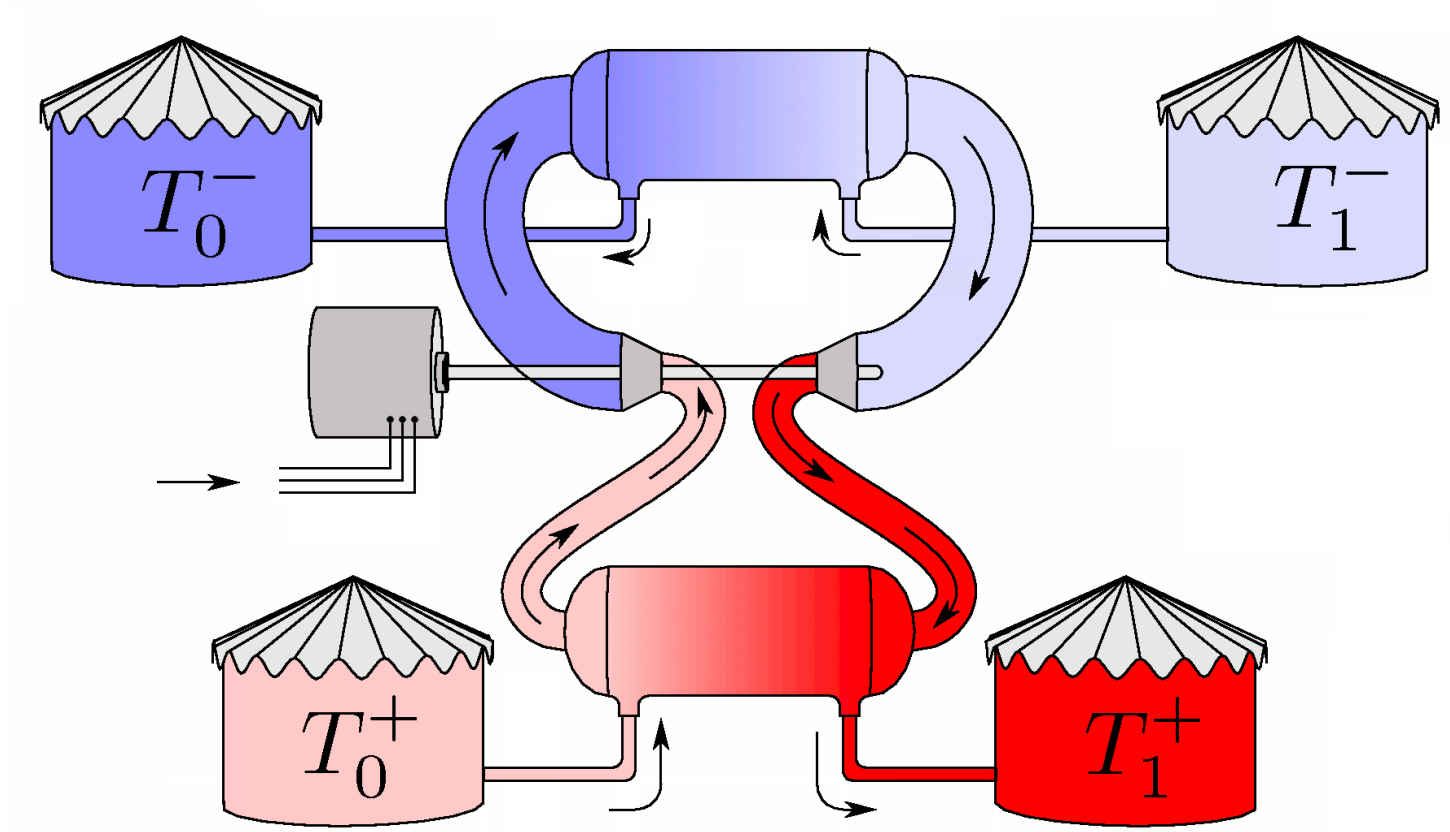
Variable Blading in Closed-Cycle Brayton Energy Storage

