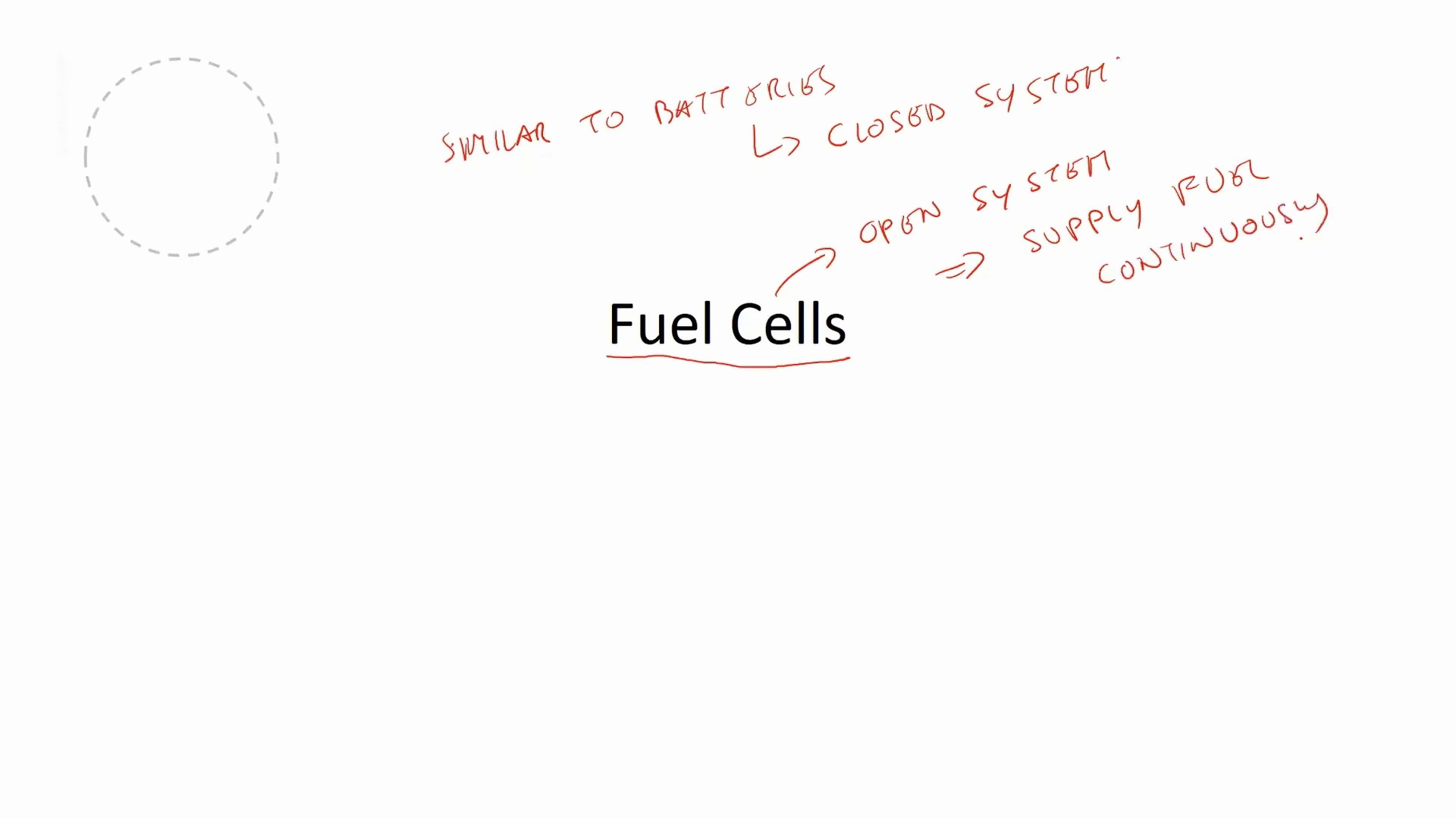
