Industrial (Steam)
Steam Turbine

- Steam turbines are one of the oldest prime mover technologies still in use.
- Steam turbines extract heat from steam and transform it into mechanical work by expanding the steam from high pressure to low pressure.
Steam Turbine Characteristics

- Run from <1 MW to 500 MW
- High-pressure steam flows through the turbine blades and turns the turbine shaft
- Steam turbine shaft is connected to an electric generator for producing electricity
- Power output is proportional to the steam pressure drop in the turbine
  - the larger the pressure drop of the steam, the larger the output capacity of the turbine/generator
- No emissions from a steam turbine
  - emissions are from the boilers used to produce the steam
Two Classes of CHP Steam Turbines

- Condensing
  - Fully Condensing
  - Extraction
- Non-Condensing
  (Backpressure)
Condensing Turbine

- Operate with an exhaust pressure less than atmospheric (vacuum pressure)
- Experiences the maximum pressure drop through the turbine which results in greater energy extracted from each lbm of steam input
- Turbine efficiencies approx. 30-40%
- The condenser can be either air or water cooled – condenser cooling water can be utilized for process or space heating loads
- Usually more expensive than Non-Condensing Backpressure turbines
Non-Condensing Turbine (Backpressure)

- Operate with an exhaust equal to or in excess of atmospheric pressure
- Exhaust steam is used for lower pressure steam process loads
- Available in smaller sizes and pass large amounts of steam per MW of output (low efficiencies)
- Produce less useful work than a condensing turbine, but since the unused steam from the turbine is passed on to process loads, the lower turbine power generation efficiencies (15% to 35%) are not a concern
- Very cost effective when paralleled with pressure reduction valves (PRV), providing an efficient use of the pressure reduction requirements
- Usually less costly than condensing turbines
Simple Steam Cycle Turbine System

- Steam
- To Generator or Mechanical Device
- Low Pressure Steam
- Fuel In
- Feedwater
- Pump
- Boiler
- Condenser
# Steam Turbine Rules-of-Thumb

<table>
<thead>
<tr>
<th></th>
<th>Backpressure</th>
<th>Condensing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Generation Efficiency, %</strong></td>
<td>15 - 35</td>
<td>30 - 40</td>
</tr>
<tr>
<td><strong>Steam Exhaust Pressure</strong></td>
<td>At or above atmospheric</td>
<td>Below atmospheric</td>
</tr>
<tr>
<td><strong>Steam Required, lb/h per kW</strong></td>
<td>20 - 100</td>
<td>7 - 10</td>
</tr>
<tr>
<td><strong>Installed Cost, $/kW</strong></td>
<td>300 - 400</td>
<td>500 - 700</td>
</tr>
<tr>
<td><strong>O &amp; M Cost, ¢/kWh</strong></td>
<td>.15 – .35</td>
<td>.15 - .35</td>
</tr>
</tbody>
</table>
Extraction Steam Turbine

- Either condensing or backpressure
- Multi-stage turbines that are designed with one or more outlets to allow intermediate pressure steam (between inlet and exhaust pressures) to be withdrawn for process applications
Extraction Steam Turbine

Steam

To Generator or Mechanical Device

Extraction Steam

To Condenser
When are Steam Turbines Utilized in CHP System…

- Prime Mover – when operated directly by steam generated on-site in a boiler and used to generate electricity through an electric generator

- Thermally Activated Machine – when operated by steam generated by recycling waste thermal energy or by replacing steam pressure reduction valves (PRVs)
Reducing Steam Pressure Wisely

Before

After
Typical Pressure Reduction Station

400-600 psig

To Very High Pressure Steam Loads

125 psig

To High Pressure Steam Loads

400-600 psig

To Low Pressure Steam Loads

15 psig
Applying Backpressure Steam Turbines

- 400-600 psig steam from the boiler is directed to high pressure steam loads.
- 15 psig steam is directed to low pressure steam loads.
# Backpressure Steam Turbine Instead of Pressure Reducing Valve

