Name ____________________

Standards and Objectives

| TN Social Studies Standards: | Students will: |
| --- | --- |
| Industrial Revolution 1750-1914<br>W.7 Explain the connections among natural resources, entrepreneurship, labor, and capital in an industrial economy including the reasons why the Industrial Revolution began in England.<br>W.10 Explain how scientific and technological changes and new forms of energy brought about massive social, economic, and cultural demographic changes including the inventions and discoveries of James Watt, Eli Whitney, Henry Bessemer, Louis Pasteur, and Thomas Edison.<br>W.12 Participate effectively in collaborative discussions explaining the vast increases in productivity and wealth, growth of a middle class, and general rise in the standard of living and life span. (C, E) | • Represent members of the Lunar Society (Birmingham, England) in group work.<br>• Write and record voiceovers to a video, discussing interactions among manufacturing, engineering, and the developing middle class from various perspectives |
| **TN Math Standards:** | **Students will:** |
| MP 1. Make sense of problems and persevere in solving them.<br>MP 4. Model with mathematics.<br>*Algebra 1:*<br>N-Q 1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.<br>N-Q 2. Define appropriate quantities for the purpose of descriptive modeling.<br>A-CED 4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. *For example, rearrange Ohm's law V=IR to highlight resistance R.*<br>S 7. Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.<br>*Geometry:*<br>G-MG 2 Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot). | • Estimate work in foot-pounds performed by a team of 2 horses applying a variable force over a displacement by using areas under a graph.<br>• Convert foot-pounds into horsepower and estimate the cost to a consumer of adopting Boulton and Watt's steam engine.<br>• Model energy and labor costs as industry converted to steam engines. |
| **TN Science Standards** | **Students will:** |
| *Physical World Concepts:*<br>CLE 3237.T/E.1 Explore the impact of technology on social, political, and economic systems.<br>CLE 3237.T/E.4 Describe the dynamic interplay among science, | • Use units analysis and areas to create a graphic representation of understandings of power. |

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| technology, and engineering within living, earth-space, and physical systems.<br>√3237.Math.16 Use concepts of length, area, and volume to estimate and solve real-world problems.<br>CLE 3237.1.3 Differentiate among work, energy, and power. | • Write on correlations between energy costs, labor costs, and industrial scale application of technology.. |

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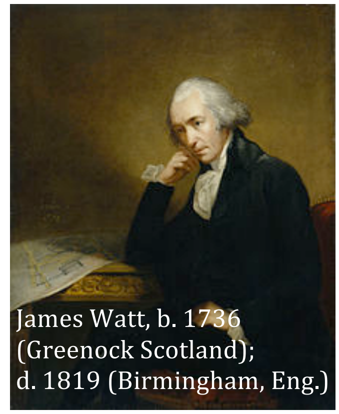
## James Watt's Steam Engine



James Watt, b. 1736 (Greenock Scotland);
d. 1819 (Birmingham, Eng.)

James Watt was born on the east coast of Scotland in 1736. In 1757, the famous moral philosopher and economist, Adam Smith, helped Watt to get a job as an instrument-maker at the University of Glasgow and the two became friends.

In 1775, instrument-maker and engineer James Watt and his business partner Matthew Boulton began producing Watt's innovative steam engines at Boulton's Foundry near Birmingham, England. Boulton and Watt used a novel pricing strategy for their invention. Miners were granted licenses to use the engines in exchange for one third of their savings in coal.

1. How might Adam Smith have explained Watt's success in convincing English manufacturers to switch from human power to steam power? Figure 2 shows the price of energy in various world cities in the 1700s, while Figure 3 shows the price of labor. Use evidence from the figures and what you know about Adam Smith's philosophy to support your argument.