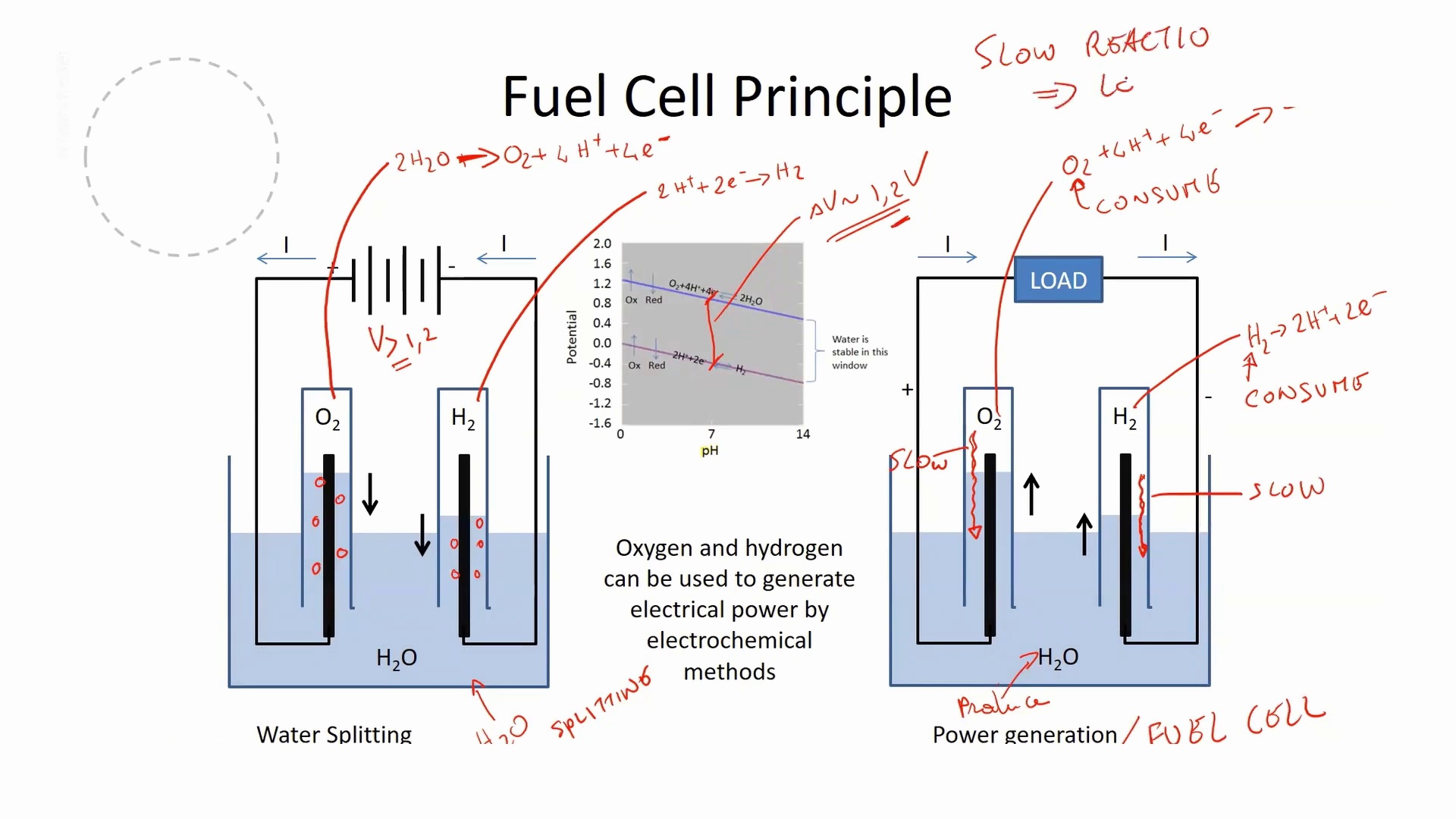
## Slide 1