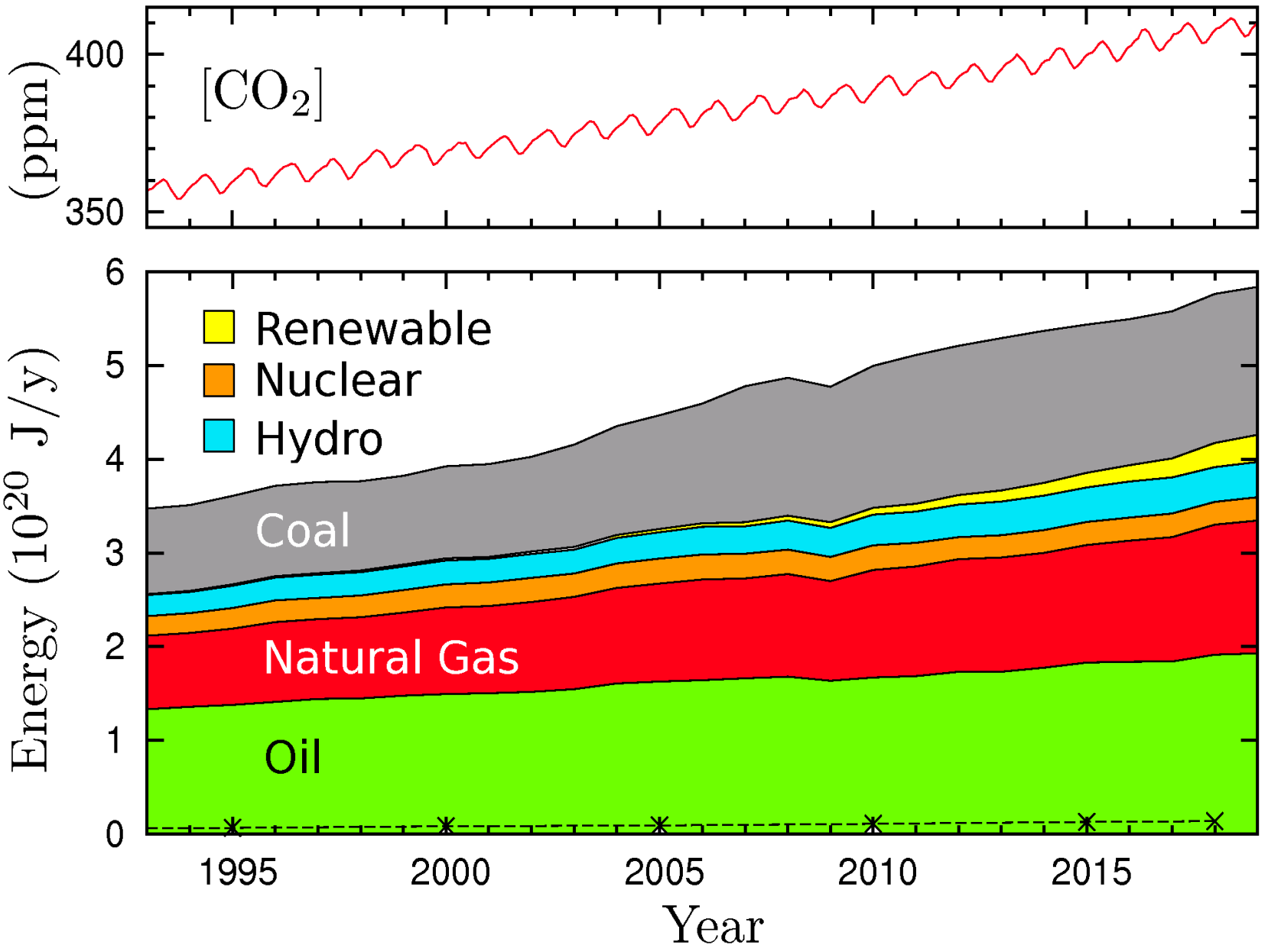
R. B. Laughlin

TMCES, San Antonio, 10 Aug 21



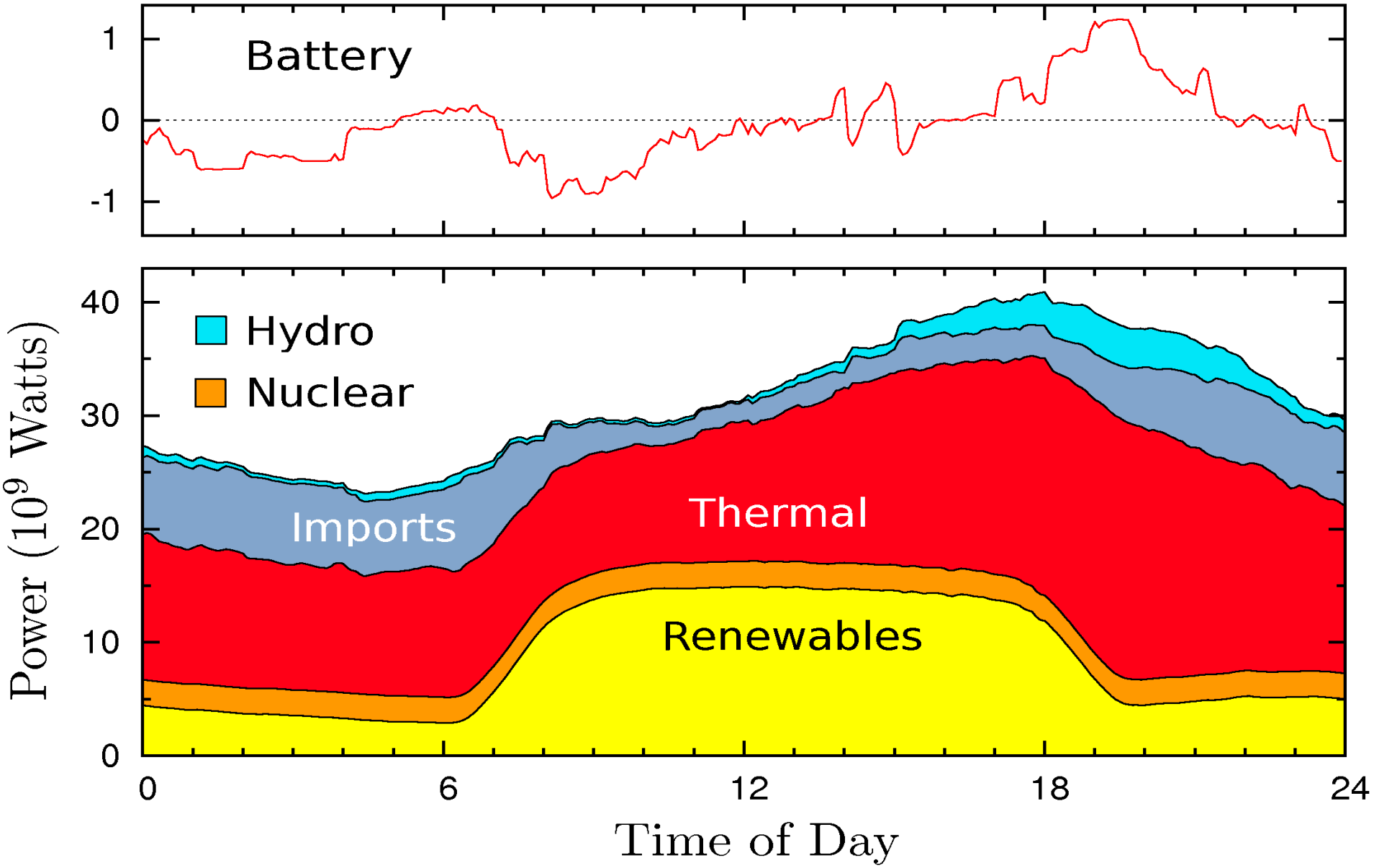
R. B. Laughlin, “Pumped Thermal Grid Storage With Heat Exchange,” J. Renew. Sustain. Energy **9**, 044103 (2017).

The Problem – Part I



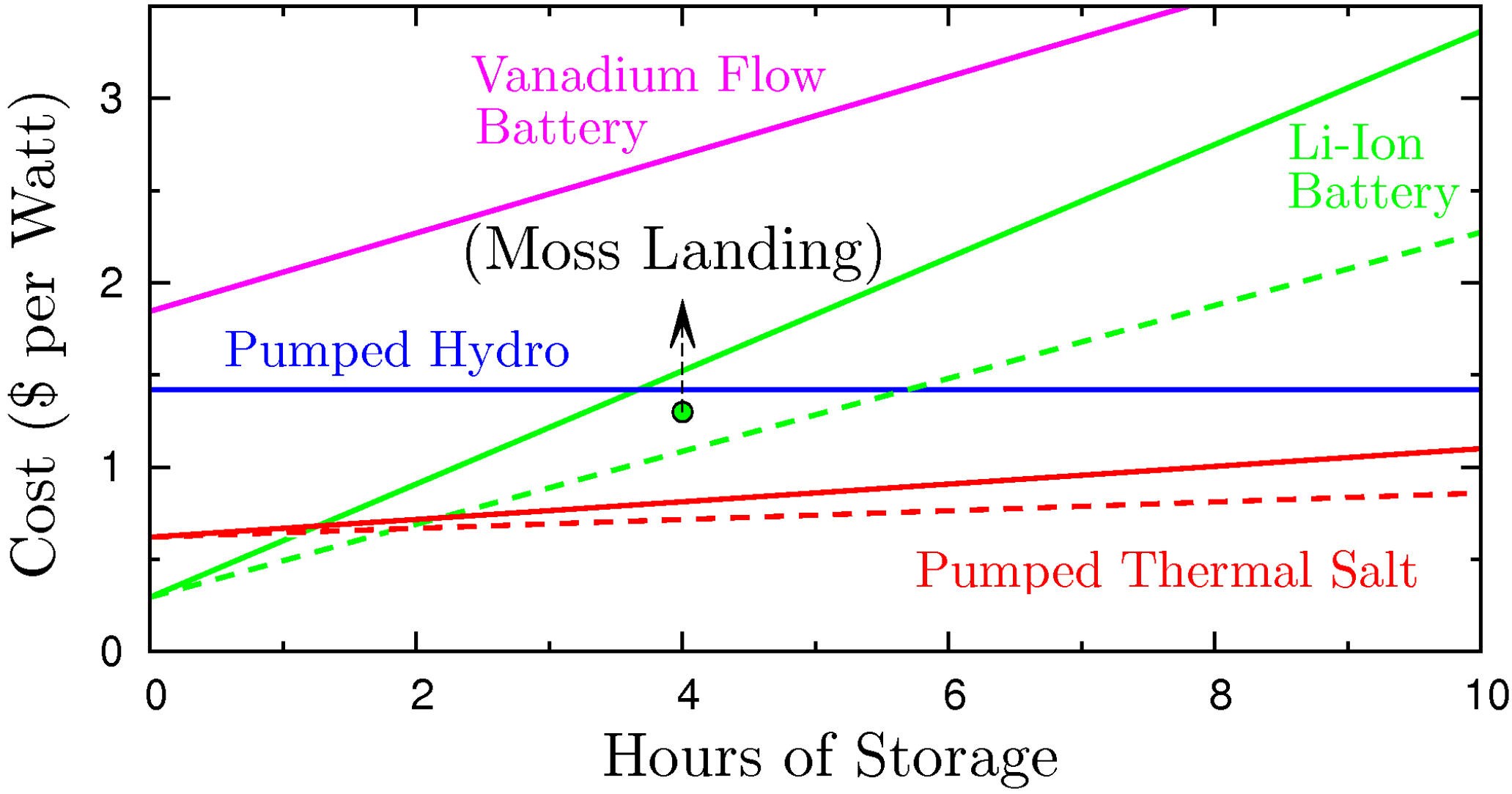
Source: "BP Statistical Review of World Energy 2020," British Petroleum, June 2020.

The Problem – Part II



Source: "Renewables Watch for Operating Day: Monday, 02 August, 2021," California Independent System Operator, 2021.

