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High Efficiency Solar Thermochemical Reactor for Hydrogen Production

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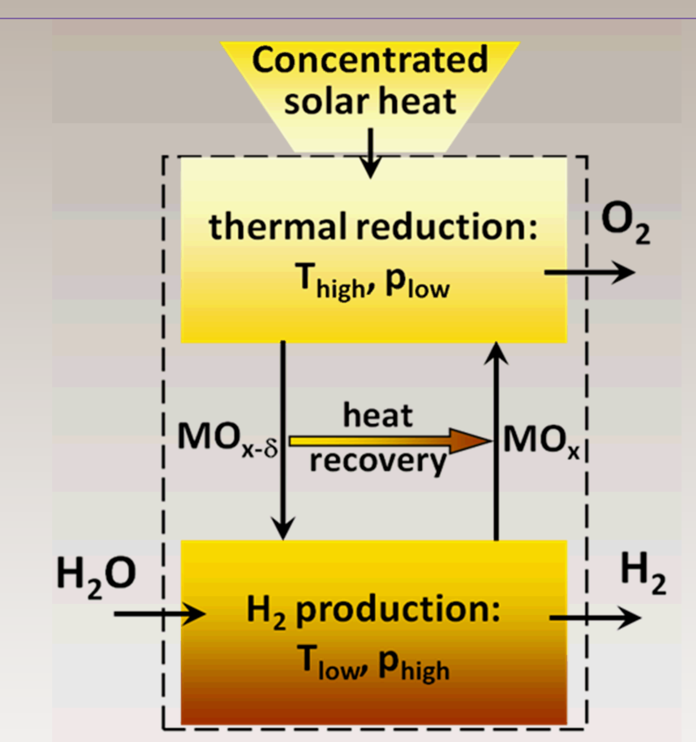
Abstract: The purpose of this project is to design, fabricate, and demonstrate a 3 kW-scale reactor prototype for splitting water via a solar thermochemical (STC) cycle using Sandia's patented cascading pressure receiver reactor (CPR2) technology. Key components of the CPR2 developed here are the reactor control system, data acquisition system, and data visualization tools. A LabVIEW program formed the basis of a complex DAQ interface that enables computer control of the reactor and provides a large data stream to visualization models written in MATLAB.

Introduction: The use of H_2 as a carbon-free energy carrier has been proposed to reverse the impacts of CO_2 on the Earth climate system, and provide renewable energy for all humanity. Water is the most abundant source of hydrogen on Earth; however, cost-competitive water splitting technologies must be developed to displace fossil fuels. Sandia's CPR2 concept exploits a simple two-step thermochemical cycle with water and solar thermal energy as the only feedstock. Metal oxide particles are first reduced in thermal reduction (TR) chambers at 1500°C, and O_2 is released. High process temperatures are provided by solar simulators, though concentrated solar power will be used at scale. The reduced oxide is then cooled to 800°C and exposed to H_2O in the water splitting (WS) chamber. The reaction produces H_2 and returns the oxide back to its initial state. The success of this renewable H_2 production process is contingent upon the incorporation of suitable redox active materials with an efficient solar reactor.

Two-step STC Cycle



$$MO_x \rightarrow MO_{x-\delta} + \frac{\delta}{2} O_2 \quad \text{(1) Reduction}$$

$$MO_{x-\delta} + \delta \cdot H_2O \rightarrow MO_x + \delta \cdot H_2 \quad \text{(2) Oxidation}$$

$$\delta \cdot H_2O \rightarrow \frac{\delta}{2} O_2 + \delta \cdot H_2 \quad \text{(3) Thermolysis}$$

