1. **The Empire of Steam**

2. **Steam Engine**
   - Greatest technological symbol of the Industrial Revolution

3. **First important technology seen as a product of science**
   - Improvement of steam engines fostered scientific investigation and new forms of engineering

4. **The key power technology of industrialization**
   - Water used more widely at first
   - Steam removed constraints
   - Steam revolutionized transport

5. **The Factory System:**
   - Power technologies important in the factory context
   - Factories concentrate capital, labor, and materials
     - Allow larger scale of production
     - Make maximum use of power and machinery
     - Allow more control over labor and materials

6. **Water Power**
   - Water wheel the most used power source in early factories
   - Great range of uses
   - Large scale factory power systems in late 18th century
   - Improving water power

7. **John Smeaton**
   - Measuring efficiency of water wheel designs
   - Overshot wheels judged the most efficient (greatest power for the size of wheel or amount of water)
   - A model of engineering research

8. **Steam Power**
   - Two ways to get work from steam
     - **Expansion**
       - The most obvious to us, and the key to modern turbines.
     - **Displacement & condensation**
       - The historically key means, since it was behind the first practical steam engines.

9. **Science of the atmosphere**
   - The atmosphere presses down everywhere with a force of about 14 lbs. per sq. inch. How to make this force do work.

10. **Torricelli (barometer)**
von Guericke (power of vacuum)

Pascal (atmospheric pressure)

Boyle (air pump)

The Problem of mines
- Some special needs for work—mining and the problem of flooding.
- Importance of coal (wood shortages, availability in Britain)
- Depth of mines as surface supplies run down

Thomas Savery’s “Miner’s Friend” (1698)
- No moving parts
- Not self-acting
- Used enormous amounts of fuel
- Very dangerous (required pressures of 8-10 atmospheres to expel water)

Thomas Newcomen’s “Atmospheric Engine” (about 1712)
- Good only for pumping (single, down action)
- Also used much fuel
  - BUT—self-acting, could be made quite large

The Newcomen Engine

Newcomen scale

James Watt
- Instrument maker
- Working with models
- Observed inefficiencies in Newcomen engine
- Measurement & analysis

Newcomen problems
- Working with models
- The problem of scale

Analytical approaches
- Heat is lost
  - BUT—How much heat?
    - Experiments & measurements
    - “Latent heat” & scientific theory
  - Designing an alternative
23  Watt's separate condenser

24  Boulton & Watt engine
  ▶ Separate condenser
  ▶ Double action
  ▶ Fly-ball governor
  ▶ Rotary motion (sun-and-planet)

25  A New Model of Power
  ▶ The Watt steam engine was typically a very large machine--it was not very effective in smaller sizes
  ▶ The Watt engine was expensive, but slowly became an important power source where water power was unavailable or inadequate
  ▶ The Watt engine became the most important model of new machinery for the 19th century

26  Further development of steam power
  ▶ High pressure steam engines appear at the end of the 18th century
    ▶ Richard Trevithick in England
    ▶ Oliver Evans in the United States
  ▶ High pressure engines were less efficient in fuel but could be made much smaller than low pressure (Watt) engines
  ▶ These became the basis for new transportation form in the 19th century

27  Question:
  ▶ How does the development of the steam engine in the 18th century reflect new relationships between science and technology?