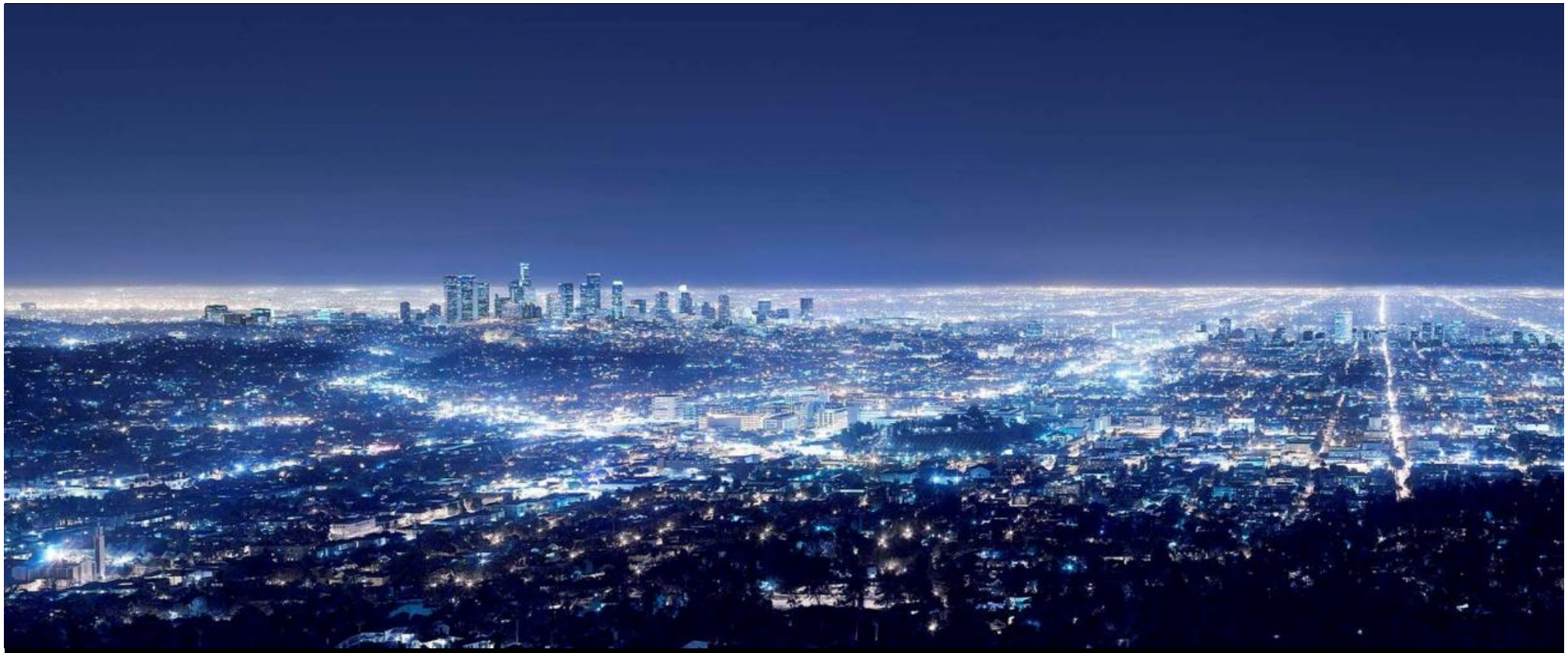


**Richard Vesel, Global Power Generation, February 2012**

# Introduction to Heat Rate & Controllable Losses
# February 2012 PGEE Workshop

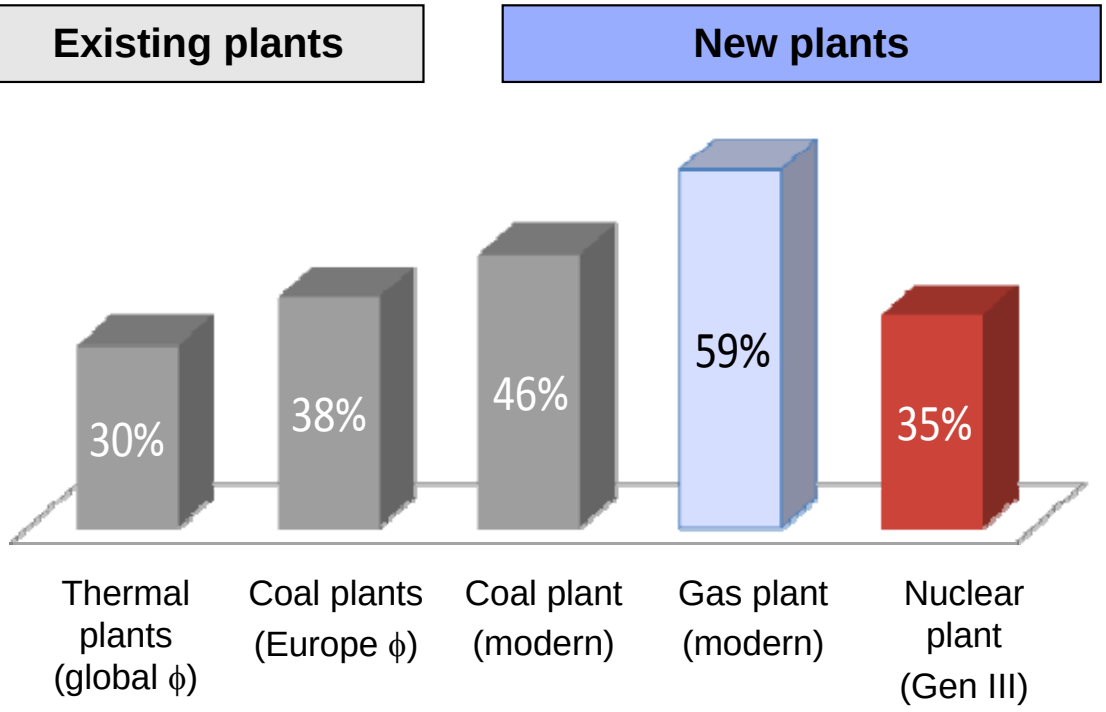
# Heat Rate & Plant Efficiency

- Efficiency:
  - Electrical Energy Out / Thermal Energy In
  - Kilowatt-hours / MJoule or kwh / Btu
  - Usually expressed in %
  - 100% Efficient would be:
    - 1kwh / 3412 Btu -or- 1kwh / 3.6MJ

- Heat Rate (HR) is the inverse of Efficiency
  - Btu per kwh -or- MJ per kwh
