Section 10: Steam System Optimization - Cogeneration

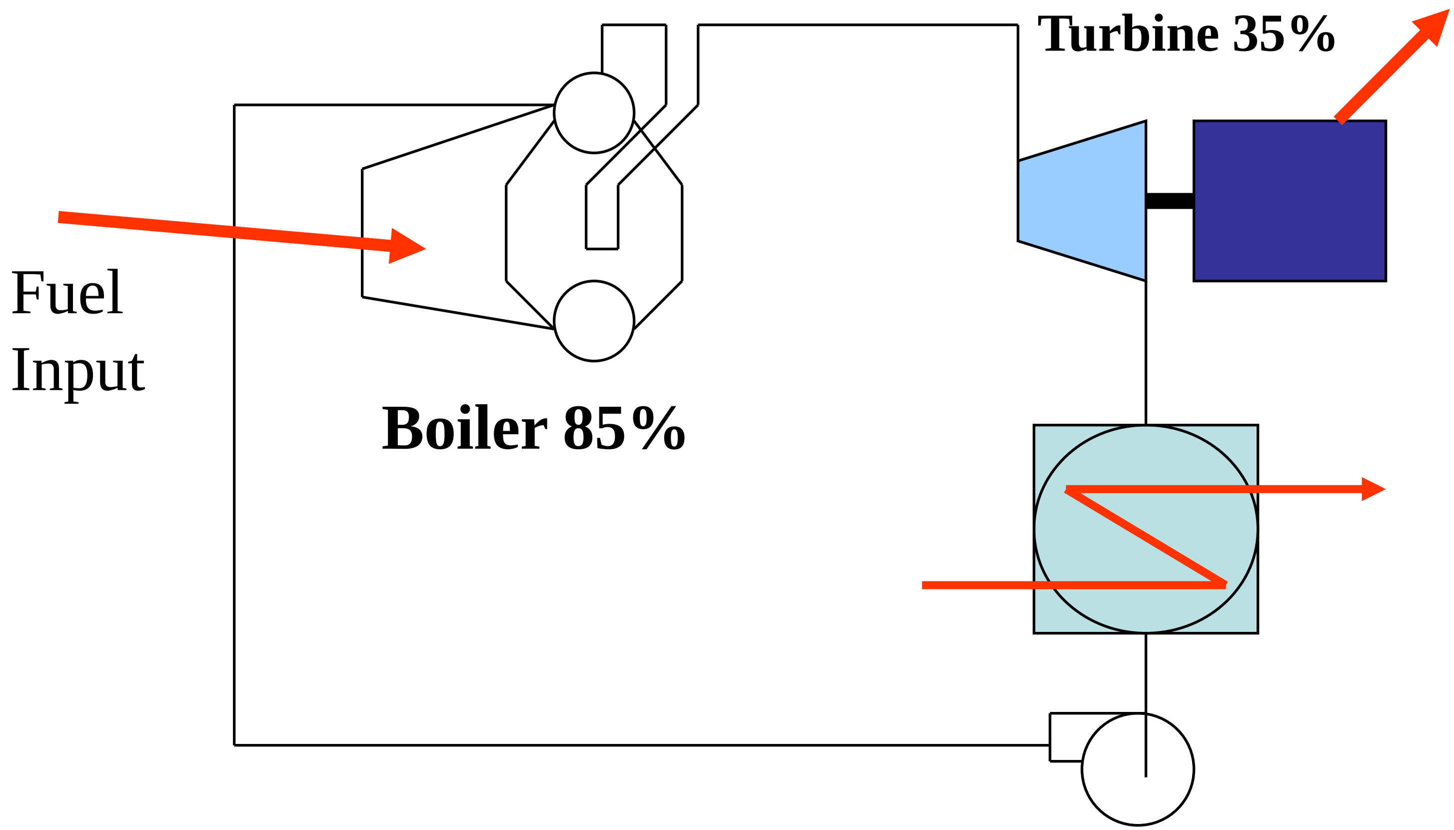
BackPressure Turbine – PRV Operations

SSAT Turbine Projects Economics

Condensing Turbine Inpacts

SSAT Condensing Turbine Projects

Industrial Cogeneration



Industrial facilities can achieve <u>"overall energy efficiency" of 70% or higher,</u> <u>because they have a need for thermal energy (heat)…….</u>

Classic Cogeneration Analysis

- The classic cogeneration analysis answers the following questions:
  - What is the true economic impact of cogeneration?
  - When is it viable?
    - To operate or shut down
    - To install
  - What changes, if any, will be required on the steam system?
  - What changes, if any, will be required for the electrical utility system and grid interconnects?

Primary Factors for Cogeneration Analysis

✓ The primary factors impacting the analysis are:

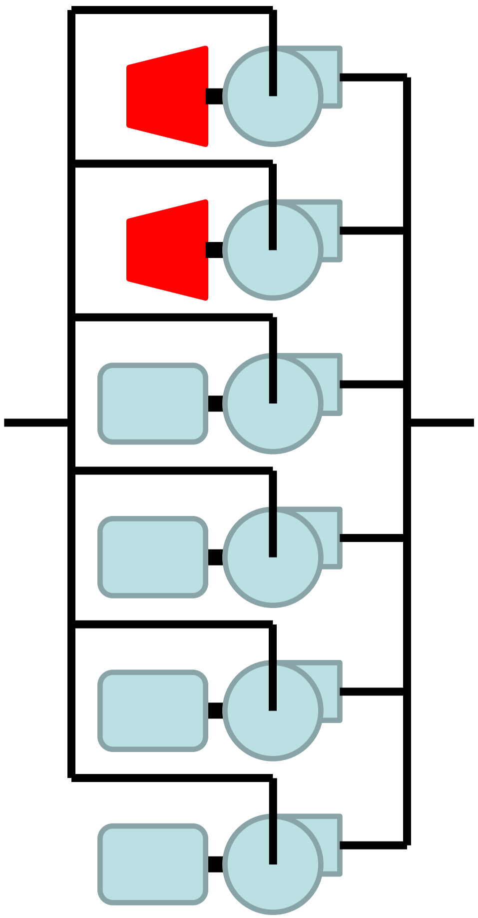
- *Impact* electrical cost
- *Impact* fuel cost
- Boiler efficiency
- Steam turbine efficiency
- Steam demand

Impact Costs

- *Impact cost* is the actual economic impact of increasing or decreasing electrical consumption
- The average cost of electricity is typically NOT the appropriate analysis value
- A thorough understanding of the electric rate structure is essential to evaluate the true impact of power generation systems

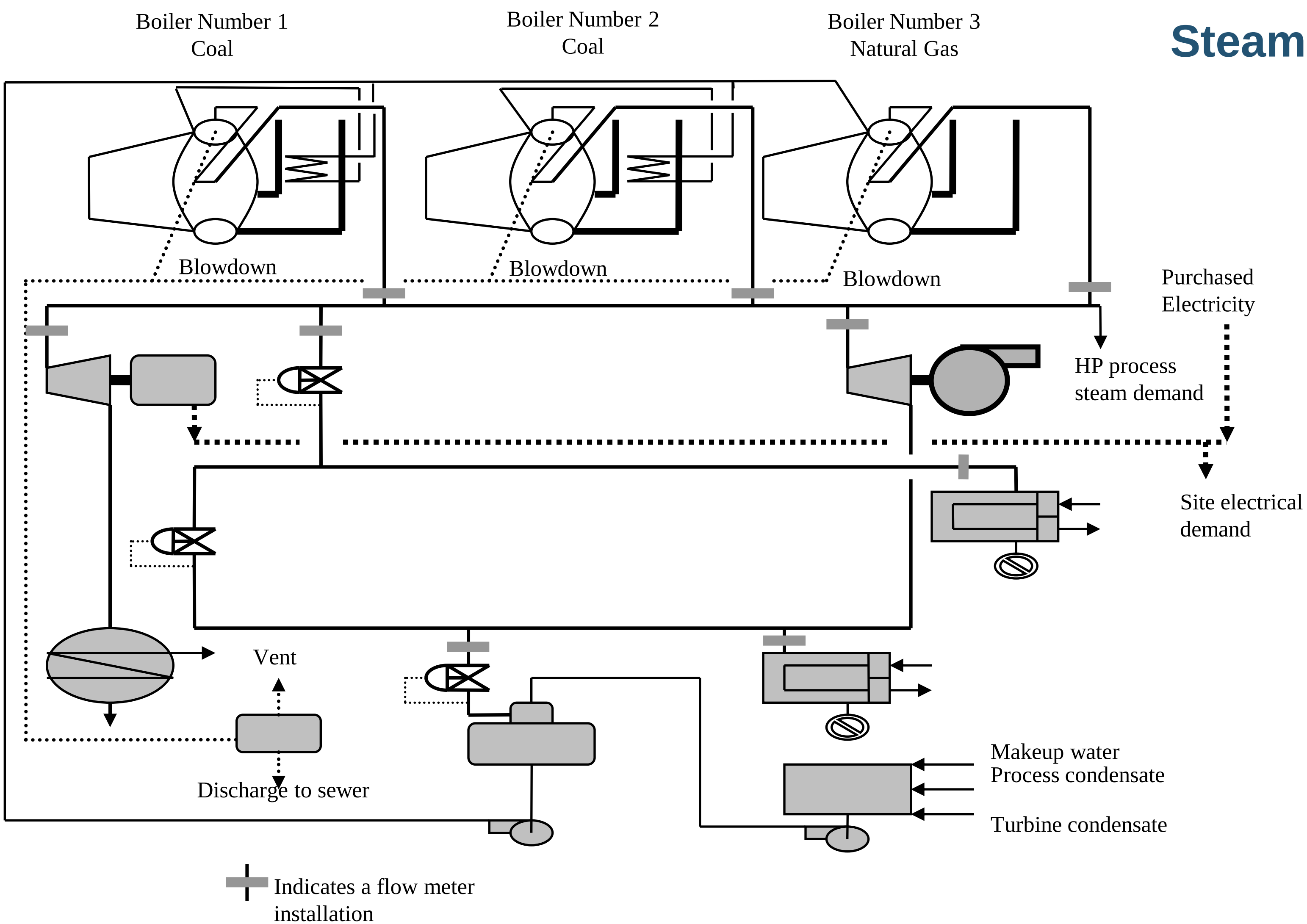
Example Turbine-PRV Evaluation

- A process unit is equipped with 6 identical pumps that are installed in parallel
  - Only 3 of the 6 pumps are required to operate continuously and the remaining pumps are spare (backup) units
  - Electric motors drive 4 of the pumps and steam turbines drive 2 of the pumps
  - Normally 3-electric motor driven pumps are in service.
  - Turbine-driven pump could be started at any time replacing a motor driven pump