The Problem – Part III

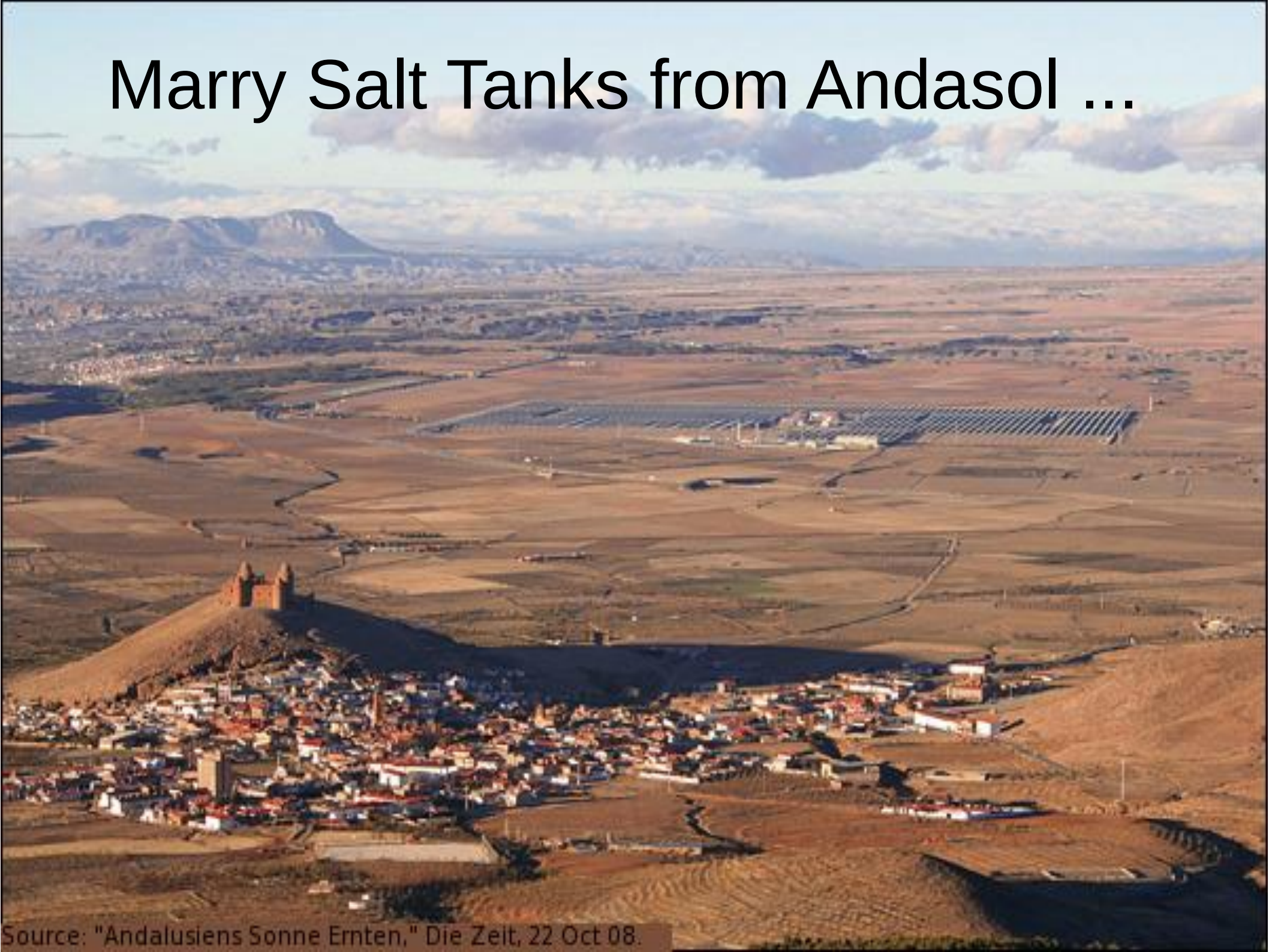


Sources: R. Fu et al., NREL/TP-6A20-7174, Nov. 18; S. Few *et al*., Energy Policy **114**, 578 (2018); D. Feldman *et al*., NREL/TP-6A20-66592, Aug. 16; T. Key *et al*., EPRI 1023144, Feb 13; T. Lüth *et al*., Energy Proc. **155**, 379 (2018); C. S. Turchi *et al*., NREL/TP-5506-22856, May 19; N. Diorio *et al*., NREL/TP-6A20/64987, Nov. 15; J. D. Morris, San Francisco Chronicle, 15 Jan 21; S. Patel, Power Magazine, 14 Jan 21; A. Colthorpe, Enegy Storage News, 17 Jun 21.

Vistra Moss Landing 300 MW x 4 h

Idea!

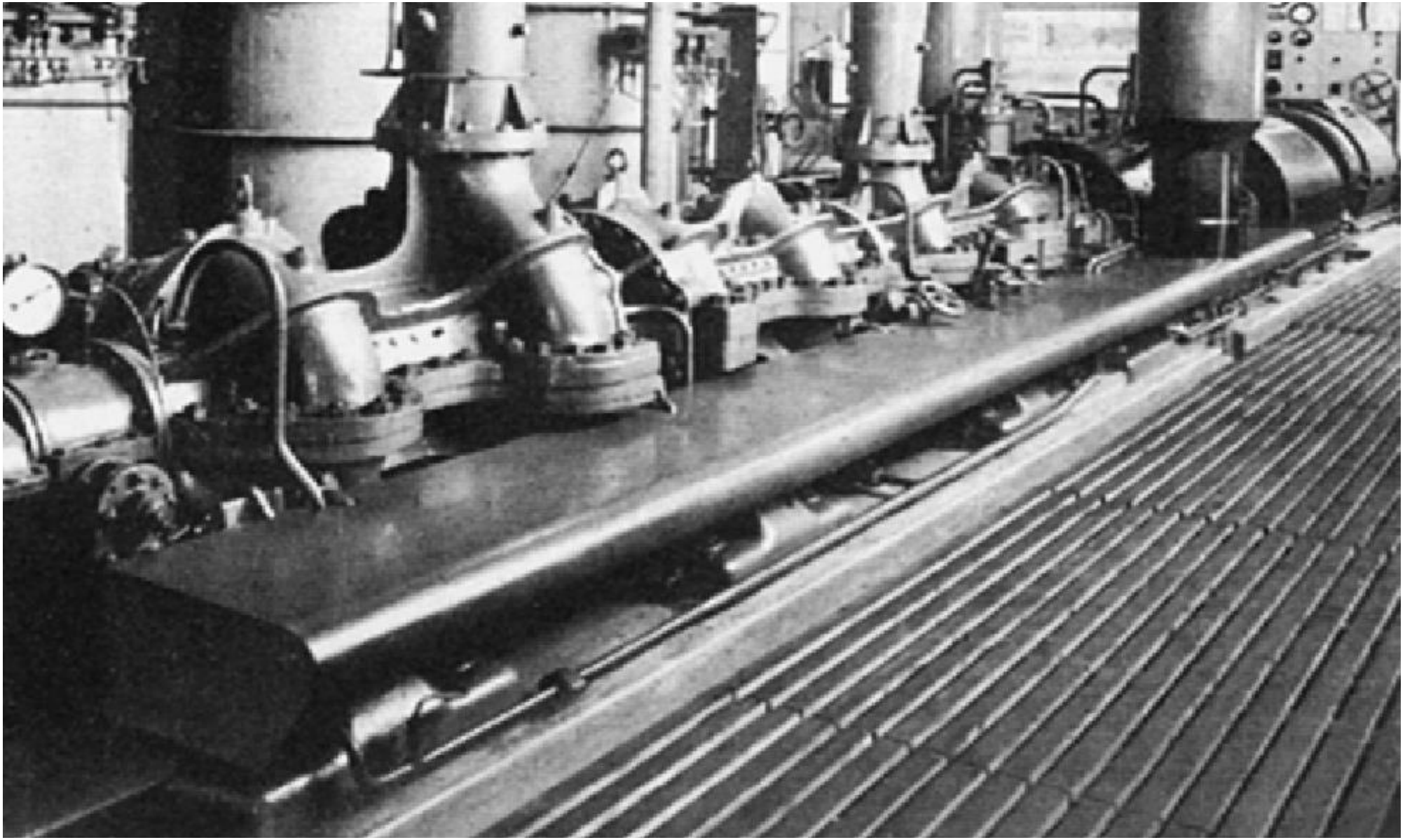
Marry Salt Tanks from Andasol ...