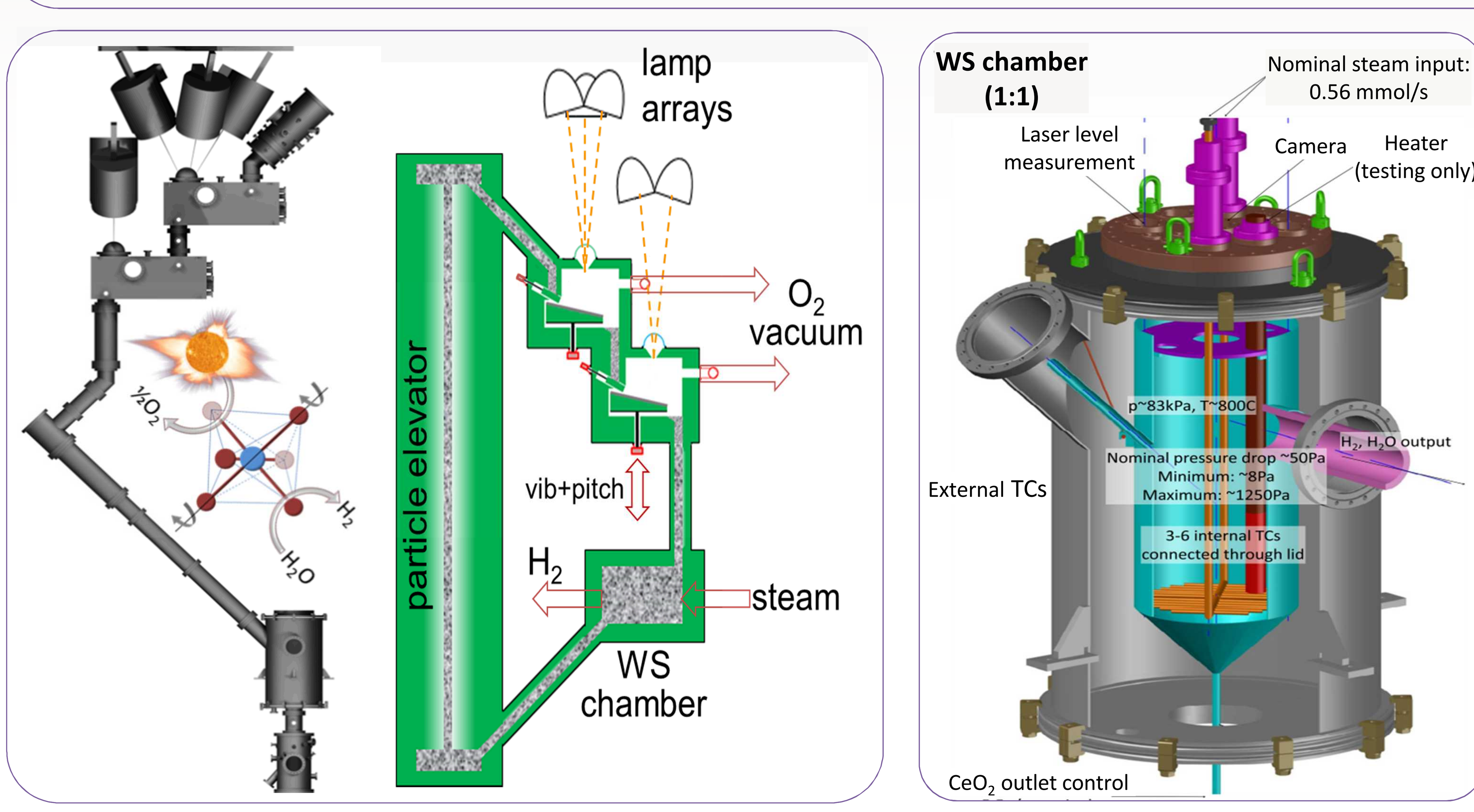


Figure 1: Schematic of CPR2 (left) and WS chamber (right)

Methods: LabVIEW's graphical programming language was used to integrate data acquisition hardware with CPR2 components. A simple user interface panel was designed to virtually control solar simulator power, steam mass flow rate, solenoid valve states, chamber backpressures, etc., using a combination of analog and digital signals that read from and write to various hardware devices. Data inputs reflecting process variable states, such as H_2 mass flow rate and reactor temperature, are returned to the LabVIEW program. Multiplexer circuits and USB devices were utilized in order to consolidate ~100 different thermocouple readings. A sensor fusion strategy was also developed using MATLAB to provide a more useful visualization of the acquired temperature data by mapping interpolated values onto a real-space, 3D rendering of main CPR2 components.

Results & Discussion: In addition to a user control system, the LabVIEW program presents real-time, streaming data. A display panel consists of the thermocouple measurements and waveform graphs with flowrates, pressure readings, and hydrogen concentration. The MATLAB program constructs a 3D temperature map of TR and WS chambers based on real-space thermocouple positions and their corresponding logged temperatures. These programs will be integrated with the reactor upon completion of the CPR2 prototype assembly. Subsequent tests will validate design and functionality of the reactor, as well as benchmark solar-to-hydrogen conversion efficiency. Information gained from running the CPR2 will inform techno-economic analysis for a large-scale H_2 production facility that will explore pathways to commercialization.