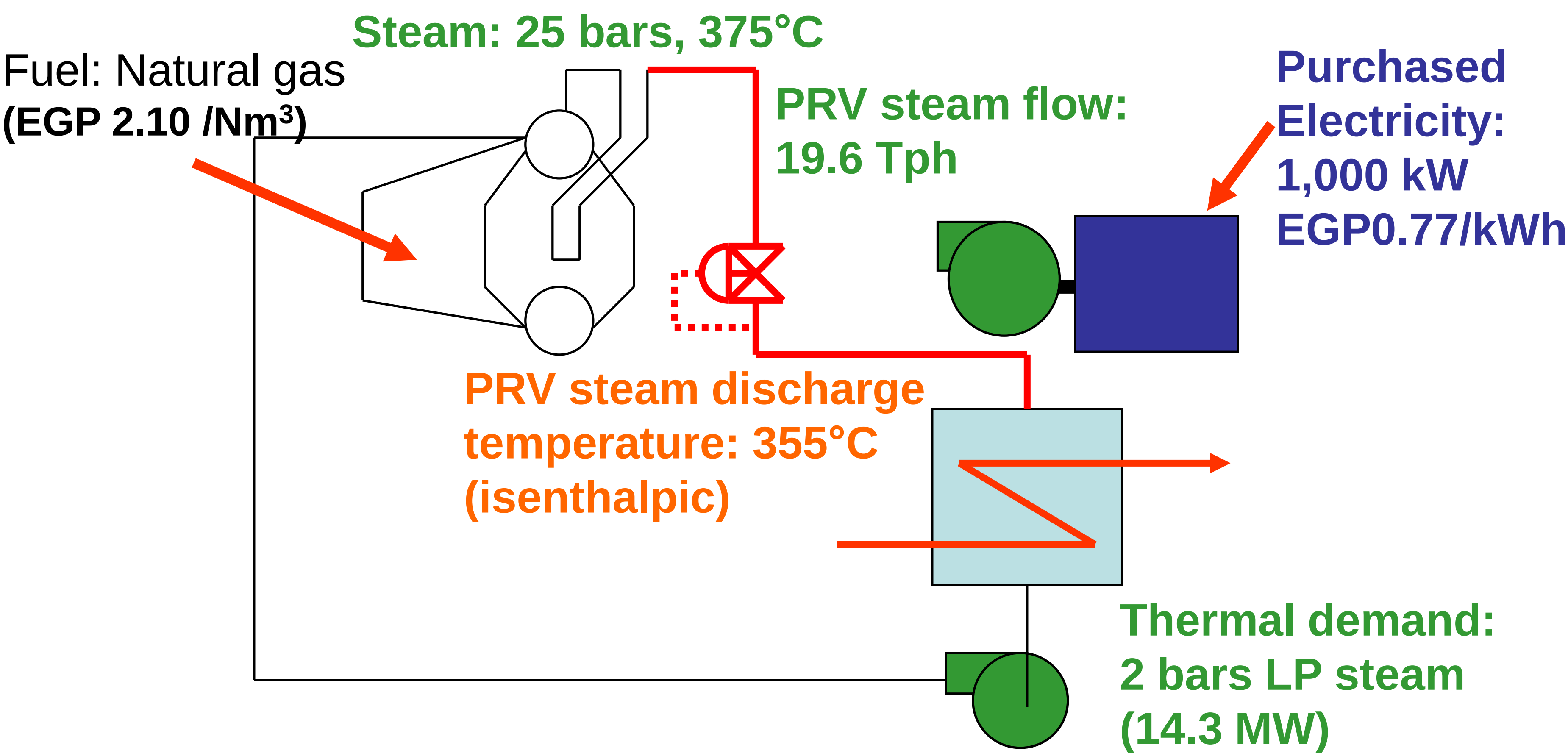


- Identify the economic incentive associated with operating the turbine driven pump
  - Compared to operating an electric motor driven pump and passing steam through a Pressure reducing Valve (PRV) to satisfy the low pressure demands

Steam System



PRV Operations



PRV Operations

$$h_{steam} = 3{,}180.9\,\frac{kJ}{kg}$$ **P = 25 bars; T = 375°C**

$$h_{PRVout} = 3{,}180.9\,\frac{kJ}{kg}$$ **P = 2 bars; Isenthalpic; T = 354.7°C**

$$h_{condensate} = 562.2\,\frac{kJ}{kg}$$ **P = 2 bars; Saturated Condensate; T = 133.7°C**

$$Q_{thermal} = 14{,}300\,kW$$

$$Q_{thermal} = m_{PRV} \times \left(h_{PRVout} - h_{condensate}\right)$$

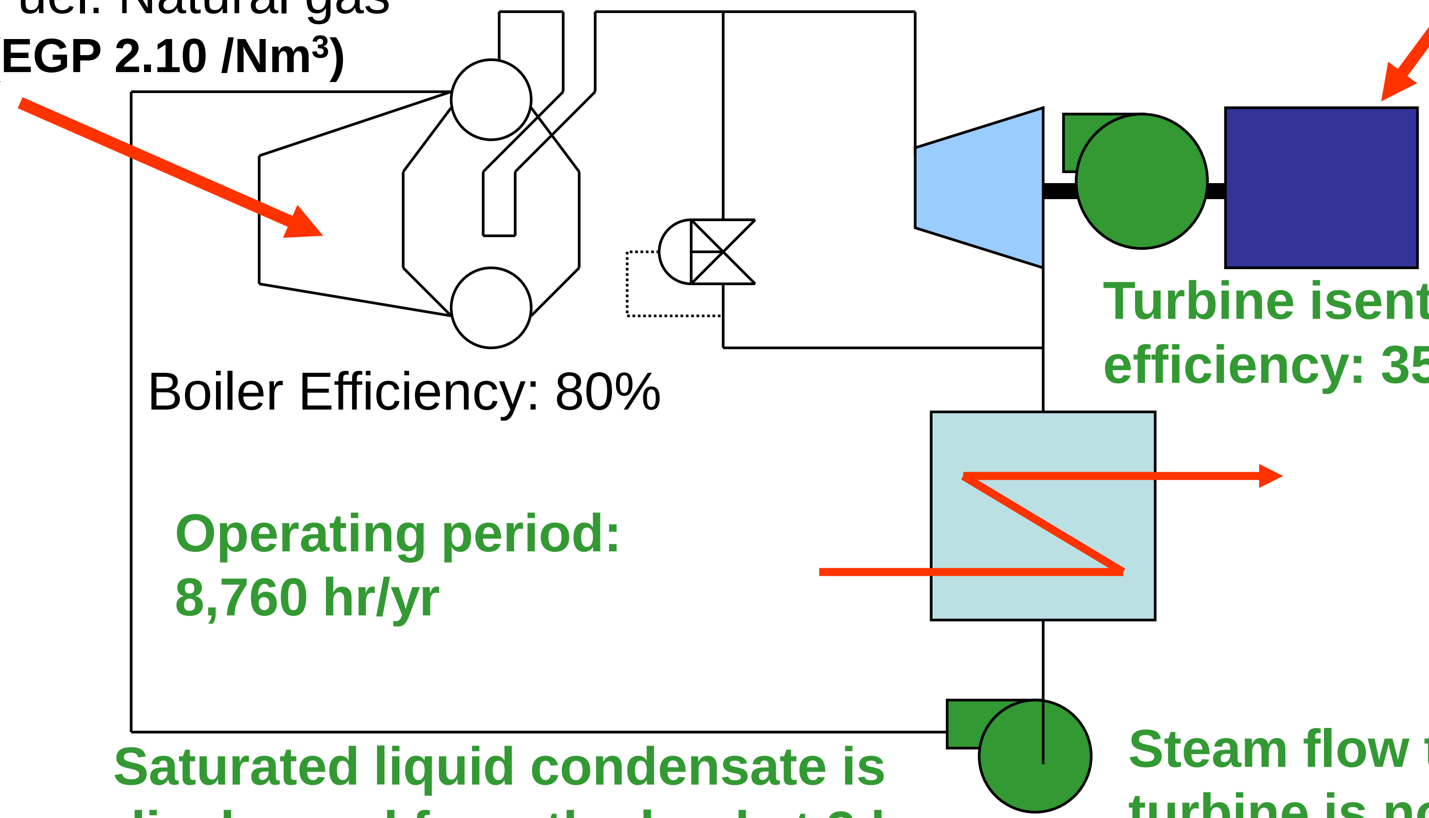
$$m_{PRV} = \frac{14{,}300}{\left(3{,}180.9 - 562.2\right)} = 5.45\frac{kg}{s} = 19.63\,Tph$$

Turbine-PRV Economics

Fuel: Natural gas
(EGP 2.10 /Nm³)

Steam: 25 bar(g), 375°C

Purchased Electricity: 0.77 EGP/kWh



Boiler Efficiency: 80%

Turbine isentropic efficiency: 35%

Operating period: 8,760 hr/yr

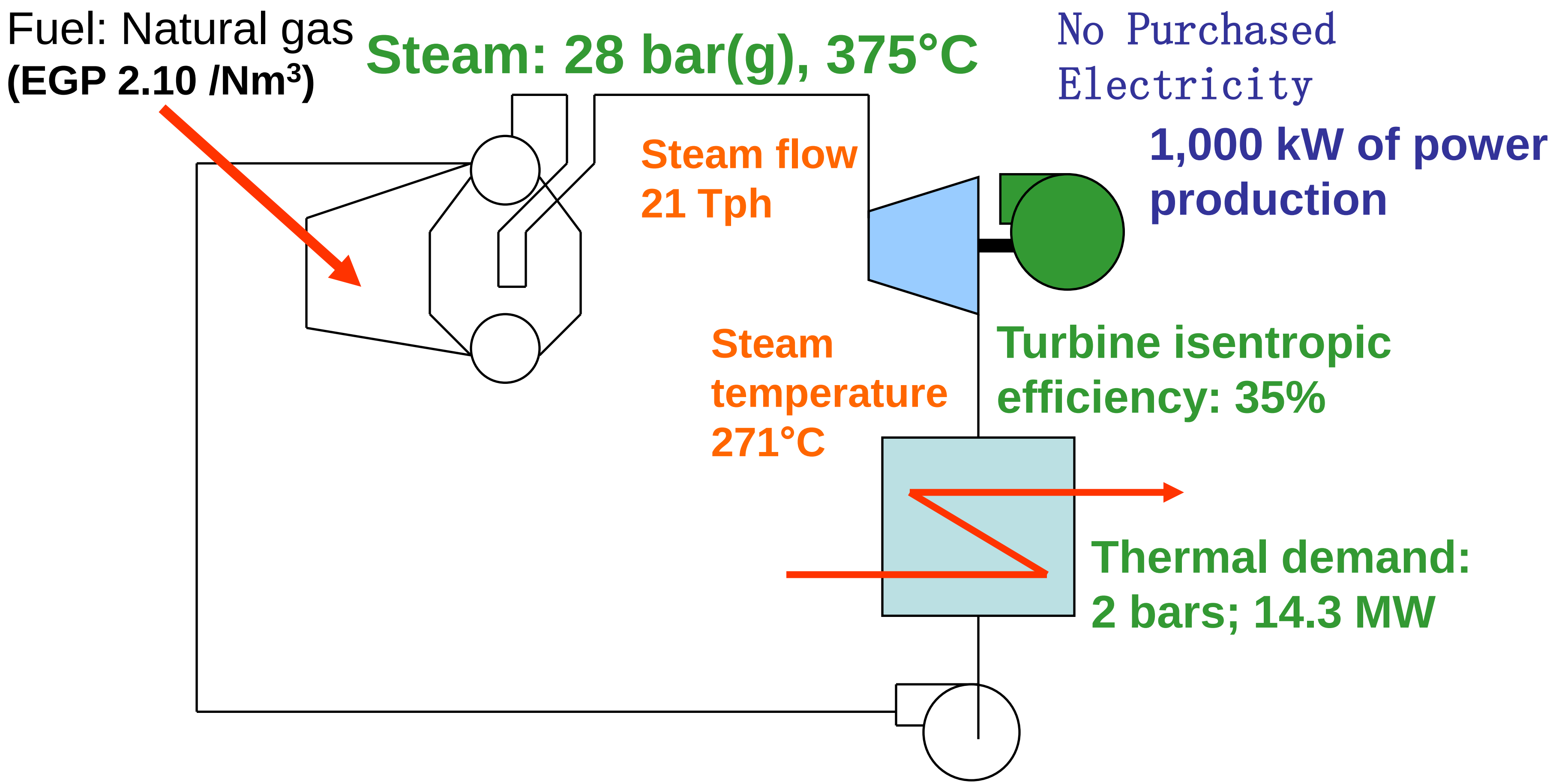
Saturated liquid condensate is discharged from the load at 2 bar

