SUPPLEMENTAL MATERIAL

Pilot-scale ItCAES

Two prototypes for testing the ItCAES were built: a one-stage, and a two-stage compression/expansion. In both cases the electric motor and generator were combined in one single reversible unit. Therefore, each of the two systems was perfectly reversible, acting as both compressor and expander, able to consume and generate electricity, respectively.

All the hydraulic cylinders in both prototypes were double-acting. The first prototype contained two two-stage compressor/expander units. The schematics of each two-stage unit is shown schematically in Fig. S1. The variable speed electric gearmotor/generator had a maximum power of 20 HP (K107 DRE180L4/TF, SEW Eurodrive, Bruchsal, Germany) and was controlled by MC07B0220-503-4-00/FSC11B (SEW Eurodrive, Bruchsal, Germany). The first stage hydraulic cylinders had a bore of 20 cm and a stroke of 50 cm (Parker Hannifin, Cleveland, OH, USA). The first stage compression/expansion vessels were steel cylinders having an inner diameter of 20 cm and a length of 1.14 m. The second stage hydraulic cylinders had a bore of 5 cm and a stroke of 50 cm (Parker Hannifin, Cleveland, OH, USA). They were connected to C/E vessels having an inner diameter of 5 cm and a length of 1.14 m. Both first- and second-stage C/E vessels had inside a nitrile rubber sleeve, fitting the inner diameter of the vessel. The rubber sleeves separated the hydraulic fluid at the inside from the compressing/expanding air at the outside of the sleeve (Fig. 3 in the main text). One layer of a stainless steel mesh with openings of 0.04 mm and wire diameter of 0.03 mm (McMaster-Carr, Elmhurst, IL, USA) placed between the rubber sleeve and the inner vessel wall was used as an extended heat transfer element inside each C/E vessel. No extended heat transfer elements were used outside of the C/E vessels. A photograph of the system is shown in Fig. S2.

The second ItCAES prototype was a single-stage compressor/expander system, shown schematically in Figs. S3 and S4. The variable speed electric gearmotor/generator was DRN132M4/FG/TF FLG MNTD, SEW Eurodrive, Bruchsal, Germany) with controller MC07B0220-503-4-00/FSC11B (SEW Eurodrive, Bruchsal, Germany). The system contained 7 double-acting hydraulic cylinders with a bore of 8.12 cm and a stroke of 50 cm, equipped with low-friction PTFE seals (Parker Hannifin, Cleveland, OH, USA). Each side of the hydraulic cylinders was connected to a custom-made steel compression/expansion vessel (14 in total) having an ID of 10.8 cm cm and a length of 1.02 m. The internals of the C/E vessels were the same as described above. A photograph of the unit is shown in Fig. S5.

The compressed air storage vessels were 11 K-size industrial high-pressure cylinders (49 L geometrical volume each) connected together.

Experimental

One of the most important parameters in this study is the isothermal efficiency, calculated using Eq. 5. Fig. 4 in the main text shows the change of the compressed air temperature in time at the exit of the compression vessels (the average of all 14) in the one-stage ItC/E. These results were obtained at an intake air flow rate of 6.2 L/s (STP) and a final pressure of 33 bar in the one-stage compression system.

Temperature difference between the compressing air and the surroundings was also measured in the two-stage ItC/E. When compressing 6.4 L/s air to 145 bar, the temperature of the compressed air leaving the first stage C/E vessel was less than 1°C above that of the ambient air, while the maximum temperature in the air leaving the second stage was between 3 and 4°C above the ambient, corresponding to 99% isothermal efficiency.

In the future commercial units, it is expected that the largest energy loss in the entire ItC/E system will be in the electric motor/generator which can be as low as 4%. The losses due to the mechanical energy transmission between the motor/generator and the C/E vessel are expected to be below 2%. The lowest losses in the system are expected to be in the process of compression and expansion, as reported above. Therefore, the overall energy efficiency of the entire compressor or expander is expected to be around 92%, and therefore, in the process of compression/expansion the roundtrip efficiency is expected to be above 85%.