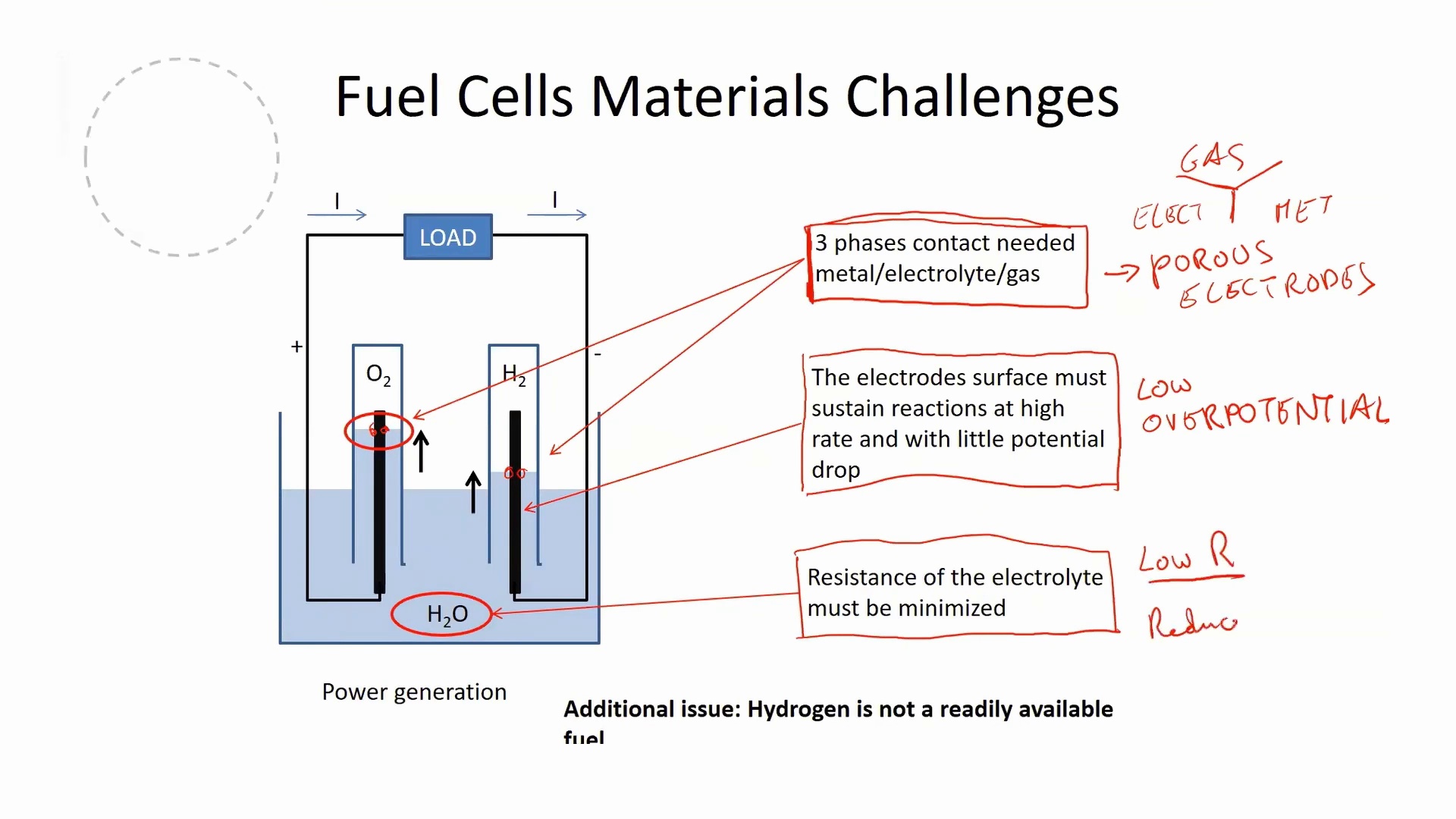
Today, we begin a new chapter focusing on fuel cells. Fuel cells possess similarities to batteries in that both systems can be utilized to generate electricity. However, there are critical distinctions between the two. In batteries, the anodic and cathodic materials are contained within the closed system of the device, limiting the reactants to those initially provided. In contrast, fuel cells function as open systems, allowing for the continuous supply of reactants—specifically, the fuels involved in the anodic and cathodic reactions—from external sources. This fundamental difference enables fuel cells to produce electricity as long as fuel is supplied. The underlying principle governing the operation of a fuel cell is conceptually straightforward and will be elucidated with reference to the accompanying slide.