Steam flow through one turbine is nominally 21 Tph discharging at 2 bar

Backpressure Turbine Economics

- ✓ Most industrial systems require thermal energy (not mass flow of steam)
- ✓ The turbine will extract energy from the steam and convert it into shaft energy
  - The steam will exit the turbine with a reduced temperature
- ✓ The result will be an increased mass flow of steam required to satisfy the thermal demand

Steam Turbine Operation



Steam Turbine Operations

$$h_{steam} = 3{,}180.9\,\frac{kJ}{kg}$$ **P = 25 bars; T = 375°C**

$$h_{Turbineout} = 3{,}009.8\,\frac{kJ}{kg}$$ **P = 2 bars; T = 271°C**

$$h_{condensate} = 562.2\,\frac{kJ}{kg}$$ **P = 2 bars; Saturated Condensate; T = 133.7°C**

$$Q_{thermal} = 14{,}300\,kW$$

$$Q_{thermal} = m_{turbine} \times \left(h_{Turbineout} - h_{condensate}\right)$$

$$m_{PRV} = \frac{14{,}300}{\left(3{,}009.8 - 562.2\right)} = 5.83\frac{kg}{s} = 21.0\,Tph$$

PRV - Backpressure Turbine Economics

- Electrical Energy and Cost Savings

$$Energy\,Savings = 1{,}000 \times 8{,}760 = 8{,}760\,MWh$$

$$Energy\,Cost\,Savings = 8{,}760 \times 1{,}000 \times 0.77 = EGP\,6{,}745{,}200$$

- Fuel Energy and Cost Increase

$$Energy\,Increase = (m_{Turbine} - m_{PRV}) \times 1{,}000 \times \frac{(h_{steam} - h_{feedwater})}{\eta_{boiler}} \times 8{,}760$$

$$Energy\,Increase = (21 - 19.6) \times 1{,}000 \times \frac{(3180.9 - 463.5)}{0.80} \times 8{,}760 = 41{,}658\,GJ$$

$$Energy\,Cost\,Increase = \frac{41{,}658 \times 1{,}000 \times 1000}{40{,}144} \times 2.10 = EGP\,2{,}179{,}200$$

PRV - Backpressure Turbine Economics

- ✓ Net Economic Impact

$$Electric\ Power\ Cost\ Savings = \$6{,}745{,}200$$

$$Fuel\ Cost\ Increase = \$2{,}179{,}200$$

$$Net\ Economic\ Benefit = \$4{,}566{,}000$$

- ✓ The primary factors impacting the analysis are:
  - *Impact* electrical cost
  - *Impact* fuel cost
  - Boiler efficiency
  - Steam turbine efficiency
  - Steam demand

PRV - Backpressure Turbine Economics

- Net Economic Impact

$$Electric\ Power\ Cost\ Savings = \$6{,}745{,}200$$

$$Fuel\ Cost\ Increase = \$2{,}179{,}200$$

$$Net\ Economic\ Benefit = \$4{,}566{,}000$$

- This identical analysis can be and <u>should be</u> done with SSAT Projects 7, 8 and 9 depending on which turbine is being modeled in the analysis
  - Systems approach versus Component-based approach

SSAT Project 7 – HP-LP Steam Turbine

Project 7 - HP to LP Steam Turbine(s)
Efficiency : 35% Operation : Operates with fixed steam flow

Do you wish to modify the HP to LP turbine operation?	No
If yes, select the appropriate turbine operating mode	Option 2 - Fixed operation

Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand

Specify a new isentropic efficiency (%)	35 %	

Note: A generator electrical efficiency of 100% is assumed by the model
Note: Isentropic efficiency of existing turbine is 35%

Option 2 - How do wish to define the fixed turbine operation?	Specify fixed steam flow

Option 2 - Fixed steam flow	42 t/h	
Option 2 - Fixed power generation	2000 kW	

Option 3 - How do wish to define the operating range?	Option 3 not selected

Option 3 - Minimum steam flow	25 t/h	
Option 3 - Maximum steam flow	75 t/h	
Option 3 - Minimum power generation	1500 kW	
Option 3 - Maximum power generation	2500 kW	

SSAT Project 8 – HP-MP Steam Turbine

Project 8 - HP to MP Steam Turbine(s) Not installed		
Do you wish to add an HP to MP turbine?		No
If yes, select the appropriate turbine operating mode		Option 1 - Balances MP header
Specify a new isentropic efficiency (%)	70 %	

Note: A generator electrical efficiency of 100% is assumed by the model

Option 2 - How do wish to define the fixed turbine operation?		Option 2 not selected
Option 2 - Fixed steam flow	50 t/h	
Option 2 - Fixed power generation	2000 kW	
Option 3 - How do wish to define the operating range?		Option 3 not selected
Option 3 - Minimum steam flow	25 t/h	
Option 3 - Maximum steam flow	75 t/h	
Option 3 - Minimum power generation	1500 kW	
Option 3 - Maximum power generation	2500 kW	

SSAT Project 9 – MP-LP Steam Turbine

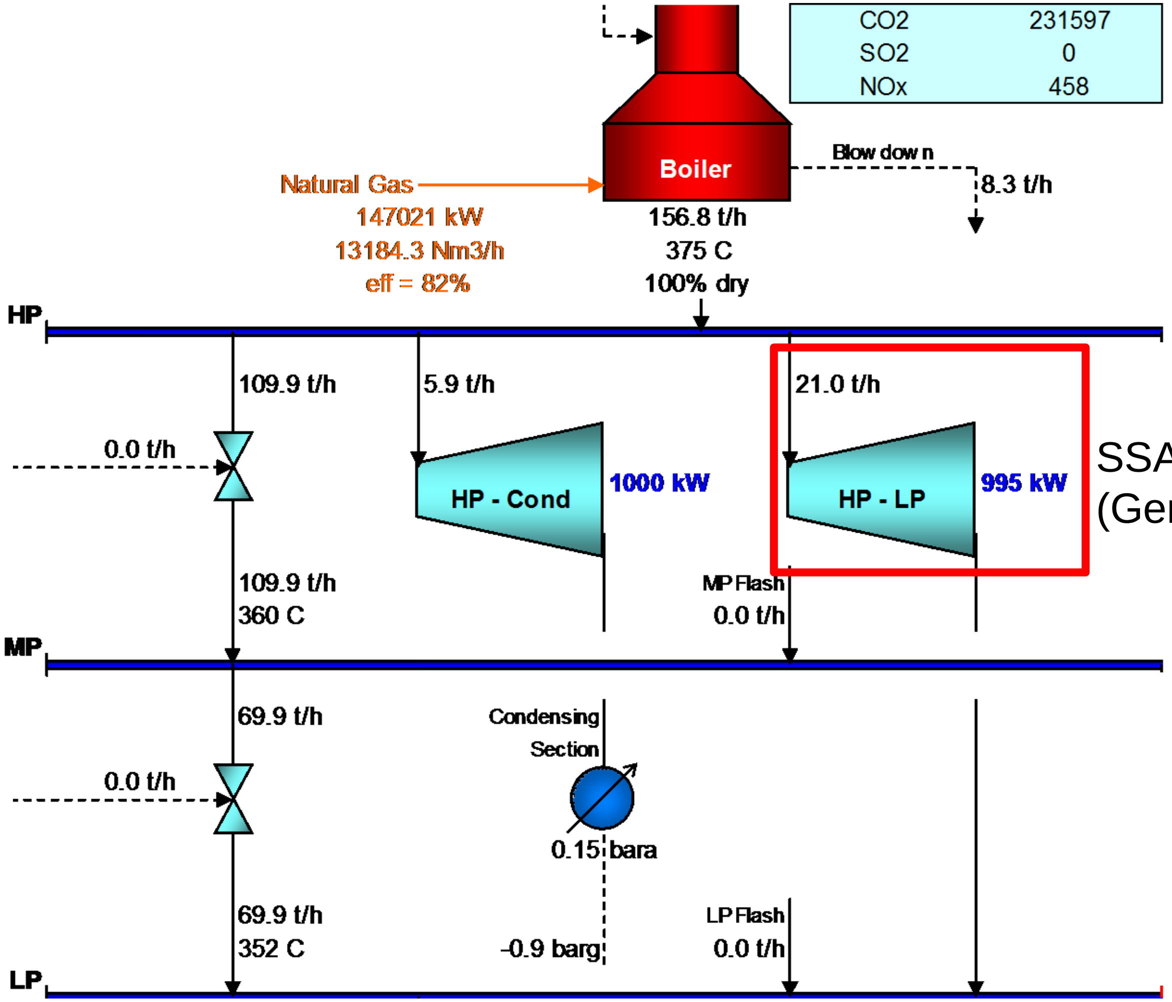
Project 8 - HP to MP Steam Turbine(s)		
Not installed		

Do you wish to add an HP to MP turbine?		No
If yes, select the appropriate turbine operating mode		Option 1 - Balances MP header
Specify a new isentropic efficiency (%)	70 %	

Note: A generator electrical efficiency of 100% is assumed by the model

Option 2 - How do wish to define the fixed turbine operation?		Option 2 not selected
Option 2 - Fixed steam flow	50 t/h	
Option 2 - Fixed power generation	2000 kW	
Option 3 - How do wish to define the operating range?		Option 3 not selected
Option 3 - Minimum steam flow	25 t/h	
Option 3 - Maximum steam flow	75 t/h	
Option 3 - Minimum power generation	1500 kW	
Option 3 - Maximum power generation	2500 kW	

SSAT Analysis – HP-LP Steam Turbine



SSAT - Shaft Power
(Generator Efficiency = 100%)

SSAT Project 7 – HP-LP Steam Turbine

Project 7 - HP to LP Steam Turbine(s)
Efficiency : 35%   Operation : Operates with fixed steam flow