  - Westar LEC Unit 5 HR: app. 10700 Btu/kwh
  - Question: What is its efficiency?

# How efficient are thermal plants?

- Westar LEC Unit 5 Efficiency is: 3412 / 10700 = 31.9%




**Inefficiency loses money via higher heat rates and reduced net capacity**

- Reduced power sales revenue / Excess fuel cost expenditures

- For North American Coal-fired plants:

Best HR: 9300 Btu/KWh (Eff = 37%)

Worst HR: 14000 Btu/KWh (Eff = 24%)

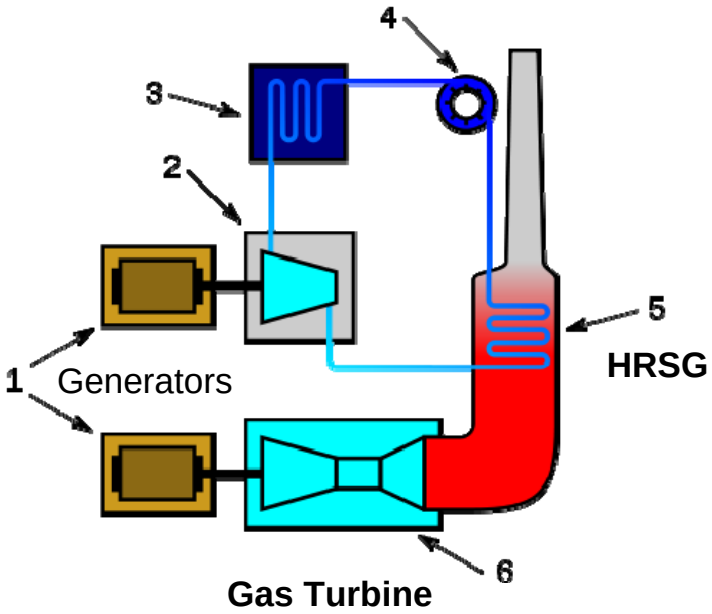
# CCGT Efficiency & Heat Rate

- If the total CCGT efficiency is 55%, what is the heat rate?