Source: "Andalusiens Sonne Ernten," Die Zeit, 22 Oct 08.

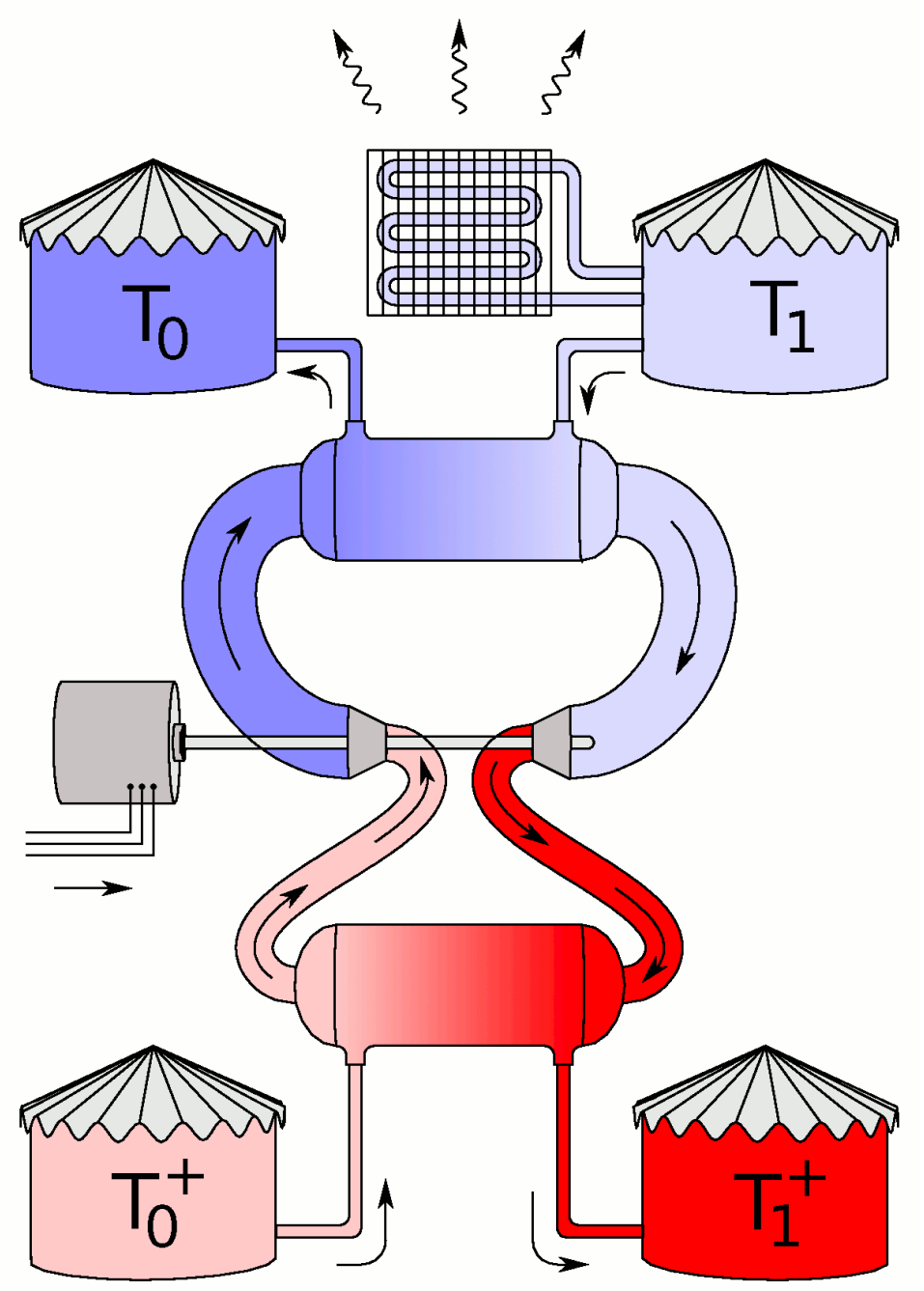
Source: "The Parabolic Trough Plants Andasol 1 to 3," Solar Millenium AG, December 2008.

With Closed-Cycle Brayton Engine

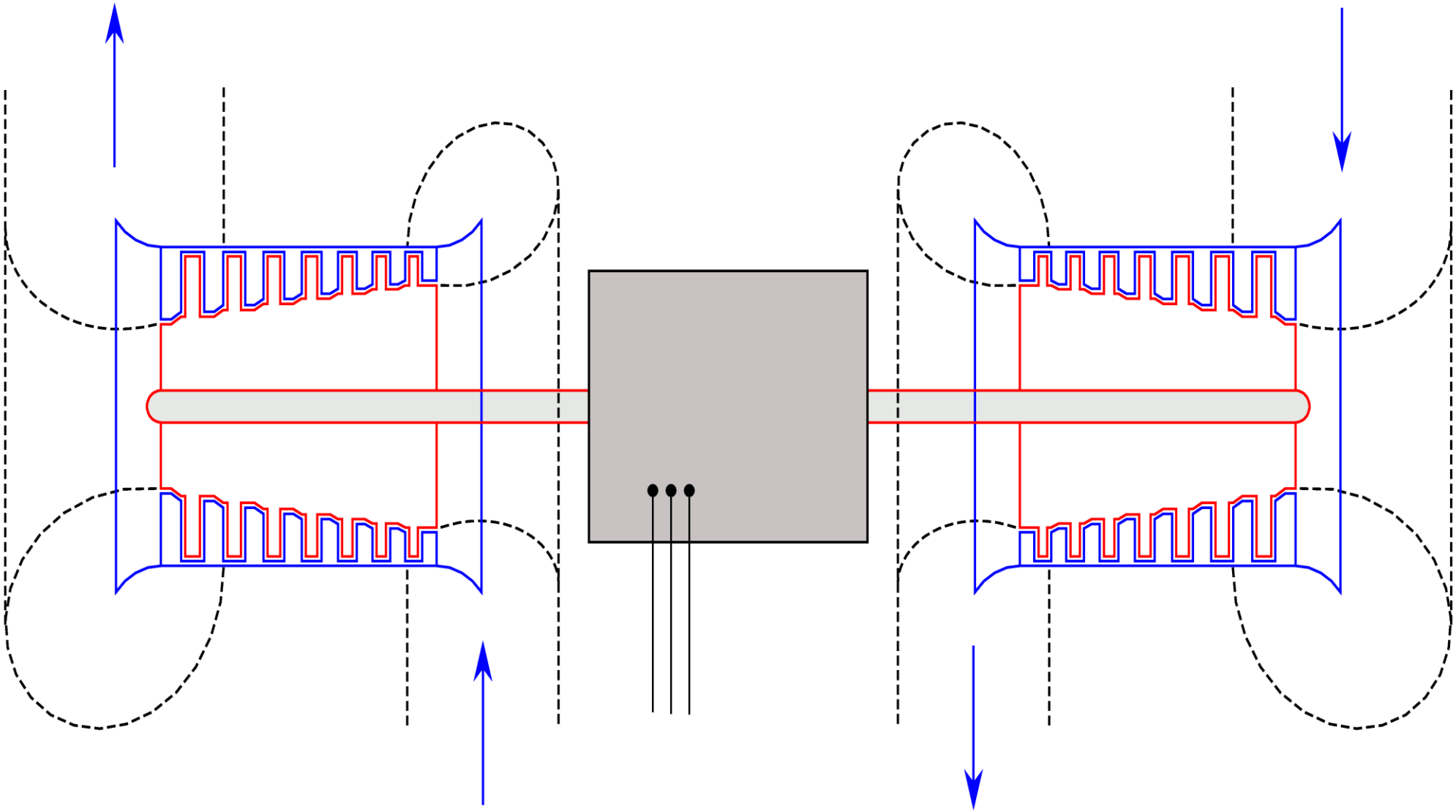


Source: J. Ackeret u D. C. Keller, “Aerodynamische Brennkraftmaschine mit geschlossenem Kreislauf,” Zeitschrift des Vereines Deutscher Ingenieure **85**, No. 22, 491 (1941).