Do you wish to modify the HP to LP turbine operation?		Yes, modify operation of existing turbine
If yes, select the appropriate turbine operating mode		Option 2 - Fixed operation

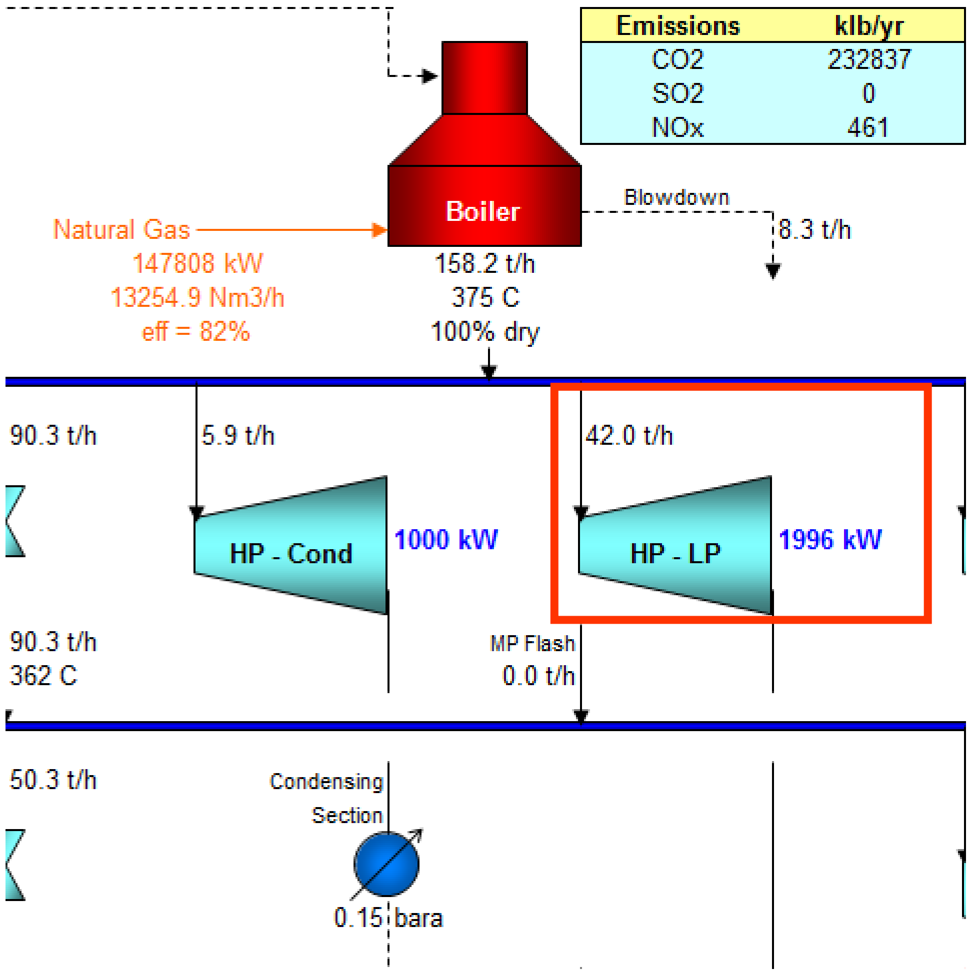
Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand

Specify a new isentropic efficiency (%)	35 %	

Note: A generator electrical efficiency of 100% is assumed by the model
Note: Isentropic efficiency of existing turbine is 35%

Option 2 - How do wish to define the fixed turbine operation?		Specify fixed steam flow
Option 2 - Fixed steam flow	42 t/h	
Option 2 - Fixed power generation	2000 kW	
Option 3 - How do wish to define the operating range?		Option 3 not selected
Option 3 - Minimum steam flow	25 t/h	
Option 3 - Maximum steam flow	75 t/h	
Option 3 - Minimum power generation	1500 kW	
Option 3 - Maximum power generation	2500 kW	

SSAT Project 7 – HP-LP Steam Turbine



SSAT - Shaft Power
(Gen Efficiency = 100%)

SSAT Project 7 – HP-LP Steam Turbine

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	33,726	26,995	6,731	20.0%
Fuel Cost	241,550	243,837	-2,286	-0.9%
Make-Up Water Cost	3,915	3,948	-33	-0.9%
Total Cost (in $ '000s/yr)	**279,191**	**274,780**	**4,411**	**1.6%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	230654 t/yr	232837 t/yr	-2183 t/yr	-0.9%
SOx Emissions	0 t/yr	0 t/yr	0 t/yr	N/A
NOx Emissions	457 t/yr	461 t/yr	-4 t/yr	-0.9%

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	2996 kW	-	-
Power Import	5000 kW	4002 kW	998 kW	20.0%
Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	146422 kW	147808 kW	-1386 kW	-0.9%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	13130.6 Nm3/h	13254.9 Nm3/h	-124.3 Nm3/h	-0.9%
Boiler Steam Flow	156.7 t/h	158.2 t/h	-1.5 t/h	-0.9%
Fuel Cost (in $/MWh)	188.32	188.32	-	-
Power Cost (as $/MWh)	770.00	770.00	-	-
Make-Up Water Flow	76 m3/h	77 m3/h	-1 m3/h	-0.9%

SSAT Project 7 – HP-LP Steam Turbine

- ✓ Differences between the “Manual” versus “Model” calculated results can be significant when working with cogeneration type projects
- ✓ The Model results are very accurate
  - Uses a SYSTEM approach and not just a component
    - Impact of condensate temperature
    - Impact of blowdown, deaerator steam flow, make-up water, etc.
  - Completes a detailed mass, energy and economic balance
- ✓ <u>ALWAYS</u> use a SYSTEM based model for analysis

Typical Energy Costs in Egypt							
Energy type	Unit	EGP/Unit	US$/Unit	HHV(kJ/kg)	EGP/GJ	US$/GJ	Remarks
Natural Gas*	MMBtu	50.2	5.60	54,220	52.43	5.90	varies between US$ 4.3 & 7.0
Diesel	Litre	2.04	0.23	45,125	53.88	6.07	US$ 0.23/Lit, (Sp. Gr. 0.84)
Petrol	Litre	2.93	0.33	46,536	85.10	9.58	US$ 0.33/Lit (Sp. Gr. 0.74)
Fuel Oil (Mozut)	Tonne	2300	259.0	43,595	52.76	5.94	range 1400-2300 EGP/Tonne
Coal (if imported)	Tonne	1066	120.0	31,890	33.41	3.76	
Electricity	kWh	0.77	0.09		214.60	24.2	US$ 0.087 /kWh

EGP = Egyptian Pound, 1 US$ = 8.88 EGP 1GJ = 0.94845 MMBtu

Nat. gas HHV	40144	kJ/Nm3	24.91	NM3/GJ		
Nat. gas cost	5.90	US$/GJ	0.24	$/NM3	2.10	EGP/NM3

Fuel Price Impact, If Gas price subsidy is removed

- Fuel price increase to EGP6.3/NM^3 from EGP2.1/NM^3

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

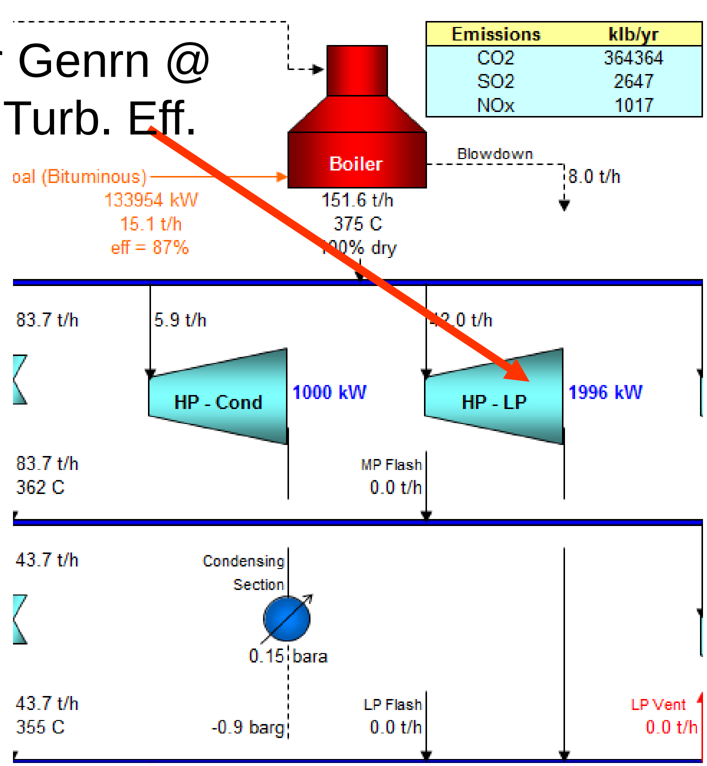
Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	33,726	26,995	6,731	20.0%
Fuel Cost	724,651	731,510	-6,858	-0.9%
Make-Up Water Cost	3,915	3,948	-33	-0.9%
Total Cost (in $ '000s/yr)	**762,292**	**762,453**	**-161**	**0.0%**

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	2996 kW	-	-
Power Import	5000 kW	4002 kW	998 kW	20.0%
Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	146422 kW	147808 kW	-1386 kW	-0.9%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	13130.6 Nm3/h	13254.9 Nm3/h	-124.3 Nm3/h	-0.9%
Boiler Steam Flow	156.7 t/h	158.2 t/h	-1.5 t/h	-0.9%
Fuel Cost (in $/MWh)	358.70	358.70	-	-
Power Cost (as $/MWh)	770.00	770.00	-	-
Make-Up Water Flow	76 m3/h	77 m3/h	-1 m3/h	-0.9%

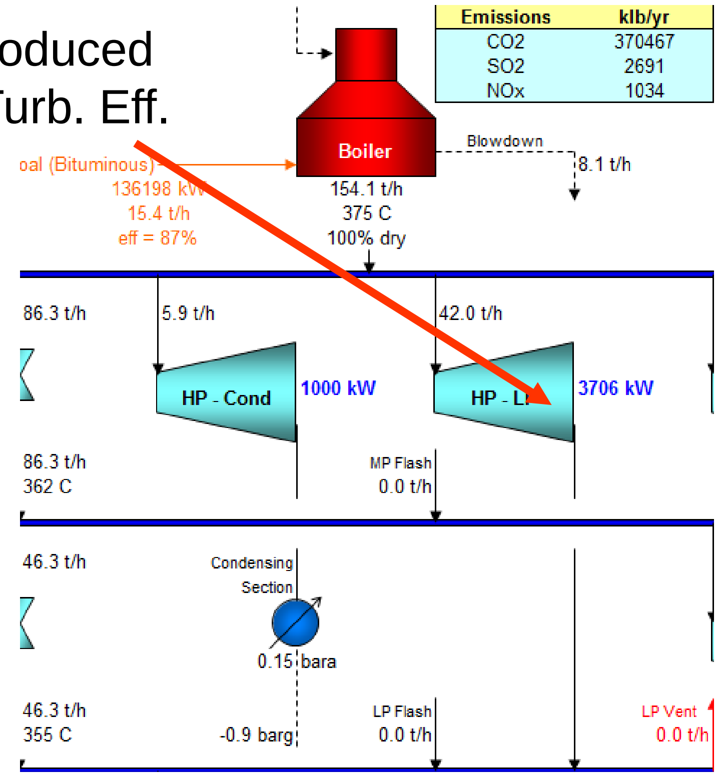
Improved Turbine Efficiency

✓ Improve the isentropic turbine efficiency to 65% when fuel cost goes up

Power Genrn @ 35% Turb. Eff.