## Slide 2



On the left side of the slide, an electrochemical cell is depicted, commonly encountered in previous coursework and utilized for the process of water splitting. In this configuration, two electrodes are immersed in separate but connected cylinders, both open at the bottom and containing an electrolyte. Upon application of a sufficient voltage difference between the electrodes, water undergoes electrolysis, resulting in its decomposition into molecular oxygen and hydrogen. This process is driven by the applied potential difference.  
  
Referring to the Pourbaix diagram of water, as previously discussed and illustrated on the slide, the minimum potential required to drive water splitting is slightly greater than one point two volts. When this voltage is applied, the electrode attached to the positive terminal of the power supply (the anode) facilitates the evolution of oxygen through the anodic reaction, while the electrode linked to the negative terminal (the cathode) generates hydrogen via the cathodic reaction.  
  
The process is, in principle, reversible. On the right side of the slide, the reverse scenario is envisioned: one cylinder is filled with pure oxygen, and the other with pure hydrogen. In this arrangement, two inert electrodes are placed within the respective cylinders. The electrode in the oxygen compartment enables the reduction of oxygen to water, whereas the electrode in the hydrogen compartment supports the oxidation of hydrogen, also forming water. Under these conditions, the theoretical cell voltage should be approximately one point two volts.  
  
Empirically, this theoretical value can be observed at the laboratory scale. For example, when platinum electrodes are employed and the open-circuit potential between the two electrodes is measured—without extracting current from the cell—a value close to one point two volts is typically obtained. However, there are significant practical limitations to utilizing this system for electrical energy generation. Although the theoretical voltage is achieved under open-circuit conditions, the rates of both the oxygen reduction and hydrogen oxidation reactions are exceedingly slow in practice.  
  
The primary limitation arises from the diffusion of oxygen from the gas phase into the liquid electrolyte and its subsequent reaction at the electrode surface. This diffusion step significantly retards the overall reaction kinetics, resulting in a very low attainable current, as described by Faraday’s laws. Moreover, the majority of the electrochemical current is generated predominantly in regions where the electrode surface, the gas phase, and the electrolyte are in simultaneous contact, known as triple-phase boundaries. Consequently, this configuration is not a practical or efficient approach for fuel cell applications.

## Slide 3



The principal material challenges in the design and construction of fuel cells, as informed by fundamental electrochemical principles, are as follows. From a practical perspective, it has been established that electrochemical reactions proceed most efficiently at sites where gas, electrolyte solution, and metal are all in simultaneous contact. Accordingly, the development of a viable fuel cell requires the engineering of materials that provide an extensive surface area or a high density of sites at which this three-phase contact can occur. This necessitates the use of porous materials that can accommodate both gas and electrolyte in distinct but adjacent regions, thereby sustaining the necessary interfaces for reaction.  
  
Furthermore, the material must ensure adequate contact with the electrolyte, facilitating the free movement of ions generated during the electrochemical processes. In addition to morphological considerations, the selection of electrode materials is critical. These materials must effectively catalyze the relevant reactions—specifically, the oxidation of hydrogen and the reduction of oxygen—at rates sufficient to support practical operation. Importantly, these reactions must proceed with minimal overpotential, as excessive overpotential would result in undesirable energy losses and reduced cell efficiency.  
  
Finally, it is essential to minimize the ohmic resistance of the electrolyte. High resistance within the electrolyte would contribute to additional potential drops within the cell, thus further diminishing the net energy output achievable from the fuel cell reactions. Therefore, the choice and configuration of materials must address both catalytic efficiency and the reduction of resistive losses to optimize overall fuel cell performance.