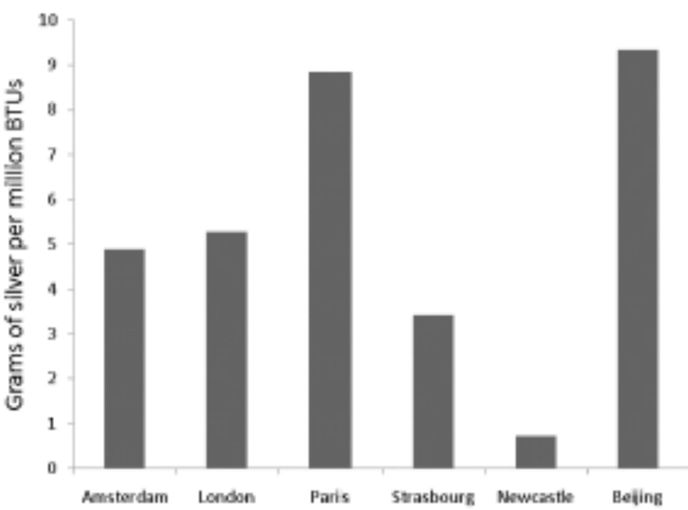



Figure 2: The price of energy, early 1700s

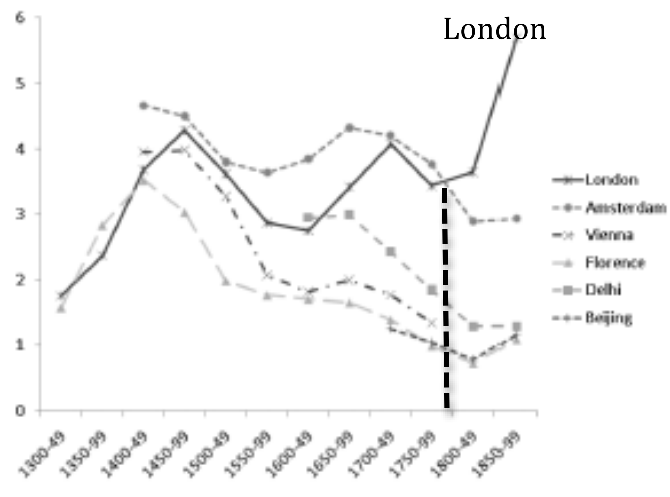



Figure 3: Real wages of labourers

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[1] Allen, R.C. (2009). Why was the industrial revolution British?. *The Oxonomics Society*. Wiley-Blackwell.

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2. “Carrying Coals to Newcastle” was an old British phrase, describing a foolish move. Use evidence from figure 2, above, to explain why it would be foolish to bring coal to Newcastle in the 1700s.

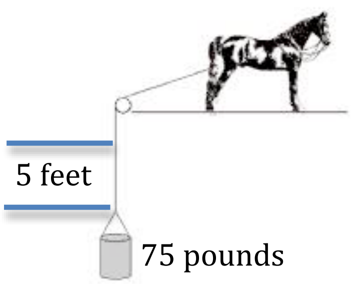

For advanced students:

Statisticians often distinguish between correlation and causation. Prior to the release of Watt’s steam engine, London and Amsterdam’s labor costs were similar. After Watt’s invention, London’s labor costs pulled away from Amsterdam’s. The timing of the release of Watt’s steam engine correlates with this labor trend. Watt’s invention might have been predicted to cut labor costs, as demand for labor decreased. What explanations might you offer for the surprising growth in labor costs?

## James Watt and Horsepower

To help potential customers to make sense of the change to steam engines, Watt had measured his engine's power in terms customers could understand: *horsepower*.

***Force (Effort) and Work***




Effort and work are not the same.

Effort is the force exerted by the horse.

Work is involves both the force and how far it is applied:

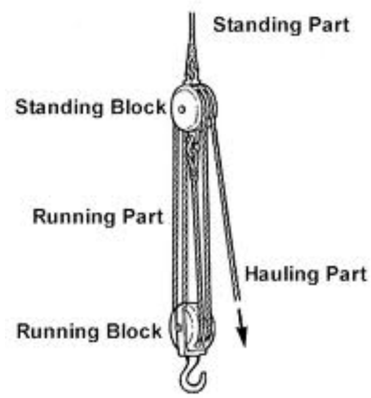
***Work = (force)(distance)***

If this horse lifts the load 5 feet, the work (or energy) applied is:

(75 pounds)(5 feet) = 375 foot-pounds.

***Foot-pounds are units of work.***

Suppose a horse needs to lift a load of 22,000 pounds a distance of 1 foot. A horse cannot apply a force of 22,000 pounds. A simple machine, like a block and tackle pulley system, allows the horse to exert less effort over a longer distance to do the same work:




If the horse walks forward to pull out 100 feet of rope while lifting the load, the horse will do the same work with less effort. Solve the following equation to determine the force the horse would have to apply using the simple machine:

1. 22,000 foot-pounds = (__________ lb)(100 feet)