Power produced @ 65% Turb. Eff.



✓ Higher efficiency turbine extracts more power out of the steam thereby reducing steam enthalpy at the exhaust

- Resulting in more steam to be generated by the boilers!

Improved Turbine Efficiency

- The isentropic turbine efficiency is now 65% instead of 35%

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	33,726	15,457	18,269	54.2%
Fuel Cost	724,651	743,262	-18,611	-2.6%
Make-Up Water Cost	3,915	4,005	-90	-2.3%
Total Cost (in $ '000s/yr)	**762,292**	**762,724**	-433	-0.1%

Net Savings further reduces to more negative with a more efficient Turbine is when the fuel price is high.

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	4706 kW	-	-
Power Import	5000 kW	2292 kW	2708 kW	54.2%
Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	140763 kW	144533 kW	-3770 kW	-2.7%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	12623.1 Nm3/h	12961.2 Nm3/h	-338.1 Nm3/h	-2.7%
Boiler Steam Flow	150.1 t/h	154.1 t/h	-4.0 t/h	-2.7%

Electrical Price Impact

✓ Electrical price also increased to 1.00 EGP/kWh (from 0.77 EGP/kWh) when fuel price went up

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	43,800	35,059	8,741	20.0%
Fuel Cost	724,651	731,510	-6,858	-0.9%
Make-Up Water Cost	3,915	3,948	-33	-0.9%
Total Cost (in $ '000s/yr)	**772,366**	**770,516**	**1,850**	**0.2%**

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	2996 kW	-	-
Power Import	5000 kW	4002 kW	998 kW	20.0%
Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	140763 kW	142152 kW	-1389 kW	-1.0%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	12623.1 Nm3/h	12747.7 Nm3/h	-124.6 Nm3/h	-1.0%
Boiler Steam Flow	150.1 t/h	151.6 t/h	-1.5 t/h	-1.0%
Fuel Cost (in $/MWh)	72.64	72.64	-	-
Power Cost (as $/MWh)	150.00	150.00	-	-
Make-Up Water Flow	73 m3/h	74 m3/h	-1 m3/h	-0.9%

Fuel Impact

- ✓ Impact fuel is now coal at a price of EGP 1066 /tonne (EGP 33.41/GJ) instead of Natural gas (EGP 52.43/GJ, i.e, EGP 2.1/Nm^3)
- ✓ Boiler efficiency is now 86.7% (for coal) versus 81.7% (for Natural gas)

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	33,726	26,995	6,731	20.0%
Fuel Cost	145,451	146,828	-1,377	-0.9%
Make-Up Water Cost	3,915	3,948	-33	-0.9%
Total Cost (in $ '000s/yr)	**183,092**	**177,771**	**5,321**	**2.9%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	375310 t/yr	378862 t/yr	-3552 t/yr	-0.9%
SOx Emissions	2726 t/yr	2752 t/yr	-26 t/yr	-0.9%
NOx Emissions	1048 t/yr	1058 t/yr	-10 t/yr	-0.9%

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	2996 kW	-	-
Power Import	5000 kW	4002 kW	998 kW	20.0%
✓ Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	137978 kW	139284 kW	-1306 kW	-0.9%
Fuel Type	Typical Eastern Coal (Bituminous)	Typical Eastern Coal (Bituminous)	-	-
Fuel Consumption	15.6 t/h	15.7 t/h	-0.1 t/h	-0.6%
Boiler Steam Flow	156.7 t/h	158.2 t/h	-1.5 t/h	-0.9%
Fuel Cost (in $/MWh)	120.34	120.34	-	-
Power Cost (as $/MWh)	770.00	770.00	-	-
Make-Up Water Flow	76 m3/h	77 m3/h	-1 m3/h	-0.9%

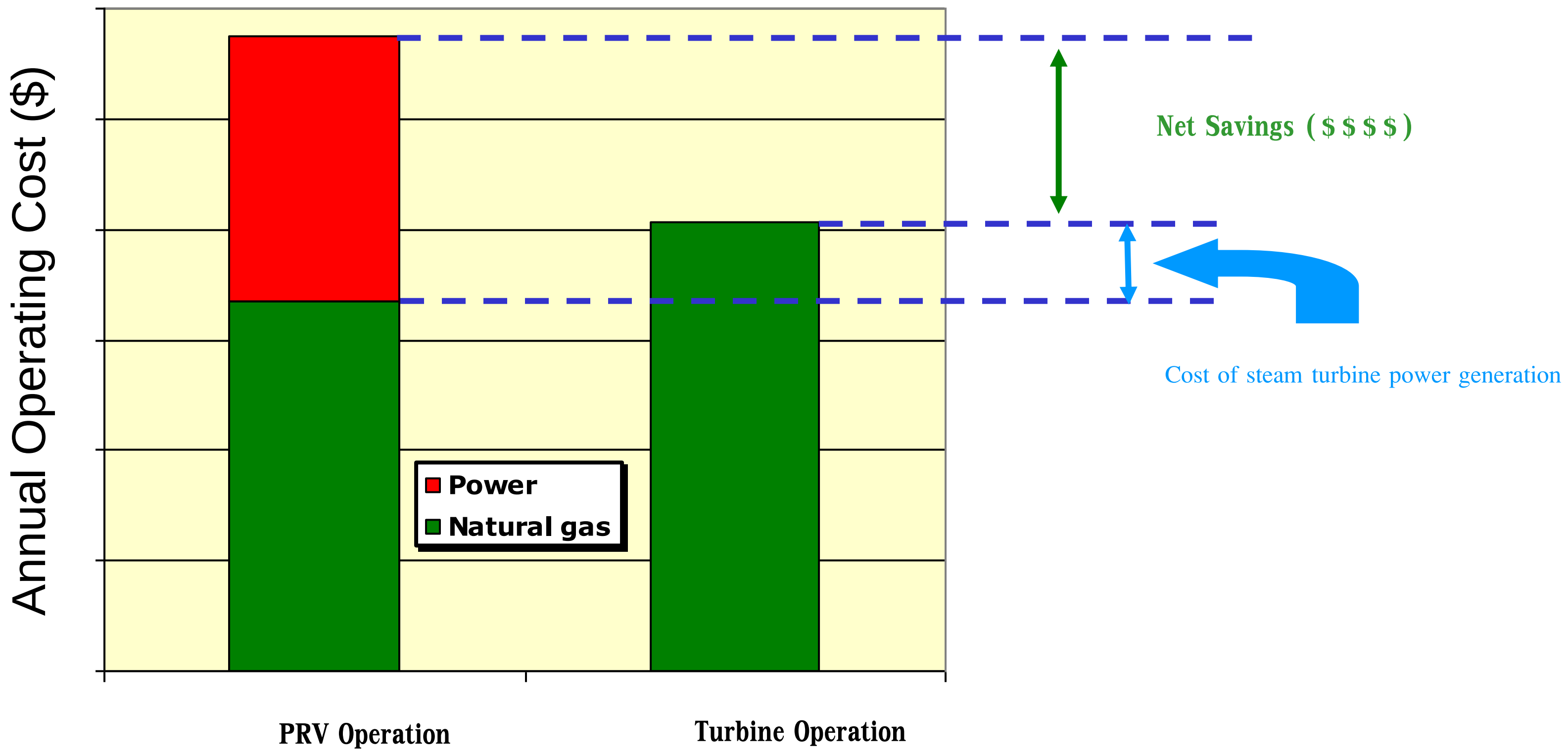
Turbine-PRV Examples Summary Information

- ✓ These examples indicate the critical importance of impact parameter accuracy

Power Cost (EGP/kWh)	Fuel Cost (EGP/GJ)	Turbine Efficiency (%)	Boiler Efficiency (%)	Power Produced (kW)	Additional Steam (Tph)	Cost Savings ('000 EGP/yr)
0.770	52.43	35.0	81.7	998.0	1.5	4,411.0
0.770	157.29	35.0	81.7	998.0	1.5	(161.0)
0.770	157.29	65.0	81.7	998.0	1.5	(433.0)
1.000	157.29	35.0	81.7	998.0	1.5	1,850.0
0.770	33.41	35.0	86.7	998.0	1.5	5,321.0

- ✓ It is VERY IMPORTANT to conduct this analysis for each facility
  - Each facility is unique and will need significant due diligence before implementation of these projects

Backpressure Turbine Economics



Variables for Industrial Applications

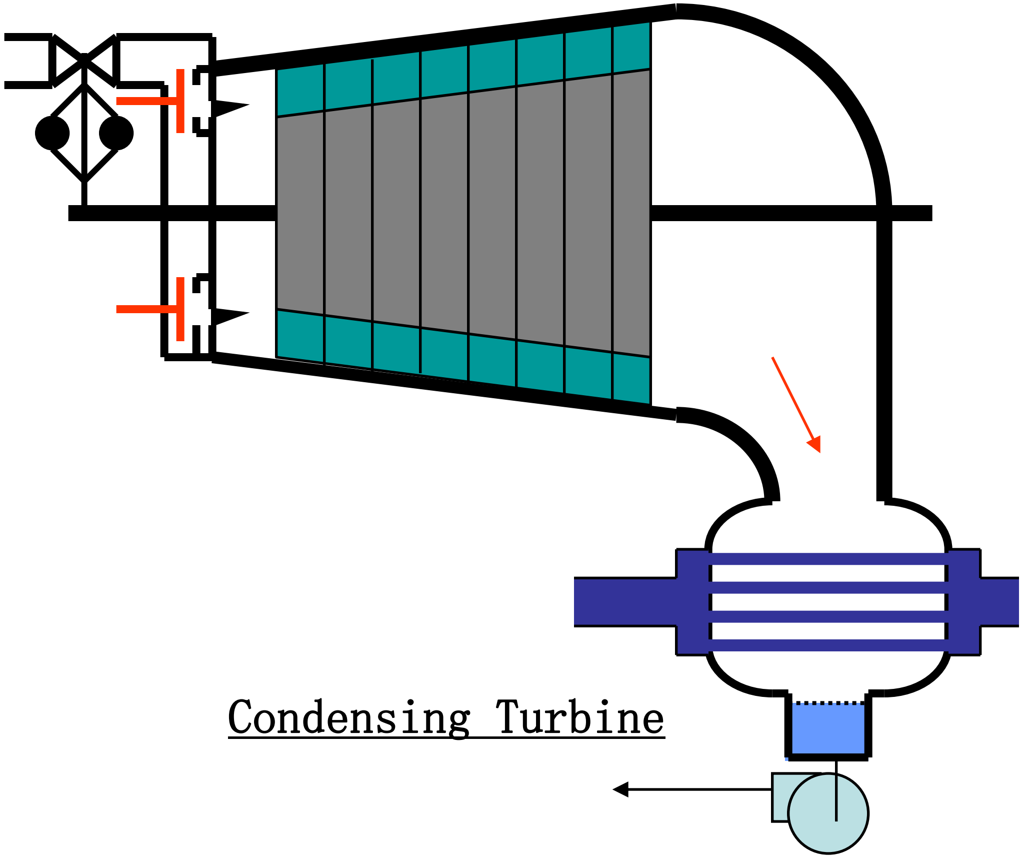
- ✓ Constant steam flow
- ✓ High pressure supply steam
- ✓ Existing Pressure Reducing Valve (PRV)
- ✓ Multiple steam header system
- ✓ Simultaneous steam and electric (power) demand
- ✓ High run hours