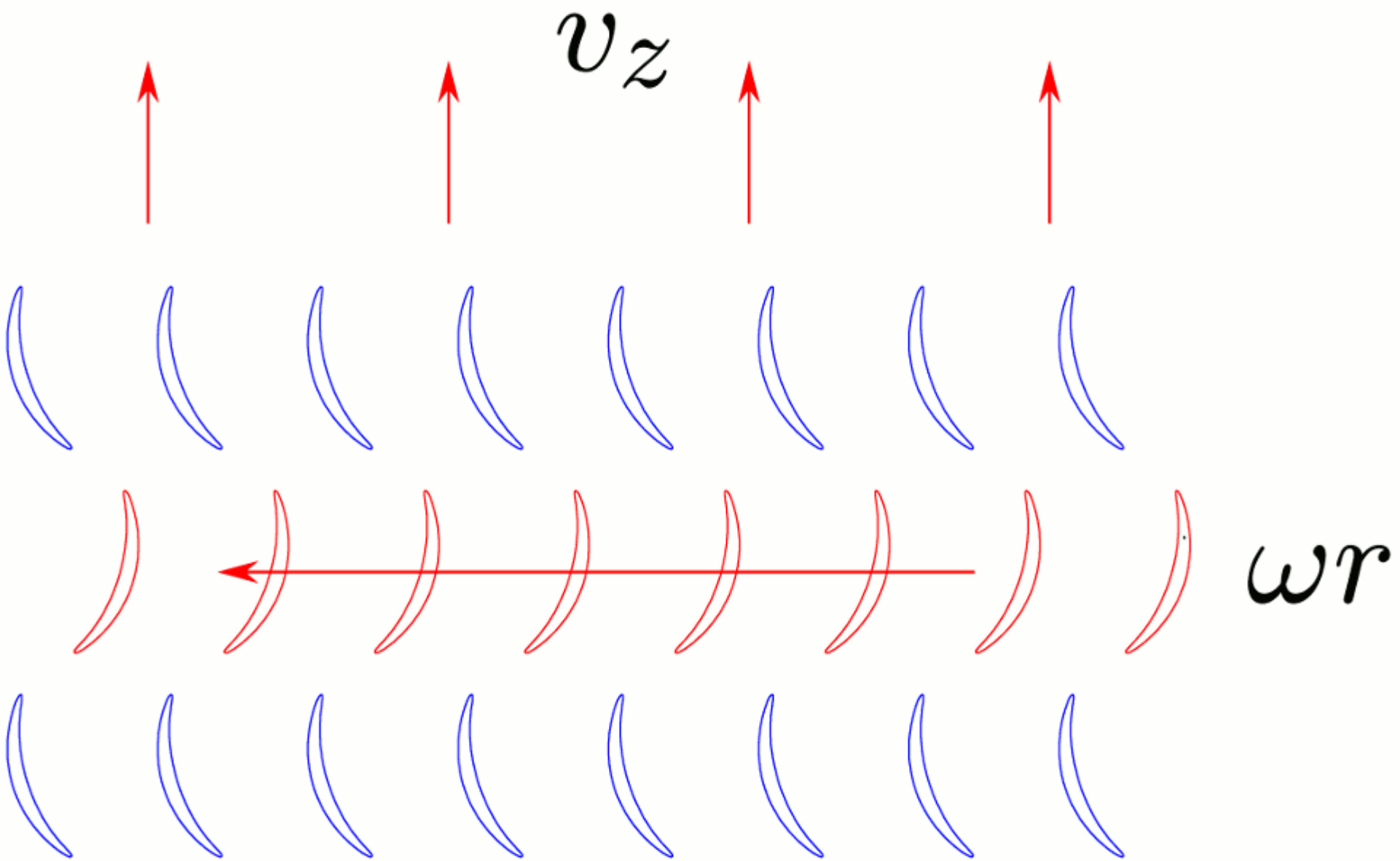
Viola! Reversible Thermal Storage



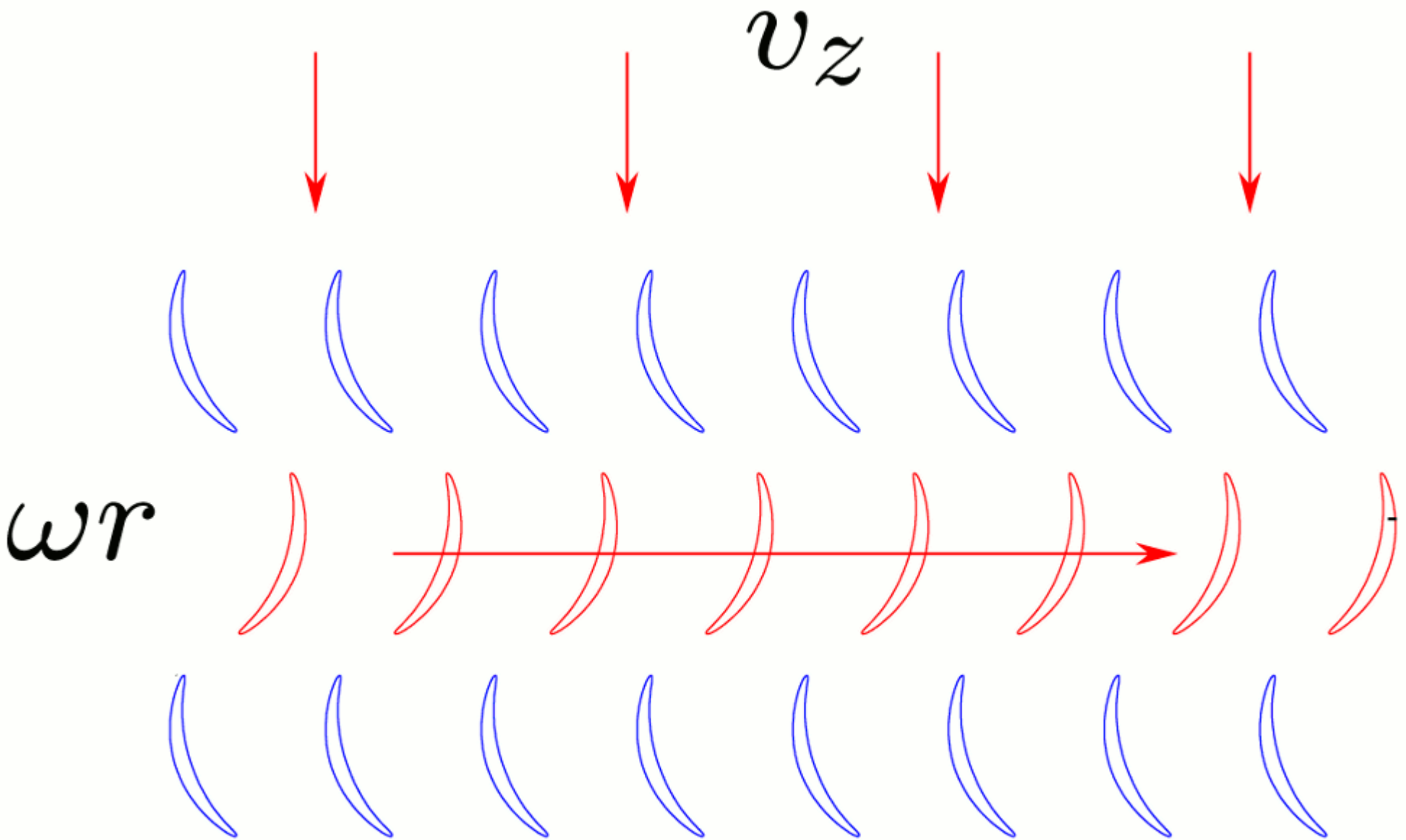
Mandate: Reduce Costs By Means of Turbomachinery That Reverses