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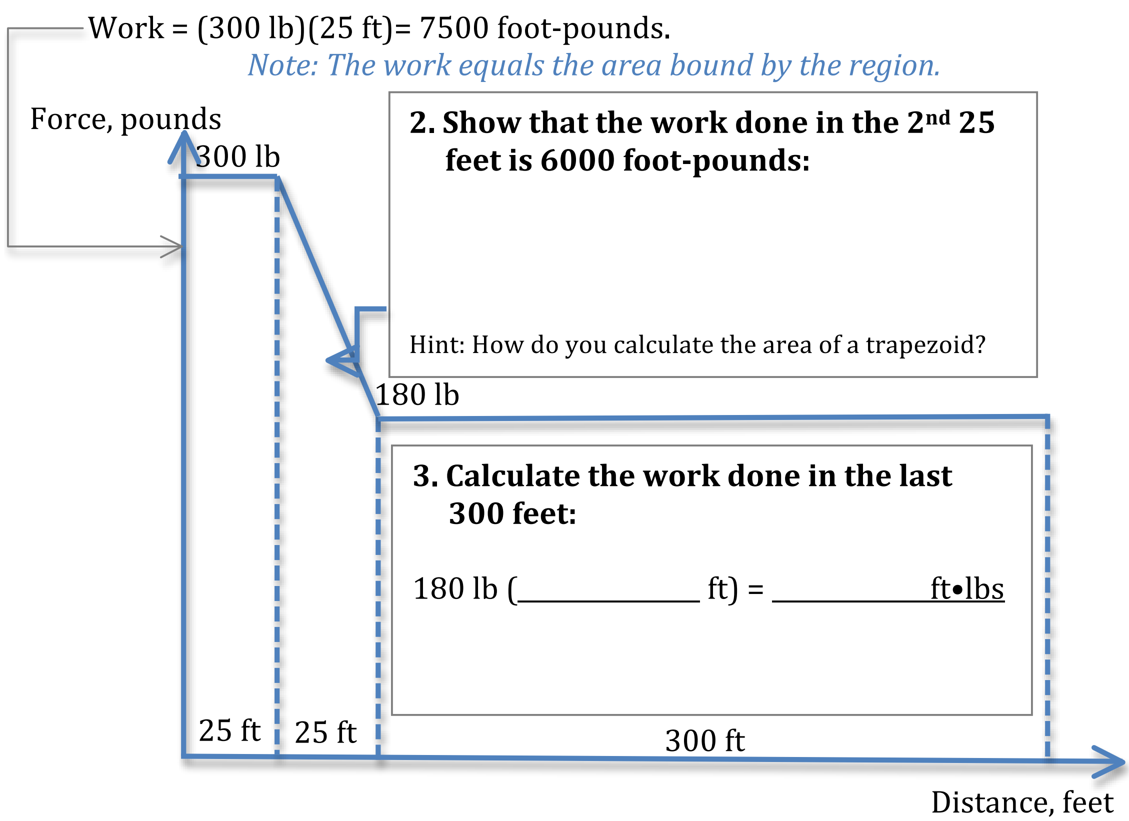
***Work (Energy) and Power***

How much force can a horse exert over the long haul? A horse may start with a surge of effort. Suppose that the horse exerted 300 pound for the first 25 feet.




**4. Total work = 7500 ft-lbs + 6000 ft-lbs + __________ ft-lbs = __________________**

Suppose the horse took 3 minutes to do this work.

***Given: The average Power is the average rate of work in foot-pounds/minute.***

**5. Average Power = Total Work/Total Time = _____________ foot•pounds/min.**

Expert opinions on how much power horses could sustain over time:

- Smeaton estimated that a pony could generate 22,916 foot-pounds/min[2]. Ponies were often used in coal mines.
- Desaguliers estimated about 27,500 foot-pounds/min.

[2] Kirby, R. S. (1956/1990). *Engineering in History*. McGraw Hill: New York.

James Watt observed that a brewery horse turned a mill wheel ***12 feet in radius*** about ***2.4 times each minute***.

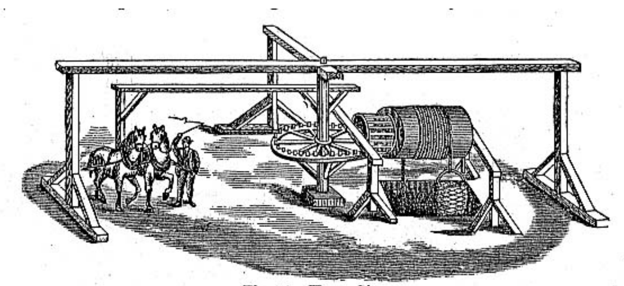


Fig. 14. Horse-Gin.

Photo retrieved September 17, 2014 from http://www.scottishmining.co.uk/barrowfig14.jpg

**6. Calculate the distance the horse walked in a minute.**

Hint: How do you calculate the length of each of the 2.4 circumferences?

Watt estimated that the amount of force a brewery horse could exert over time was about 180 pounds.

Thus, he calculated 1 horsepower to be just under 33,000 foot-pounds/min.

(180 pounds)( distance walked ft/min.)~33,000 foot-pounds/min

In 1783, Boulton and Watt defined the horsepower as 33,000 foot-pounds/min.

**7. Given:** ***min sec , m . ft , pound . Newtons***

a.) Convert *33,000 foot•pounds min* to *foot•pounds sec*

b.) Convert your value for *foot•pounds sec* to *meter•pounds sec*

c.) Convert your value for *meter•pounds sec* to *Newton•meter sec*.

Notes:

- 1 Newton•meter = 1 Joule, so 1 *Newton•meter sec* = 1 *Joule sec*
- 1 *Joule sec* is defined to be 1 Watt.
- So 746 Watts = 1 horsepower.

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7. Scaffolded:

$$33{,}000\, foot \bullet poundsmin \bullet 1min60seconds = 550\ foot \bullet poundssec$$

1 meter = 3.28 feet:

$$550\ foot \bullet poundssec \bullet 1meter3.28\, foot = 167.68 meter \bullet poundssec$$

1 pound = 4.449 Newtons:

$$167.68\, meter \bullet poundssec \bullet \qquad = \qquad Newton \bullet metersec$$

To honor the Scottish engineer, the metric unit for power, the Newton•meter/sec, is named the Watt.

Thus, 1 horsepower = 746 Watts.

**8. How much energy (in Joules) can be saved over 1000 hours by burning a 20 W bulb instead of a 60 W bulb?**