Key Points / Action Items

1. Backpressure turbines are used instead of pressure letdown stations
2. Turbine efficiency is NOT 1st law efficiency but a comparison of actual turbine versus an ideal turbine
3. Continuous operations with a simultaneous thermal and electric demand are good candidates for backpressure turbines
4. Each facility analysis is unique and will depend on several economic as well as operating factors
5. Turbine analysis will need a solid thermodynamic steam system model

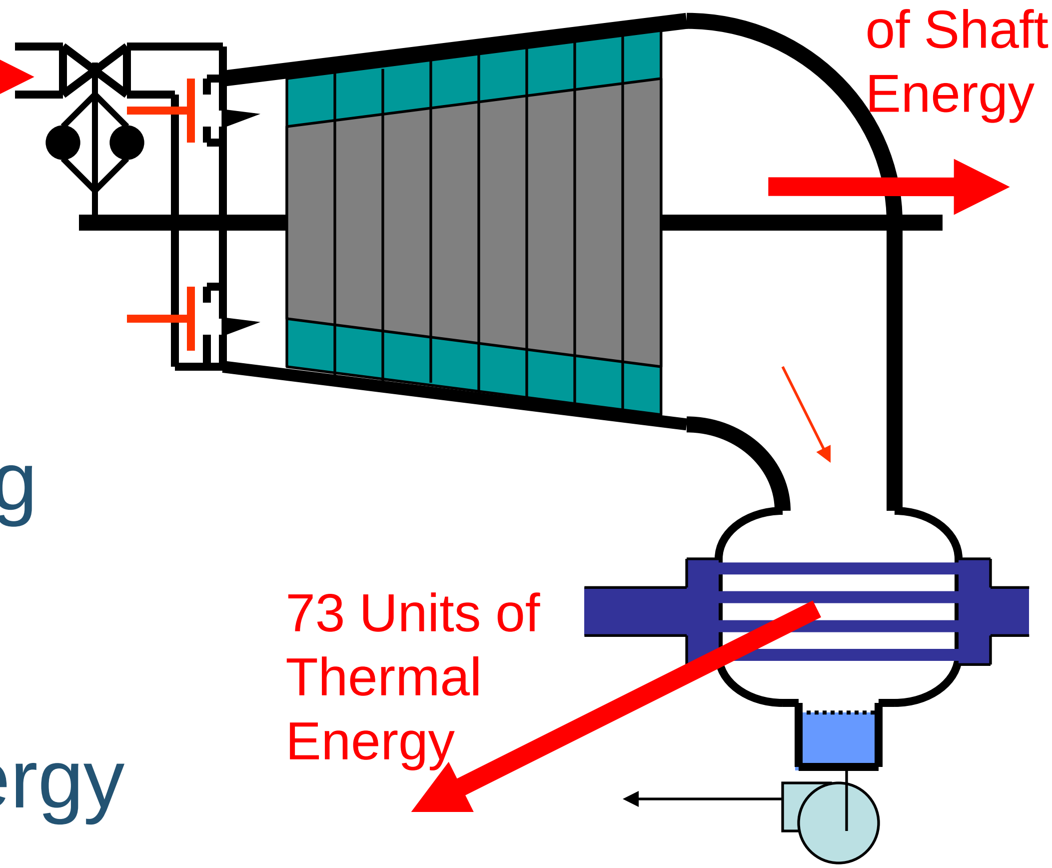
Condensing Steam Turbines

- ✓ Condensing turbine discharge steam pressure is less than atmospheric pressure
  - The steam must be condensed to pump it back into the boiler
  - Exiting steam quality is typically much greater than 90%



Source: US DOE ITP Steam BestPractices Program

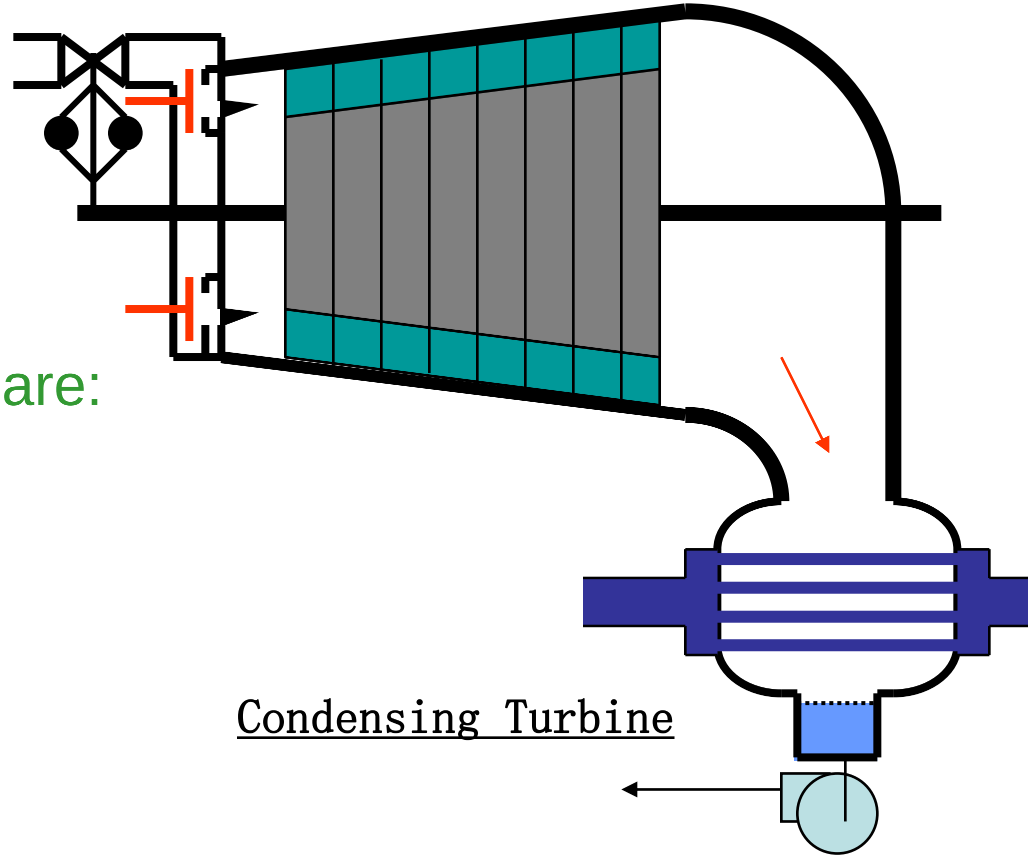
Condensing Steam Turbines



- ✓ The steam entering the condenser contains a huge amount of fuel energy

Source: US DOE ITP Steam BestPractices Program

Condensing Steam Turbines

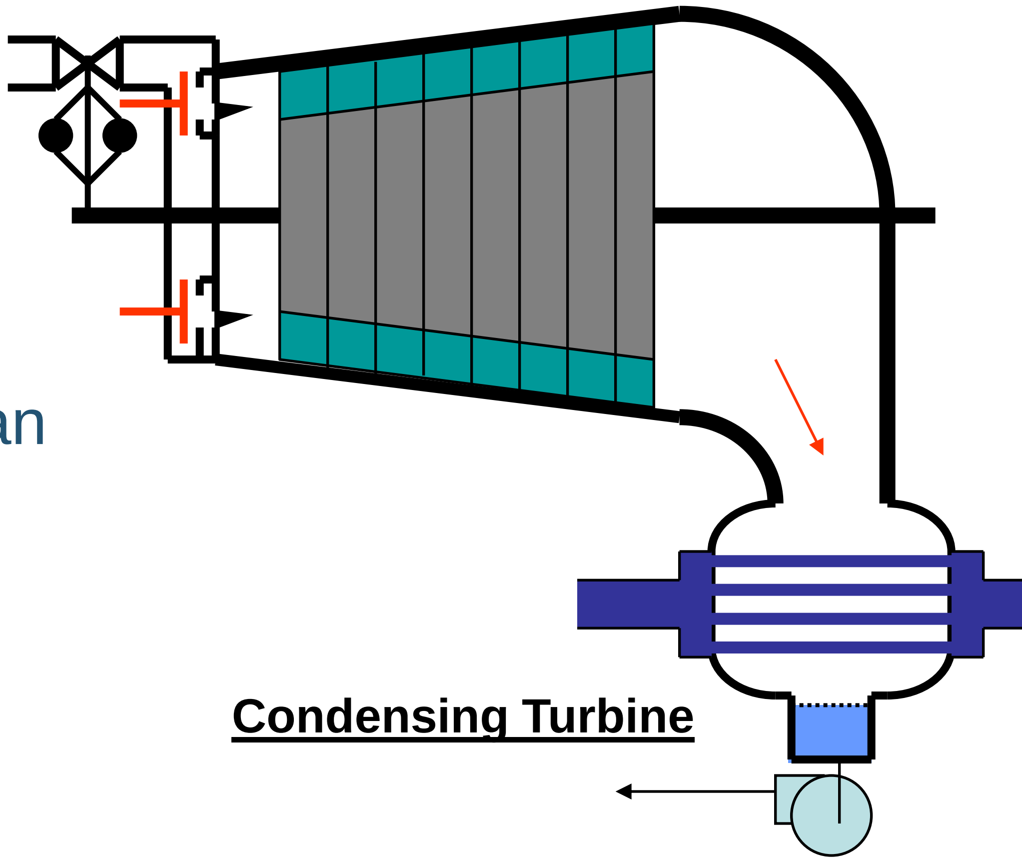


✓ The primary factors influencing condensing turbine operations are:

- **Purchased power cost**
- **Purchased fuel cost**
- **Turbine efficiency**
- Boiler efficiency
- Turbine discharge pressure