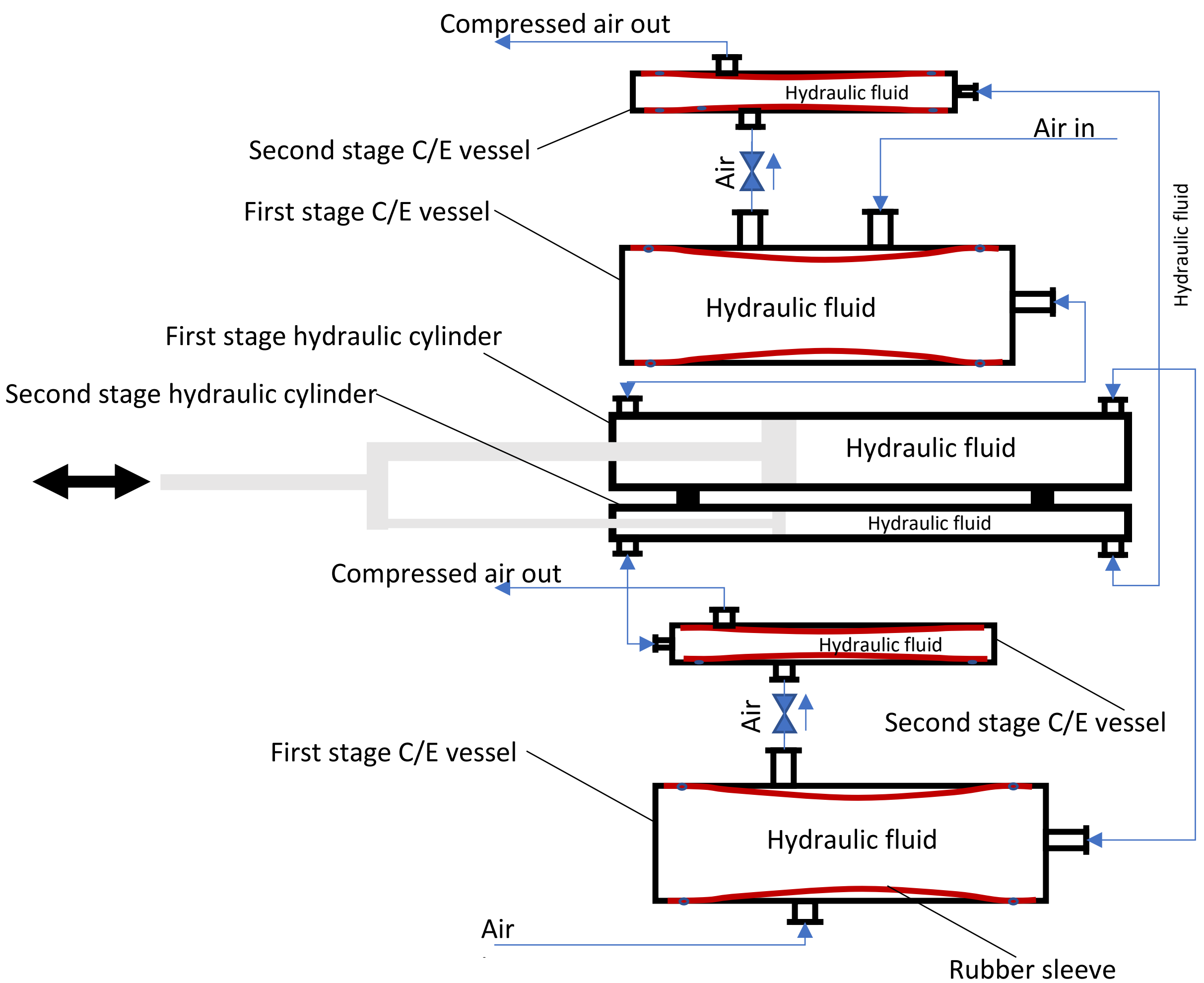

Fig. S1. Schematics of the two-stage compressor/expander.

