turbine, but the gas comes from coal
- More efficient than standard pulverized coal (PC) plants.
  - Makes it possible to capture and sequester CO_2 more easily



See Hand Notes