Here is a study guide on solar energy, drawing on the provided sources:

Study Guide - How do wind turbines work

The Rise of Solar Energy: From Expensive to Cheapest

- **Definition and Current Status**: Solar energy is clean energy from the Sun that has become the **cheapest way to generate electricity**, even cheaper than coal. Despite this, it currently only produces **3% of the world's electricity**.
- **Price Drop Over Time**:
    - In 2005, a solar panel cost about **$4 a watt**.
    - Today, that same watt costs about **20 cents**.
    - This dramatic price drop has occurred over the last 15 years, with even more impressive reductions looking further back in time.
- **Key Drivers of Cost Reduction**:
    - **US Innovation**: The modern-day solar cell, made from silicon, was **invented in the US in 1954**. Initially, it was mainly used in the space industry and was very expensive.
    - **German Policy**: In 2000, Germany passed a law to boost renewable energy development. This law fixed the price for energy generated from sources like wind or solar, providing an **incentive for people and companies to install solar panels**.
    - **Chinese Manufacturing**: After the German law, **China built a whole industry for solar cells on a massive scale**, becoming the biggest producer of solar panels, accounting for about **70% of the world's production**today. China was almost a non-existent player 20 years ago.
    - **Global Collaboration**: No single country was responsible for this price drop; it was an exchange of one country building on another's efforts.

2. The "Duck Curve" Problem: Solar's Main Challenge

- **Solar's Intermittency**: The primary problem with solar energy is that it **only works when the sun is shining**. When it's cloudy or dark, solar cells are largely useless, which is problematic because demand is often highest when the sun isn't available.
- **Understanding Energy Demand (The Duck Curve)**:
    - The "duck curve" charts the **demand for power from non-renewable sources** (like coal and gas) throughout the day.
    - **In places without much solar**, demand spikes in the morning, stays level, rises again in the evening when people come home, and then drops at night.
    - **In places with lots of solar (e.g., California)**, the curve changes:
        - Morning demand is similar.
        - As the sun rises, solar energy production increases, causing the **demand for non-renewable energy to drop significantly**.
        - However, when the sun sets, conventional demand **shoots up again, much steeper** than in areas without high solar penetration. This shape resembles a duck.

- **Problems Caused by the Duck Curve**:
    - **Traditional Power Plants Struggle**: Conventional power plants are not good at **ramping up quickly** to meet the steep evening demand. This means they must be kept running at a certain output all day, even when solar is abundant.
    - **Excess Production and Curtailment**: This can lead to **more power being produced in the middle of the day than is used**. There are limits to how much energy the grid can handle, so too much solar can overpower it and needs to be **"thrown away"** (curtailed).

3. Solutions to the Storage Problem

- **Lithium-Ion Batteries (Primary Solution)**:
    - **Availability**: Lithium-ion batteries are a widely available solution, likely already in many devices you use.
    - **Application**: They can be scaled up to create battery packs for cars, and even larger stationary power storage systems for wind parks or solar farms.
    - **Cost Reduction**: These batteries have become **much cheaper and better than expected** in recent years.
    - **Functionality**: They are now a **viable option for storing and shifting at least a few hours' worth of solar energy** from the middle of the day to the evening peak demand.
    - **Real-world Example**: New Mexico in the US plans to shut down a coal plant and build new solar farms with large battery storage.
    - **Dominance**: They are becoming so flexible and inexpensive that it will be hard for other alternatives to compete for most applications.
- **Alternative Storage Solutions**: While lithium-ion batteries are leading, other options exist for longer-term storage or specific applications:
    - **Flow Batteries**:
        - Separate the charge outside a cell.
        - Advantages: Can **store more energy and for longer** periods.
        - Disadvantage: Still **relatively expensive**.
    - **Pumped Hydro Storage**:
        - Mechanism: Uses solar energy to pump water from a lower lake to a higher lake in a hill during the day; at night, water runs down through a turbine to generate energy.
        - Current Use: Already used quite a bit.
        - Requirement: Needs **two lakes and a hill**.
    - **Gravity-Based Storage (Swiss Company)**:
        - Mechanism: A tower raises building blocks with solar energy and releases energy by lowering them again.
        - Requirement: Needs **space**.
    - **Hydrogen Production**:
        - Mechanism: Uses solar energy to produce hydrogen.
        - Applications: Hydrogen can then be used to fuel cars or even make steel.
        - Disadvantage: The **entire process is still costly**.

    - **Role of Alternatives**: These alternatives might hold a charge longer and play an important role in specific applications where lithium-ion batteries may not be ideal.

4. Future Outlook for Solar Energy

- **Expected Growth**: Solar is projected to be "big" and "everywhere".
- **Forecasts**:
    - Even without further policy changes, solar is forecast to supply about **23% of global electricity by 2050**.
    - Some experts believe it could be much higher, with solar potentially doing a large part of the world's electricity supply by **2030**.
- **"Time to Shine"**: Now that the technology is in place and the biggest problems (cost and storage) are largely addressed, solar energy looks ready to significantly expand its role.