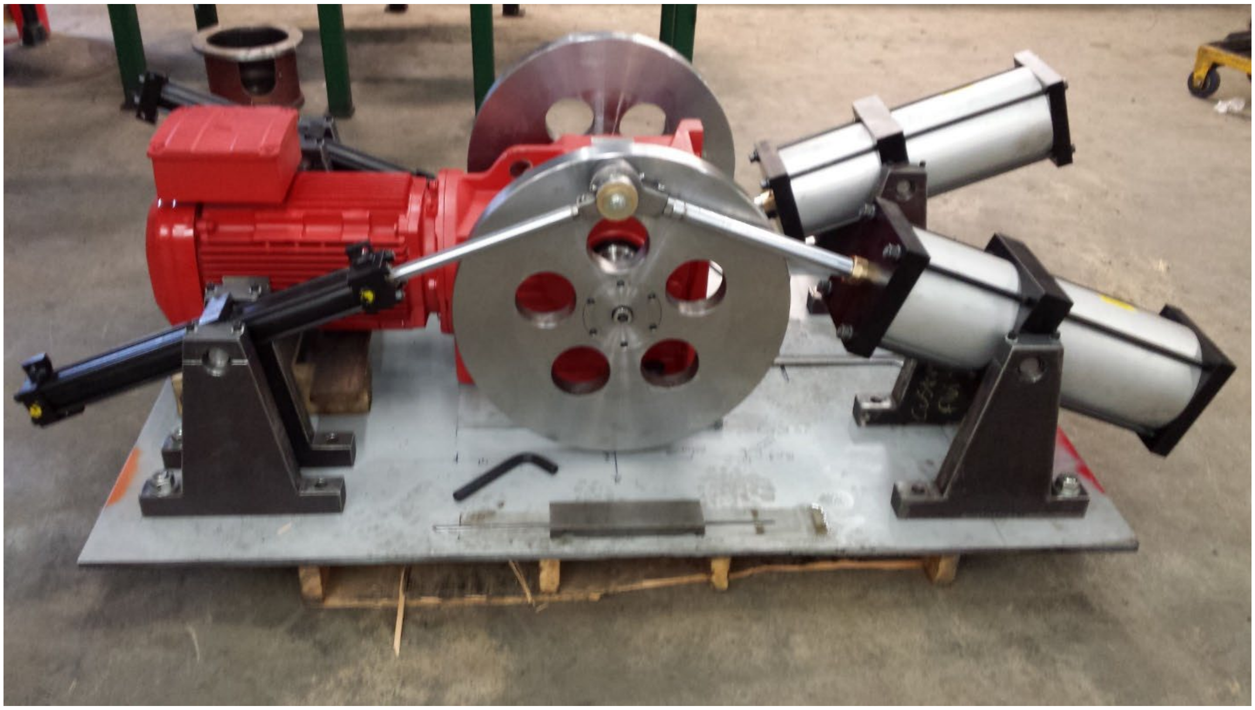

Fig. S2. Photograph of the two-stage compressor/expander (C/E vessels not attached).

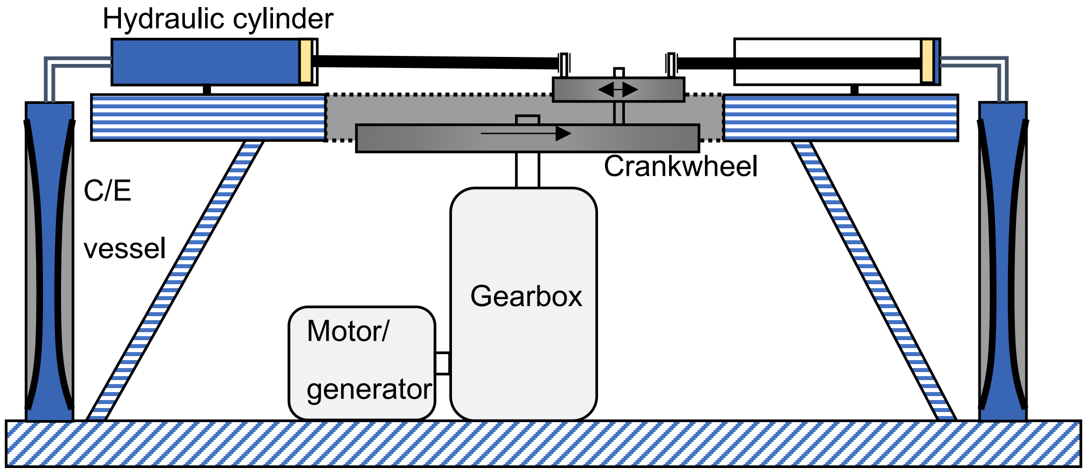

Fig. S3. Side view schematics of the one-stage compressor/expander. Only two out of seven hydraulic cylinders are shown.

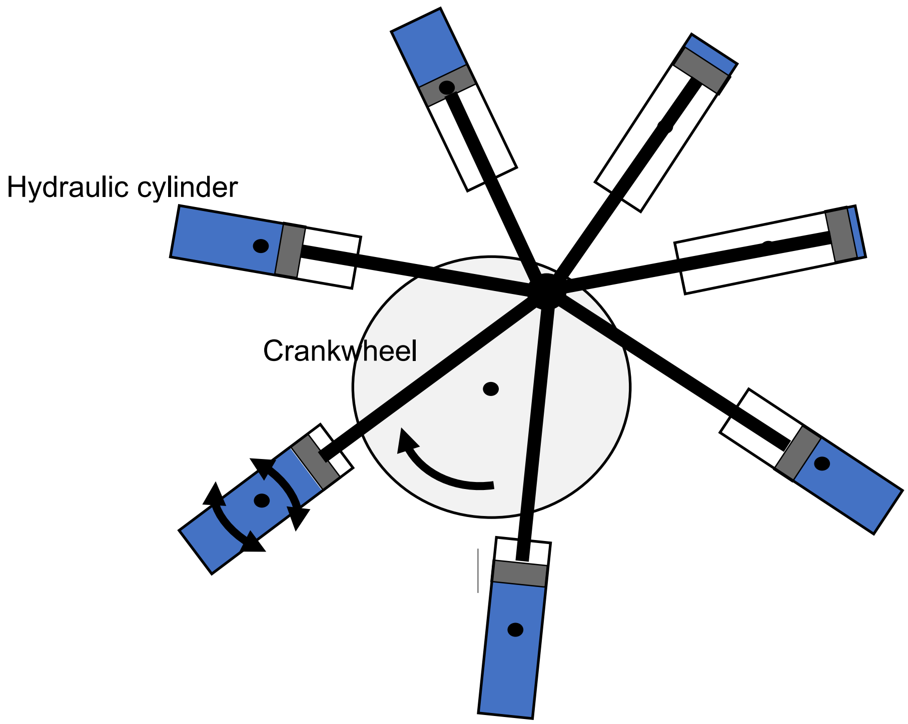

Fig. S4. Top-view schematics of the one-stage compressor/expander (C/E vessels not shown).

Fig. S5. Photograph of the one-stage compressor/expander.