0.55 = 3412 / HR

HR = 3412 / 0.55 = 6203 Btu/kwh

= 6.55 MJ/kwh



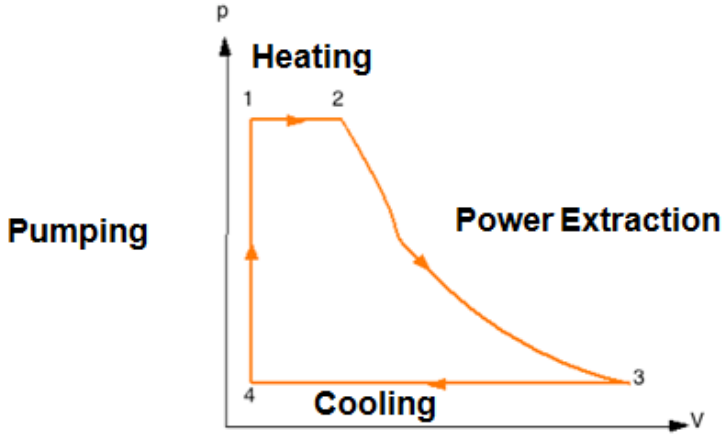

These are very good numbers for a real CCGT plant.

Most plants will be above 7000 Btu/kwh (7.3MJ/kwh)

# Where does all that energy ultimately go?

- **Plant loses thermal energy via two designated & necessary routes**
  - **Waste heat goes out the stack as hot gases**
  - **Waste heat goes out the condenser into cooling water / air**
- **Question: Which one of these two is the largest loss?**

- **Heat from fuel combustion: Where does it go?**
  - **Useful "work"**
    - **Mechanical work spinning gas turbine**
    - **Boils water into steam in the boiler/HRSG tubes**
    - **Superheats steam before it enters HP turbine**
    - **Reheats steam from HP turbine before it enters IP turbine**
    - **Preheats feedwater in the economizer**
    - **Preheats combustion air in the air-heater (thermal plant)**
  - **Wasted "work"**
    - **Evaporates moisture bound in the fuel (coal: up to 20% by weight!)**
    - **Creates NOx (endothermic process)**
    - **Heat lost through leaks and poor insulation**



# Ok, so energy is put into steam … where does it go?

- HP Steam: 1005 deg-F(540C) at 2450 psi (These are ideal subcritical T&P)
  - Enters HP turbine
  - After a few stages, some 15% or so is extracted to go to high pressure feedwater heaters
  - Remainder after exiting HP turbine at reduced T&P goes back through top of boiler for reheat back to 1005 deg-F at about 400-600 psi (ideally)
- Reheated steam goes to IP turbine.
  - Some of it is extracted along the way through the IP for FW heating.
  - At exit of IP turbine, steam is routed to LP turbine.
- LP steam gives up remaining energy (still a lot!) to rotary power and initial FW heating. Final energy is removed by the condenser to get spent steam turned back into water…this waste thermal energy often exceeds the electrical energy output of the plant.

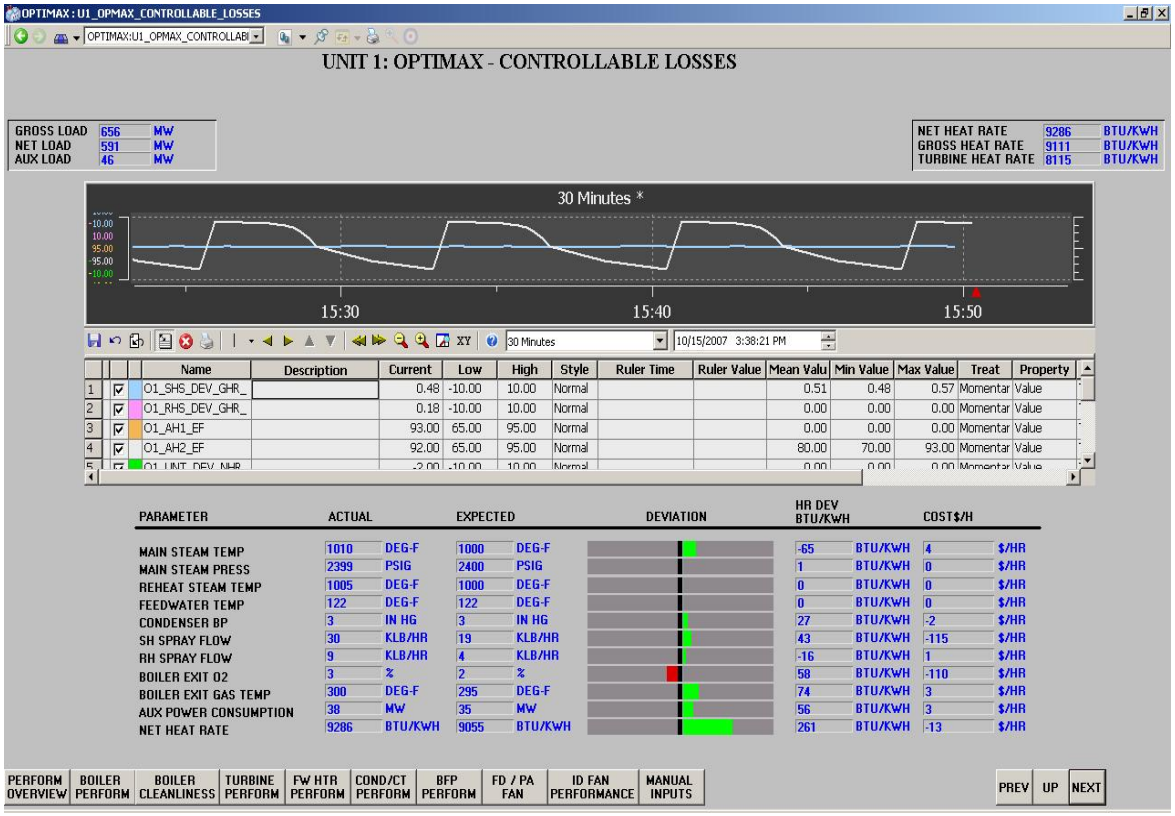
- Mechanical power splits: HP: 25% IP: 30% LP: 45% (approximately)
- Turbines are generally almost 90% efficient converting steam enthalpy into mechanical power.