Condensing Steam Turbines

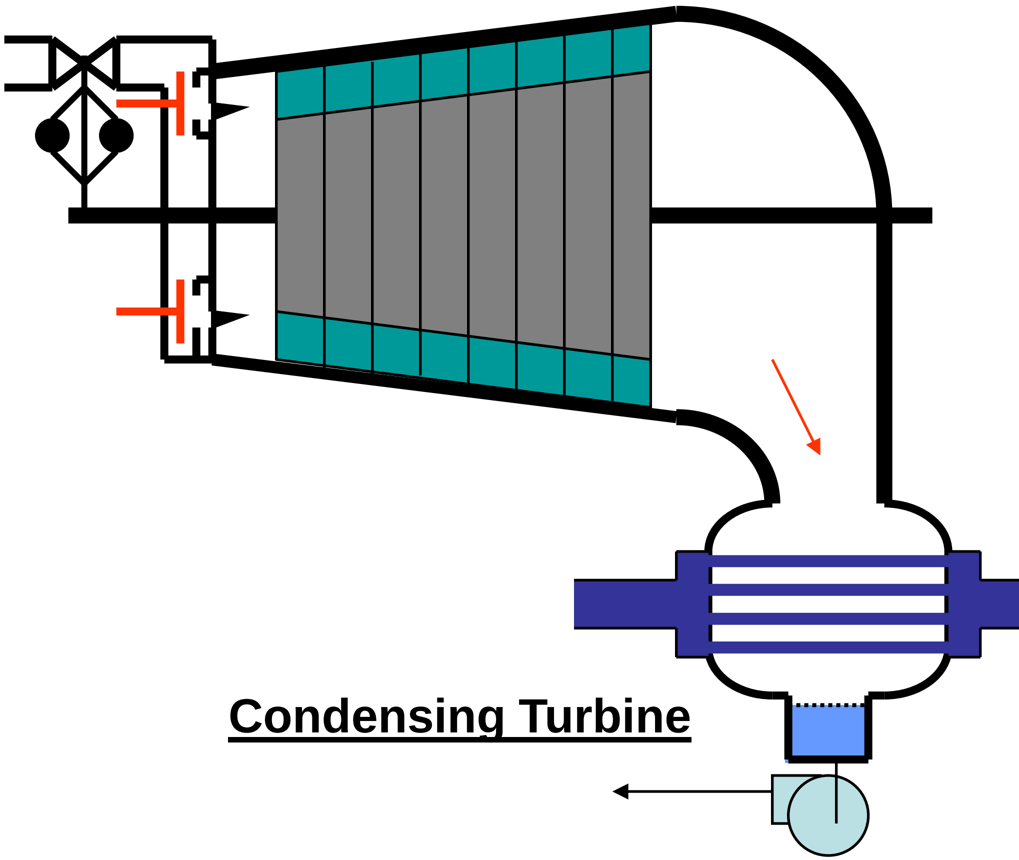
- ✓ Efficiency reductions can result from:
  - Blade deposits
  - Blade erosion
  - Seal wear
  - Wet steam
  - Throttling
- ✓ Efficiency improvements can result from
  - Replaced blades
  - Improved seals
  - Turbine replacement
  - Increased load



Source: US DOE ITP Steam BestPractices Program

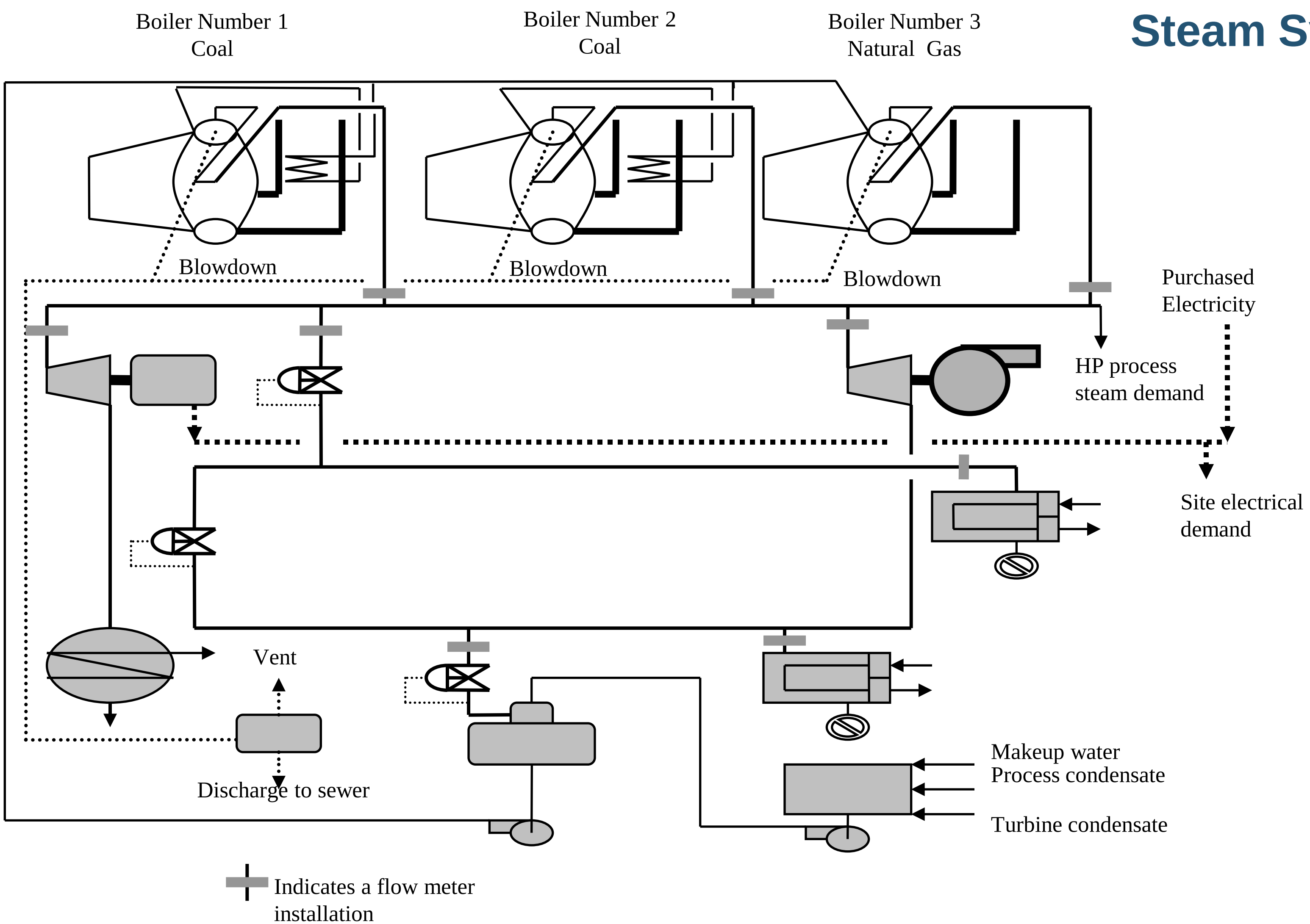
Condensing Steam Turbines

- Condenser pressure can be reduced (improved) by
  - Removing non-condensable gases from condenser
  - Cleaning the condenser
  - Supplying the condenser with reduced temperature water
  - Supplying the condenser with additional cooling water



Source: US DOE ITP Steam BestPractices Program

Steam System



SSAT Project 10 – Condensing Steam Turbines

Project 10 - HP to Condensing Steam Turbine(s)
Efficiency : 65%   Operation : Operates at fixed power generation

Do you wish to modify the HP to condensing turbine operation?		No, maintain current operation
If yes, enter a new isentropic efficiency (%)	70 %	

Note: A generator electrical efficiency of 100% is assumed by the model
Note: Isentropic efficiency of existing turbine is 65%

If yes, select the units to specify the condenser pressure		bara
New condenser pressure (bara)	0.15	

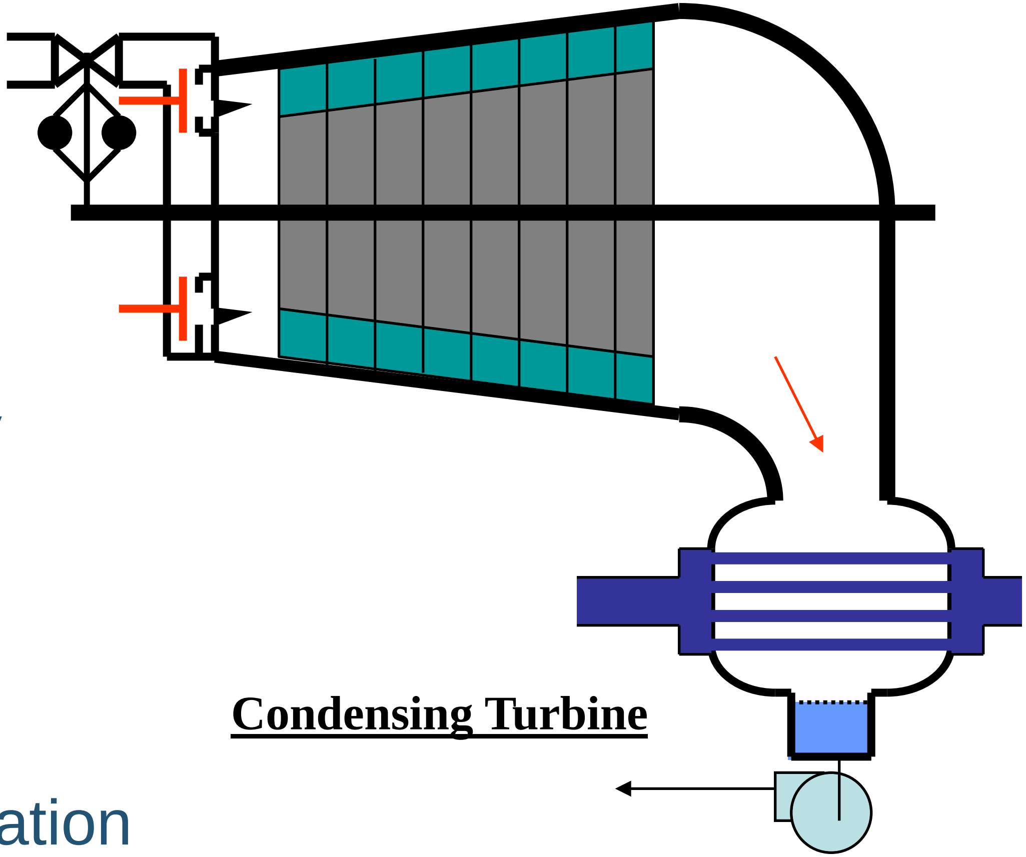
Note: Existing condenser pressure is 0.15 bara

If yes, select the new mode of operation		Option 1 - Fixed power generation
Option 1 - Fixed power generation	1000 kW	
Option 2 - Fixed steam flow	25 t/h	

- ✓ Implementing SSAT Project 10 will involve a major change in steam demand
  - Be very careful while evaluating this project

SSAT Project 10 - Condensing Steam Turbines

- SSAT allows
  - The addition of a condensing turbine
  - Modification of major aspects of an existing turbine
    - Isentropic efficiency
    - Discharge pressure
    - Load
      - Flow
      - Power
  - Elimination of the operation of a turbine



Condensing Turbine

SSAT Project 10 - Condensing Steam Turbines

Project 10 - HP to Condensing Steam Turbine(s) Efficiency : 65% Operation : Operates at fixed power generation		
Do you wish to modify the HP to condensing turbine operation?	Yes, switch off existing turbine	
If yes, enter a new isentropic efficiency (%)	70 %	