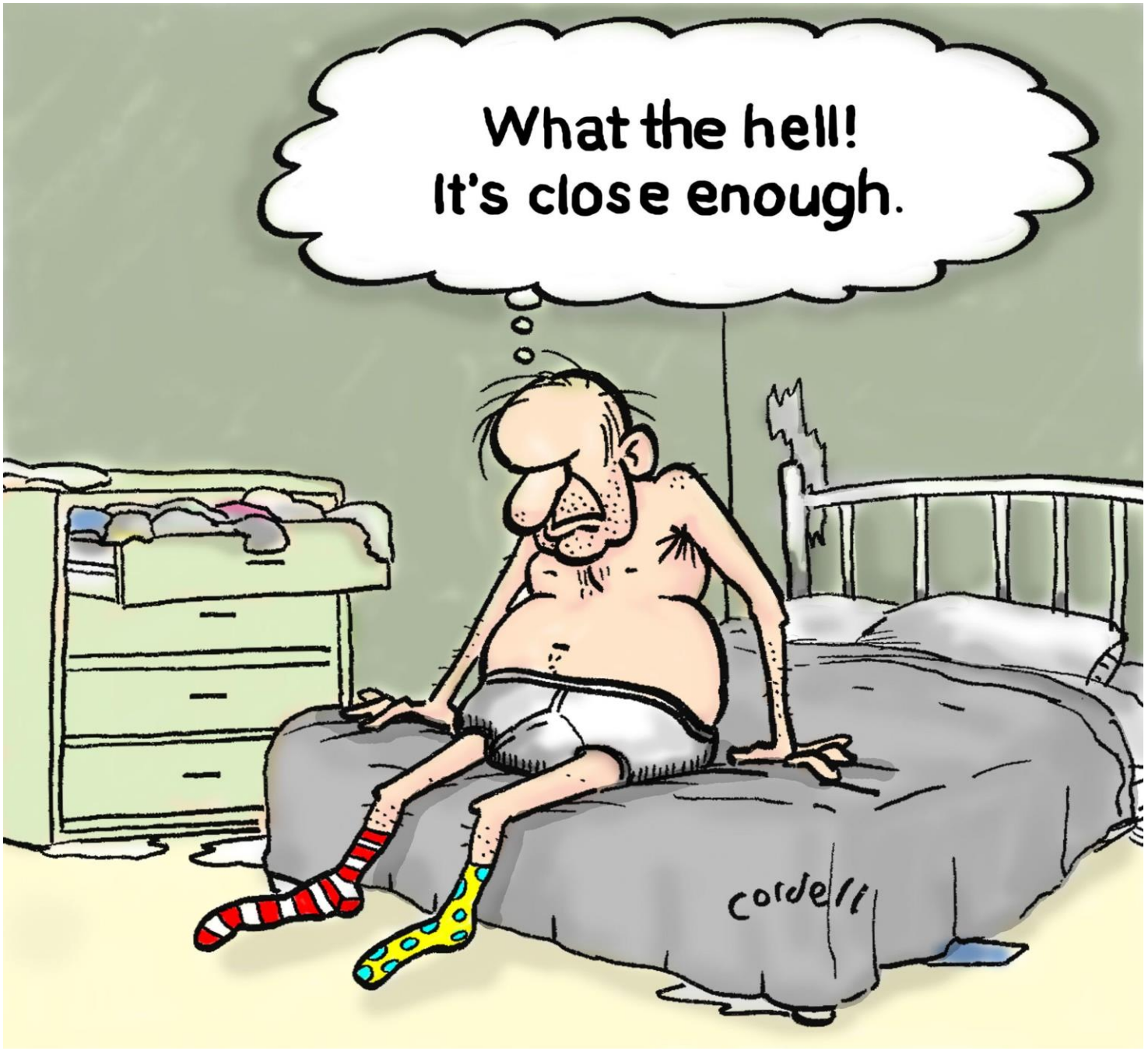
Compressor Mode



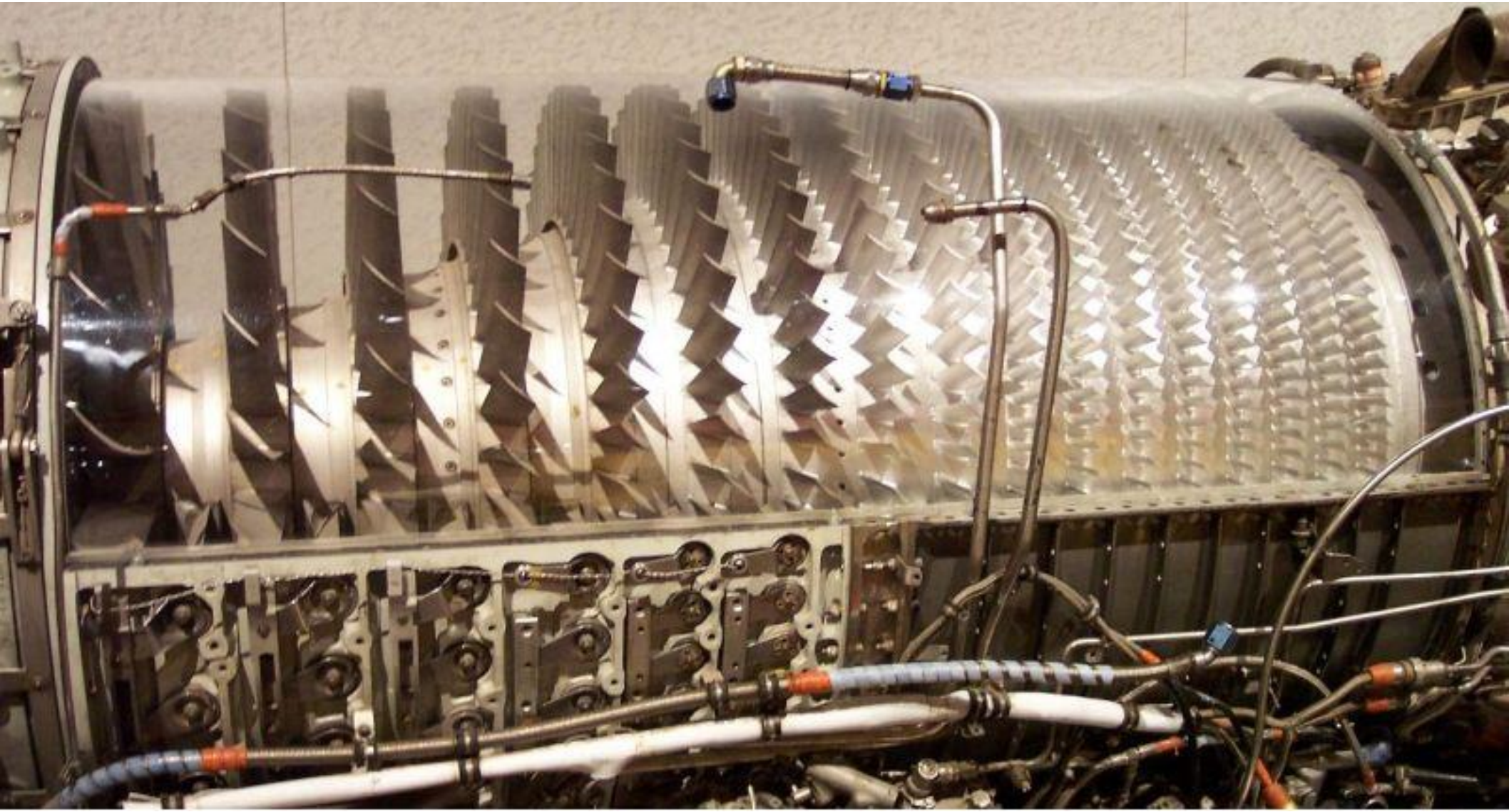
Turbine Mode



… But There is a Physics Issue



… Resolved With Variable Blading

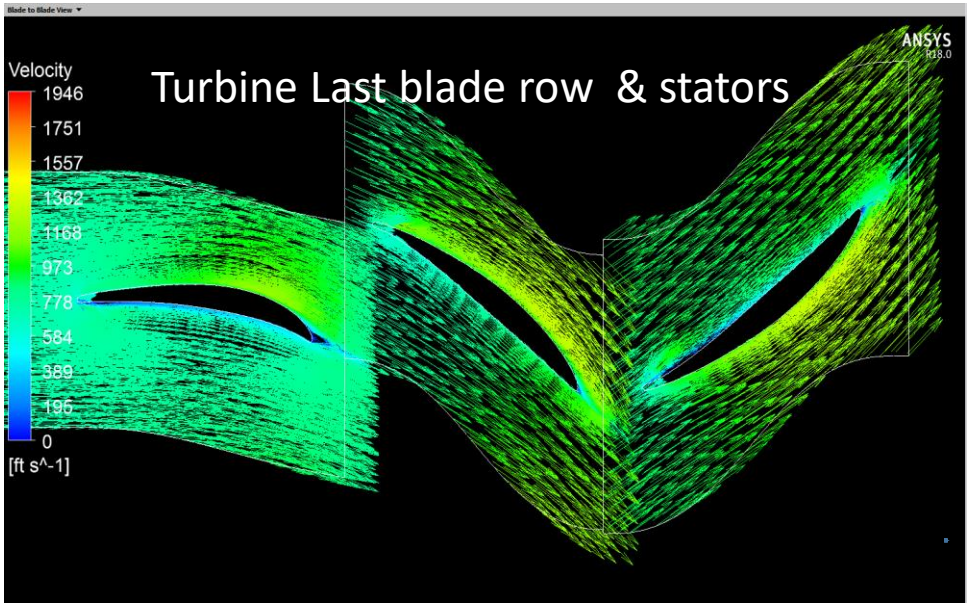