<table>
<thead>
<tr>
<th></th>
<th>Probably Not Attractive</th>
<th>Probably Attractive</th>
<th>Drop Dead Gorgeous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Flow Rate</td>
<td>&lt;4,000 lbm/h</td>
<td>&gt;4,000 lbm/h</td>
<td>&gt;10,000 lbm/h</td>
</tr>
<tr>
<td>Inlet Pressure</td>
<td>&lt;125 psig</td>
<td>&gt;125 psig</td>
<td>&gt;150 psig</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>&lt;100 psi</td>
<td>&gt;100 psi</td>
<td>&gt;150 psi</td>
</tr>
<tr>
<td>Cost of Electricity</td>
<td>&lt;1.5 ¢/kWh</td>
<td>&gt;1.5 ¢/kWh</td>
<td>&gt;6.0 ¢/kWh</td>
</tr>
<tr>
<td>Capacity Factor</td>
<td>&lt;25%</td>
<td>&gt;25%</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

*Source: TurboSteam*
How Much Power Can Be Developed?
## How Much Power Can Be Developed?

<table>
<thead>
<tr>
<th></th>
<th>Power Available from Backpressure Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inlet Pressure</td>
</tr>
<tr>
<td>2</td>
<td>Outlet Pressure</td>
</tr>
<tr>
<td>3</td>
<td>Steam Usage</td>
</tr>
<tr>
<td>4</td>
<td>Steam Usage</td>
</tr>
<tr>
<td>5</td>
<td>Power Gen Heat Rate</td>
</tr>
<tr>
<td>6</td>
<td>Power Available</td>
</tr>
</tbody>
</table>
How Much Power Can Be Developed?

~ 24 kW/Mlb-hour
## How Much Power Can Be Developed?

### Power Available from Backpressure Turbine

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inlet Pressure</td>
<td>From Owner</td>
<td>600 psig</td>
</tr>
<tr>
<td>2</td>
<td>Outlet Pressure</td>
<td>From Owner</td>
<td>65 psig</td>
</tr>
<tr>
<td>3</td>
<td>Steam Usage</td>
<td>From Owner</td>
<td>40,000 pounds/hour</td>
</tr>
<tr>
<td>4</td>
<td>Steam Usage</td>
<td>Divide Line 3 by 1,000</td>
<td>40 Mlb per hour</td>
</tr>
<tr>
<td>5</td>
<td>Power Gen Heat Rate</td>
<td>Get Value from Chart</td>
<td>24 kW/Mlb-hour</td>
</tr>
<tr>
<td>6</td>
<td>Power Available</td>
<td>Multiply Line 4 by Line 5</td>
<td>960 kW</td>
</tr>
</tbody>
</table>
What are the annual savings experienced by a backpressure steam turbine?

**Assumptions**
- Gen Size: 960 kW
- Hours of Operation: 3,000 hrs
- Average Electricity Cost: 6.0 ¢/kWh
- Backpressure Turbine Installed Cost: $400 /kW
- Backpressure Turbine O&M Cost: 2.5 ¢/kWh
- Standby Charge: $3 /kW

**Calculations**
- Electricity Generated: \((960 \text{ kW}) \times (3,000 \text{ hrs}) = 2,880,000 \text{ kWh}\)
- Electricity Generated: \((2,880,000 \text{ kWh}) \times (6.0 \text{ ¢/kWh}) = 172,800 \text{ $}\)
- O&M Charges: \((2,880,000 \text{ kWh}) \times (0.25 \text{ ¢/kWh}) = 7,200 \text{ $}\)
- Standby Charges: \((960 \text{ kW}) \times ($3/kW) \times (12 \text{ months}) = 34,560 \text{ $}\)
- Annual Savings: \((172,800) - (7,200) - (34,560) = 131,040 \text{ $}\)
- Installed Costs: \((960 \text{ kW}) \times ($400/kW) = 384,000 \text{ $}\)
- Simple Payback: \((384,000) / (100,800) = 2.9 \text{ years}\)
Steam Turbine Summary

- If a facility is utilizing a Pressure Reducing Valve (PRV) to reduce steam pressure, a backpressure steam turbine can be substituted in using “free fuel” (steam) to reduce the steam pressure and generate electricity simultaneously.
- One of the more easily applied CHP technologies.
- Relatively short paybacks.