Note: A generator electrical efficiency of 100% is assumed by the model

Note: Isentropic efficiency of existing turbine is 65%

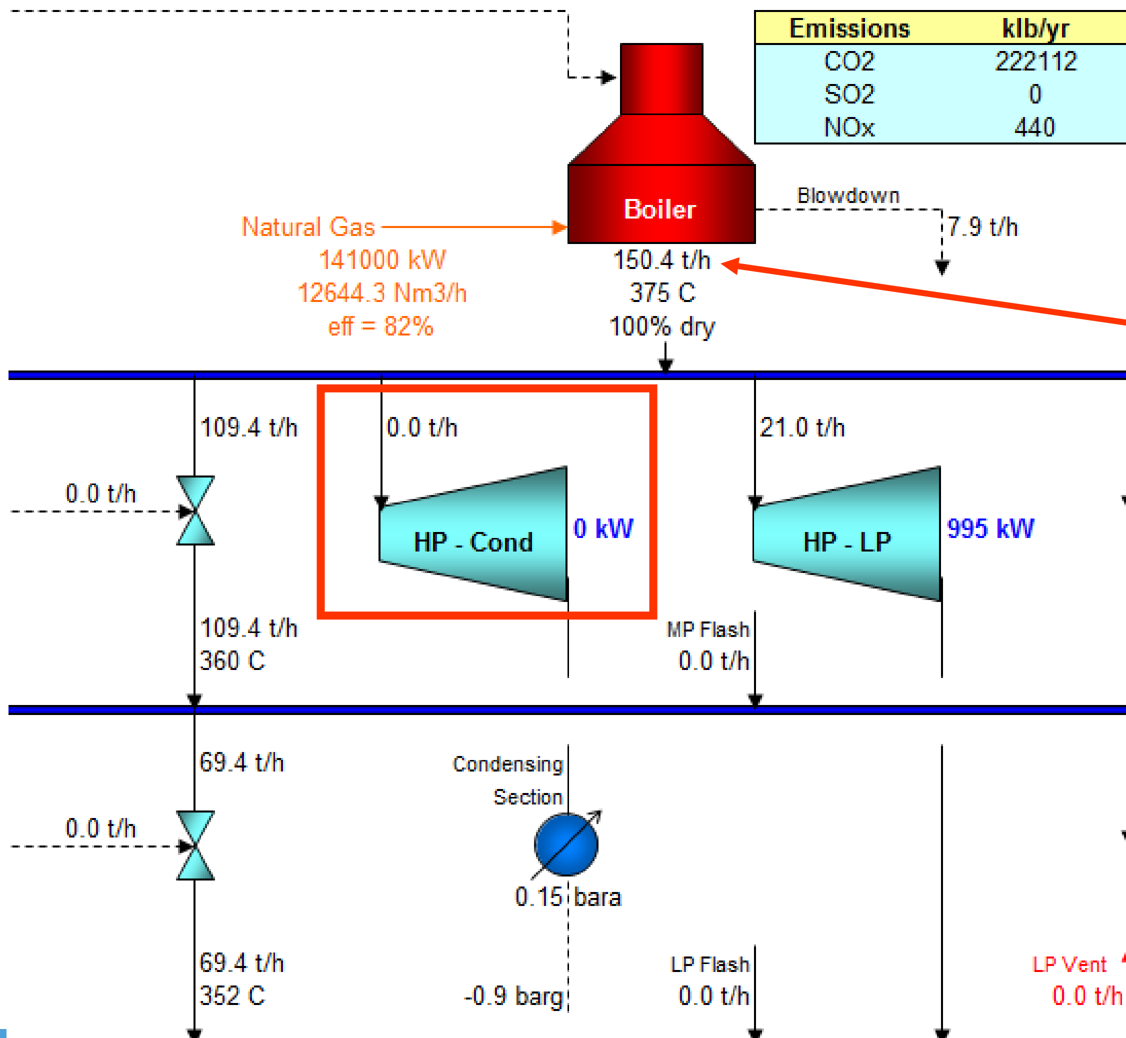
If yes, select the units to specify the condenser pressure	bara	
New condenser pressure (bara)	0.15	

Note: Existing condenser pressure is 0.15 bara

If yes, select the new mode of operation	Not installed	
Option 1 - Fixed power generation	1000 kW	
Option 2 - Fixed steam flow	25 t/h	

- ✓ Impact of switching off the condensing turbine

SSAT Project 10 - Condensing Steam Turbines



Large change
in steam demand

SSAT Project 10 - Condensing Steam Turbines

Results Summary

SSAT 3 Header Metric Model for User Training Egypt

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	33,726	40,471	-6,745	-20.0%
Fuel Cost	241,550	231,641	9,910	4.1%
Make-Up Water Cost	3,915	3,897	17	0.4%
Total Cost (in $ '000s/yr)	**279,191**	**276,009**	**3,182**	**1.1%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	230654 t/yr	221191 t/yr	9463 t/yr	4.1%
SOx Emissions	0 t/yr	0 t/yr	0 t/yr	N/A
NOx Emissions	457 t/yr	438 t/yr	19 t/yr	4.1%

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	1998 kW	998 kW	-	-
Power Import	5000 kW	6000 kW	-1000 kW	-20.0%
Total Site Electrical Demand	6998 kW	6998 kW	-	-
Boiler Duty	146422 kW	140415 kW	6007 kW	4.1%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	13130.6 Nm3/h	12591.9 Nm3/h	538.7 Nm3/h	4.1%
Boiler Steam Flow	156.7 t/h	150.3 t/h	6.4 t/h	4.1%
Fuel Cost (in $/MWh)	188.32	188.32	-	-
Power Cost (as $/MWh)	770.00	770.00	-	-
Make-Up Water Flow	76 m3/h	76 m3/h	0 m3/h	0.4%

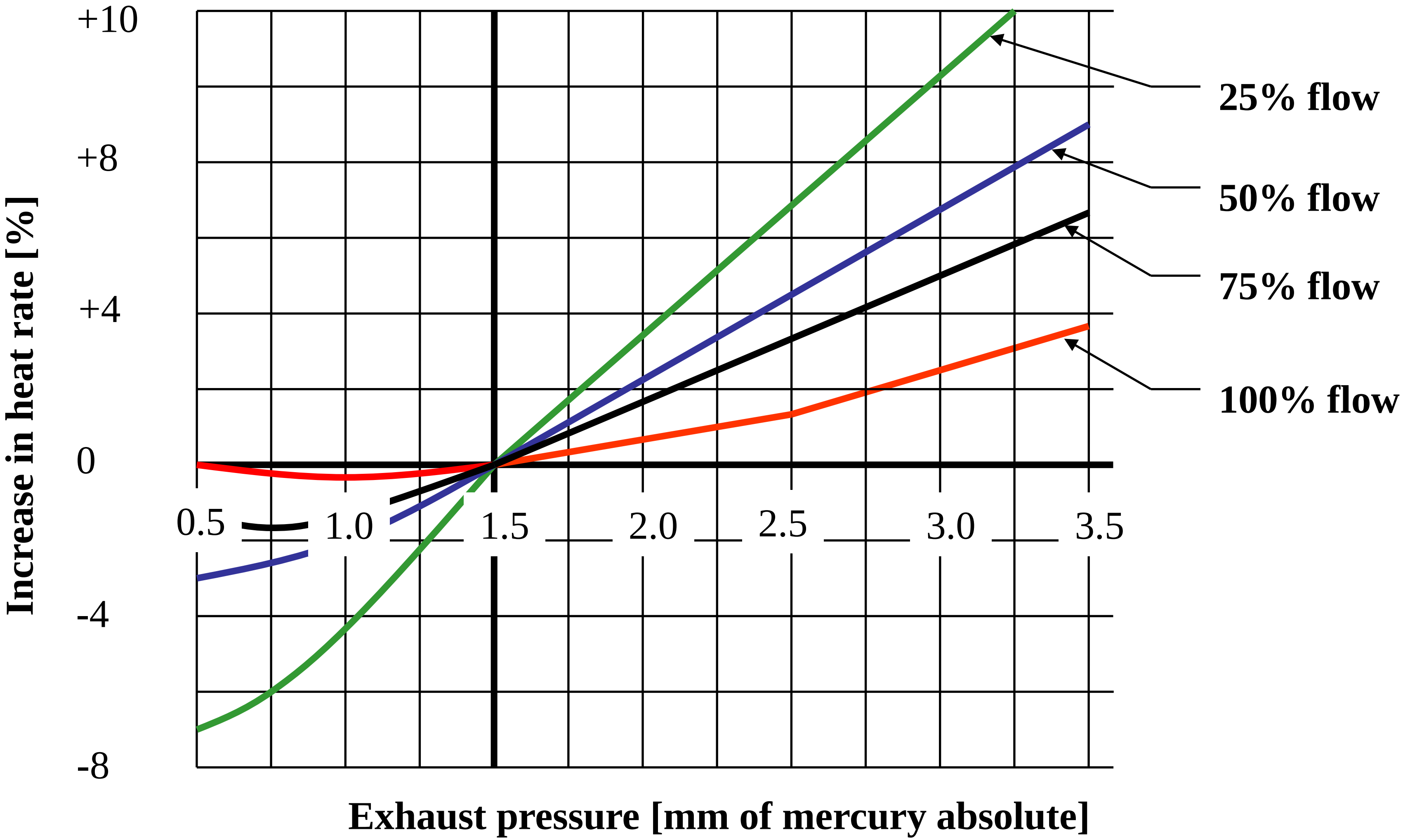
Condensing Turbine Performance

Condensing Turbine Impact Power Cost			
Fuel Cost [EGP/GJ]	**Impact Condensing Power Cost [EGP/MWh]**		
	Turbine Isentropic Efficiency [%]		
	40	**60**	**80**
50	1807	1204	903
75	2694	1796	1347
100	3582	2388	1791
125	4469	2980	2235
150	5357	3571	2678
Steam inlet	25	bars	
Steam inlet	375	°C	
Steam exit	0.15	bar(a)	

Condensing Turbine Pressure Effect

- ✓ It should be noted that a minimum pressure is generally attained where maximum energy utilization efficiency is achieved
  - In other words, there is generally a pressure threshold that further reductions in discharge pressure result in reducing overall cost effectiveness
  - Velocity losses begin to be excessive
    - This is very dependent on the turbine design
      - Larger annular steam flow area reduces the loss
  - Condensate is returned to the boiler at lower temperature
  - Common design is for 1.5 inches of mercury absolute (0.74 psia) condenser pressure

Condensing Turbine Pressure Effect



Key Points / Action Items

1. Condensing turbines are used strictly for power generation or driving large mechanical equipment
2. They serve niche applications in the industry
3. Condensing turbines provide maximum shaft power per unit of steam flow
4. Each facility analysis is unique and will depend on several economic as well as operating factors
5. Turbine analysis will need a solid thermodynamic steam system model

Common BestPractices –Turbines

- ✓ Process and utility integration leads to overall energy optimization of the plant
- ✓ Install backpressure turbines in parallel with pressure letdown stations and minimize flow through letdown stations
- ✓ Evaluate backpressure turbine applications for direct mechanical drives
- ✓ Evaluate condensing turbines and optimize their operations to maintain design conditions
- ✓ Condensing turbines can serve as a system balance mechanism especially, in industries which have significant waste heat steam generation

Source: US DOE BestPractices Steam System Sourcebook