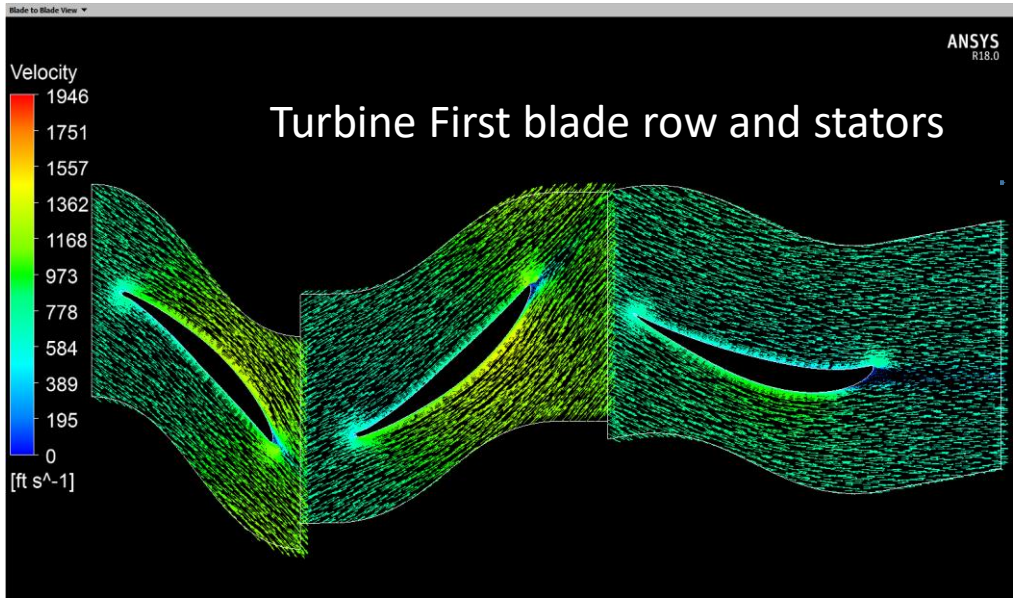
Source: O. Cleynen, Wikimedia Commons (Compressor of J-79 jet engine on display at Deutsches Museum).

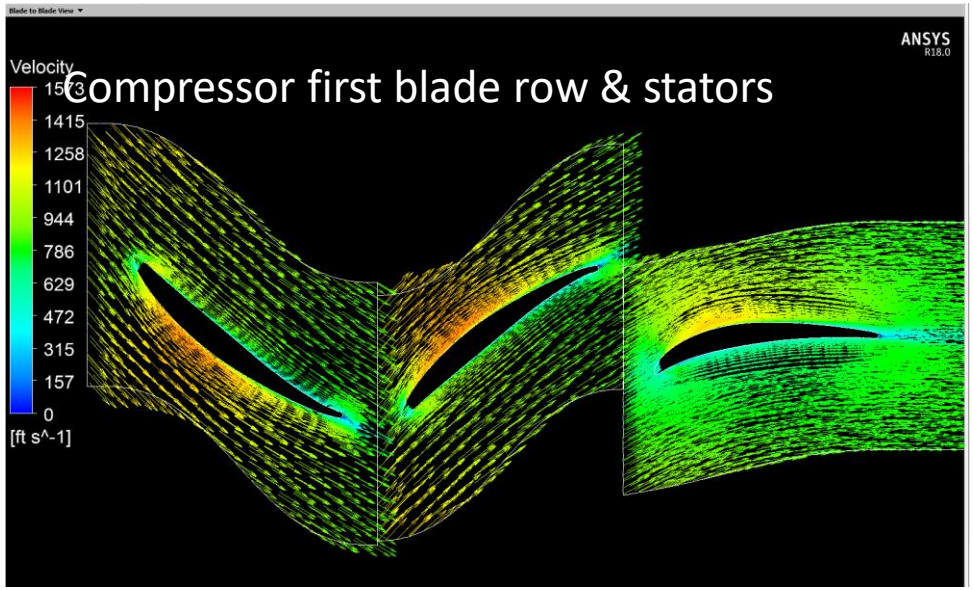
Problem Is Not Airfoil Shape ...