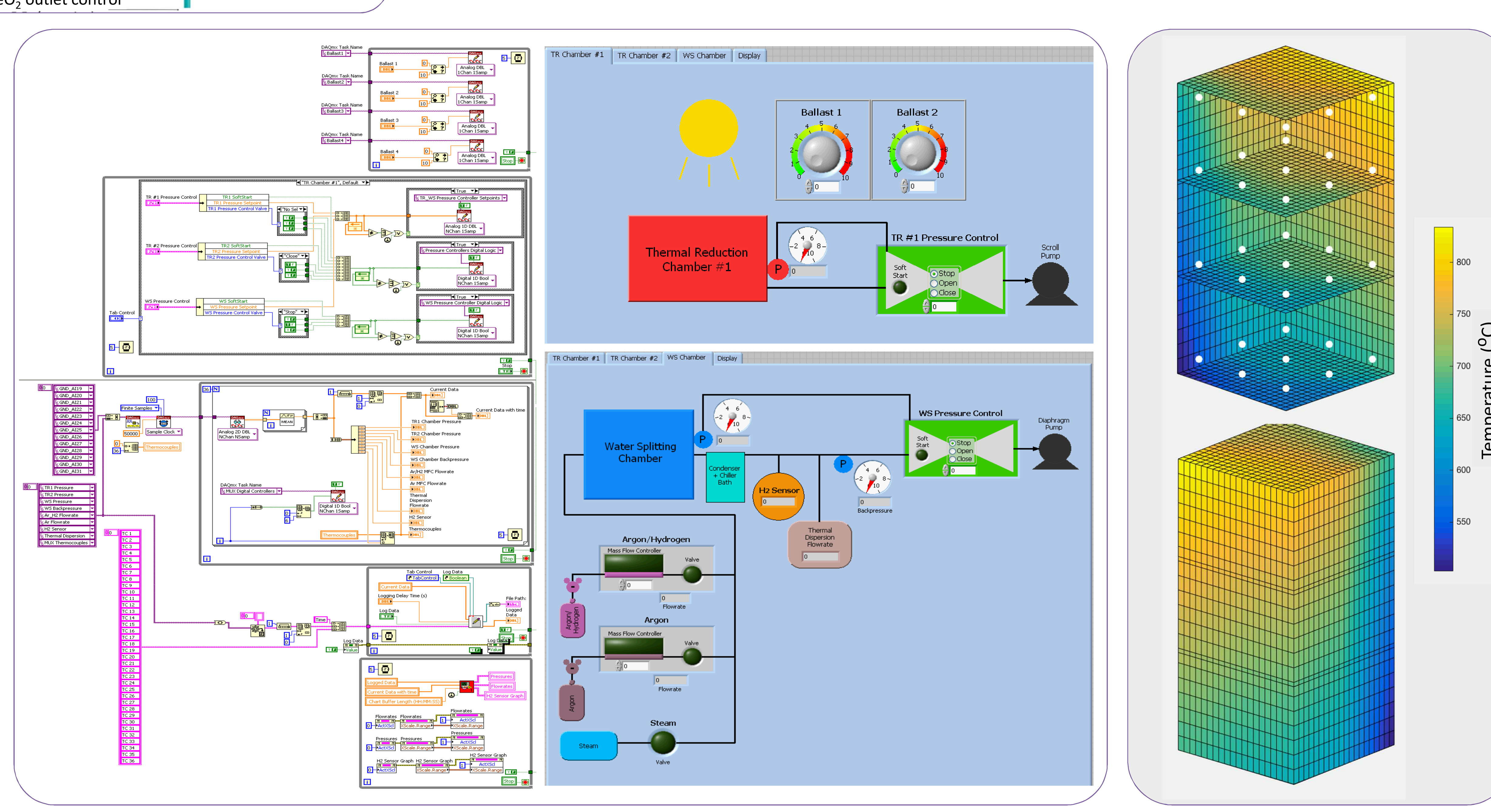


Figure 2: Segment of LabVIEW code and sample panels (left) and MATLAB visualization of TR chamber (right)

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