# “Controllable Losses” – General Definition

- The ways in which energy can be wasted through non-ideal operation of the boiler & auxiliary systems, and gas turbine & HRSG
- Different items each have their own degree of influence on plant heat rate, some small, some quite large.
  - See ITC Quick Reference Guide
  - See EPRI Report CS-4554 Guide to Heat Rate Improvement
- Generally, a boiler or CCGT operator can manage operation to balance operating points of individual controls to attempt to minimize many such losses.
- A poor operating plan or strategy will set up the boiler to operate away from an optimized setup, and controllable losses will usually show very clearly where the deficiencies are. Typical red flags are high spray flows, excess O2, condenser backpressure, and poor turbine efficiency.
- A good performance monitoring program, such as Optimax or EtaPRO, will contain Controllable Losses dashboards. These specifically show the operator where he could change the degree of controllable losses by modifying boiler/turbine settings to effect efficiency improvements.

# “Controllable Losses” – Operator Controllable

- Main Steam Temperature
- Main Steam Pressure
- Reheat Steam Temperature
- Feedwater Temperature
- Condenser Backpressure
- Superheat Spray Flow
- Reheat Spray Flow
- Boiler Exit Gas - Excess O2
- Boiler Exit Gas – Temperature
- Turbine inlet air temperature (if cooling is available)
- **<u>Auxiliary System Power Consumption</u>**



# “Controllable Losses” for Gas Turbine Operations & Maintenance Controllable

- Monitoring & Maintenance of Fuel Quality
  - Methane content v. Ethane, etc.
  - “Real-time” analyzer instrumentation
- Compressor efficiency management
  - Inlet temperature optimization (via spray cooling)
  - Fouling, erosion & foreign object damage monitoring
  - Online washes (minor cleaning)
  - Offline washes (major cleaning)
- Gas turbine efficiency management
  - Burner balancing & tuning
  - Fouling, erosion & foreign object damage monitoring

# “Controllable Losses” for Boiler / HRSG Operations & Maintenance Controllable

- Maintenance of surface cleanliness & integrity
  - Boiler tubes – fireside surface (sootblowing)
  - All water/steam surfaces – water chemistry
  - Condenser performance – tube maintenance & config
  - Cooling water / tower pipes and surfaces
- Unburned carbon in ash (pulverizers, air & burner setup)
- Feedwater Heaters – Terminal Temperature Differential
- Blowdown rates ***← THIS CAN BE A HUGE LOSS!!!***
- Air Heater integrity & performance
- Steam leaks at seals, traps and FWH bypass valves
- Turbine seal leaks & blade design / quality
- Auxiliary System Electrical Power Consumption
- Fuel Moisture content

# Questions about Heat Rate & Efficiency

- For a subcritical coal/oil/gas-fired thermal plant, is a net heat rate of 13500 good or bad?
  - Bad!  Average is 10400
- For a CCGT plant, is a net heat rate of 6800 Btu/kwh good or bad?
  - Good!  Average is above 7000
- What is the difference between gross heat rate and net heat rate?  Which one is numerically higher of the two?
  - Net is related to power-to-grid, and is higher
- From the lists of controllable losses, name some operator “tasks” which can be automated to help manage some of these issues in a thermal plant.
  - Excess air/O2
  - Spray flows
  - Main Steam Temp & Pressure

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