Designed as a *Charge* Compressor, it functions reas , fl

Brayton Energy LLC







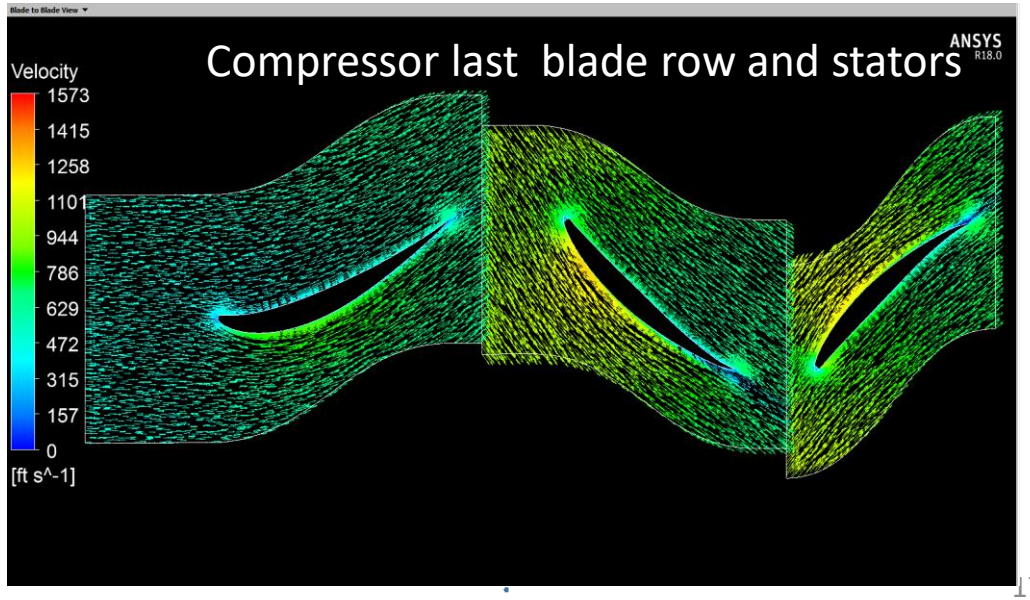


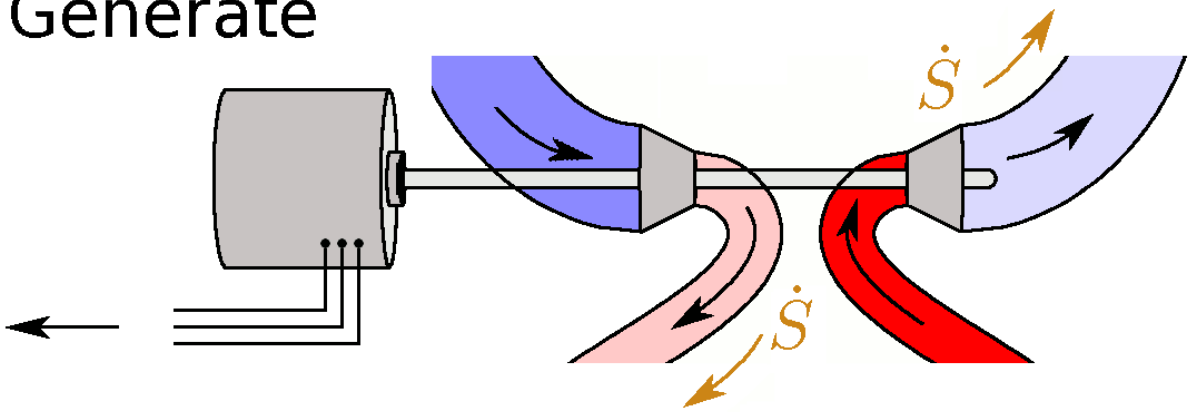
Image Courtesy of Brayton Energy LLC, 3 Feb 20.

Problem Is Throttling

$$\Delta S > 0$$

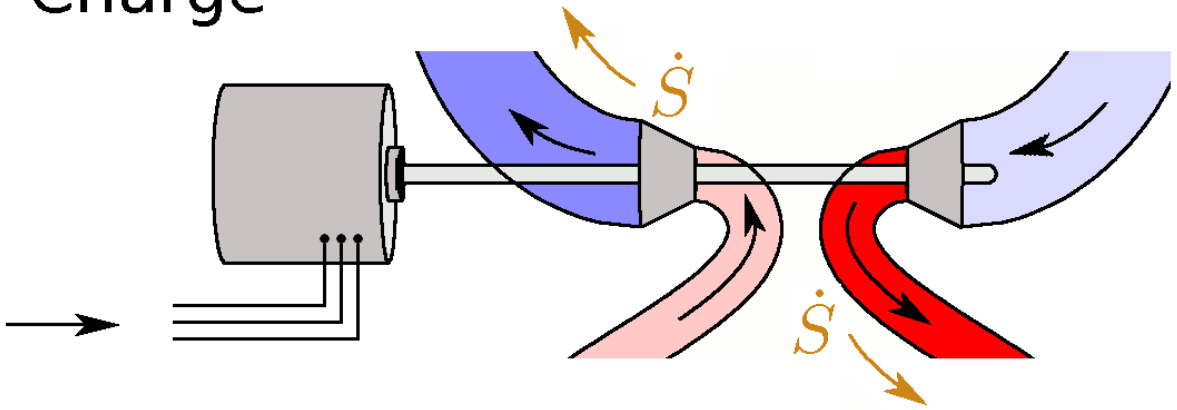
Entropy Creation Causes Pressure Drops in the Flow Direction ...

Generate



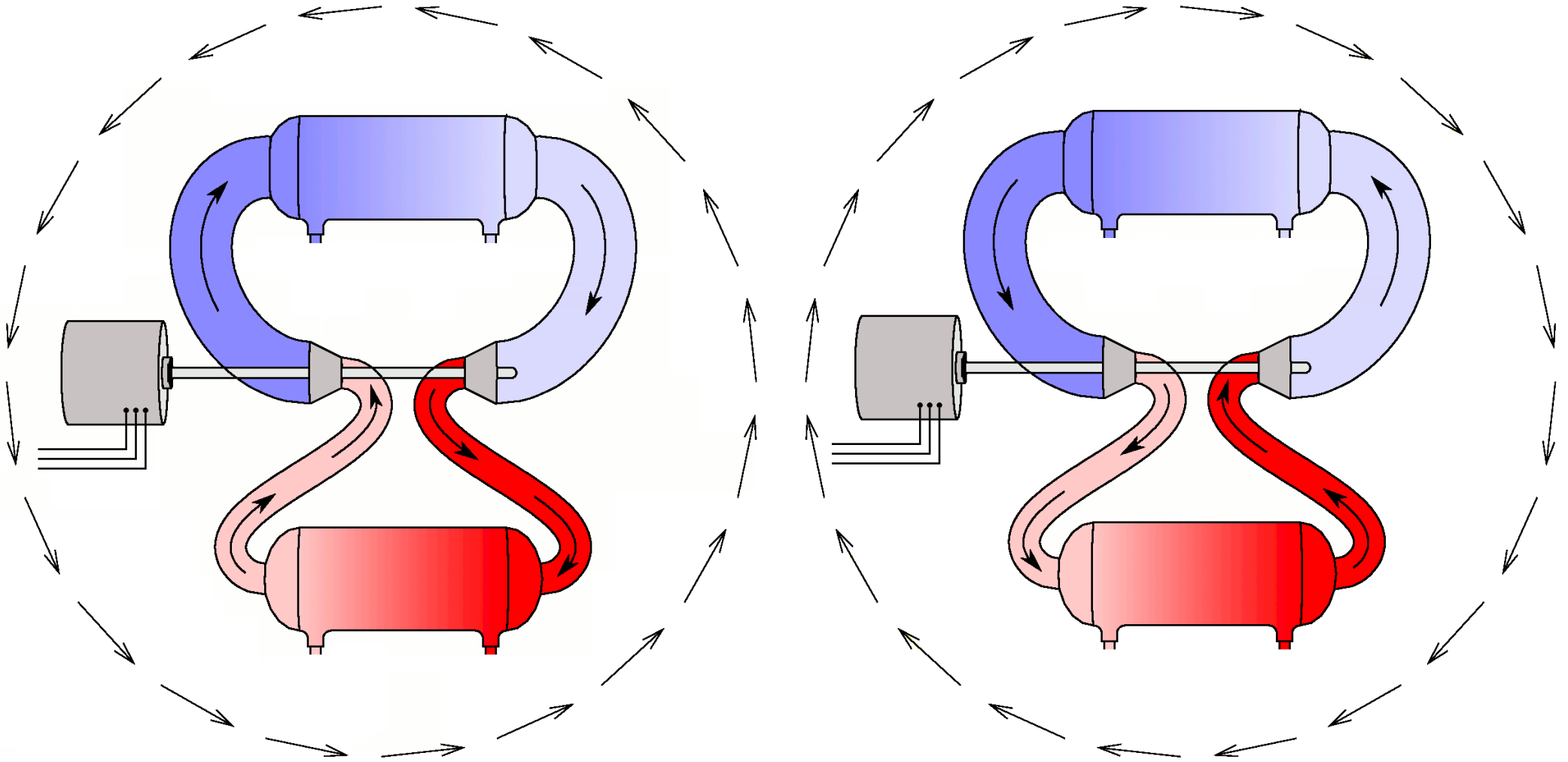
$$\dot{S} = \dot{\nu} R \left[\frac{\gamma}{\gamma - 1} \frac{\Delta T}{T}^{0} - \frac{\Delta p}{p} \right]$$

Charge

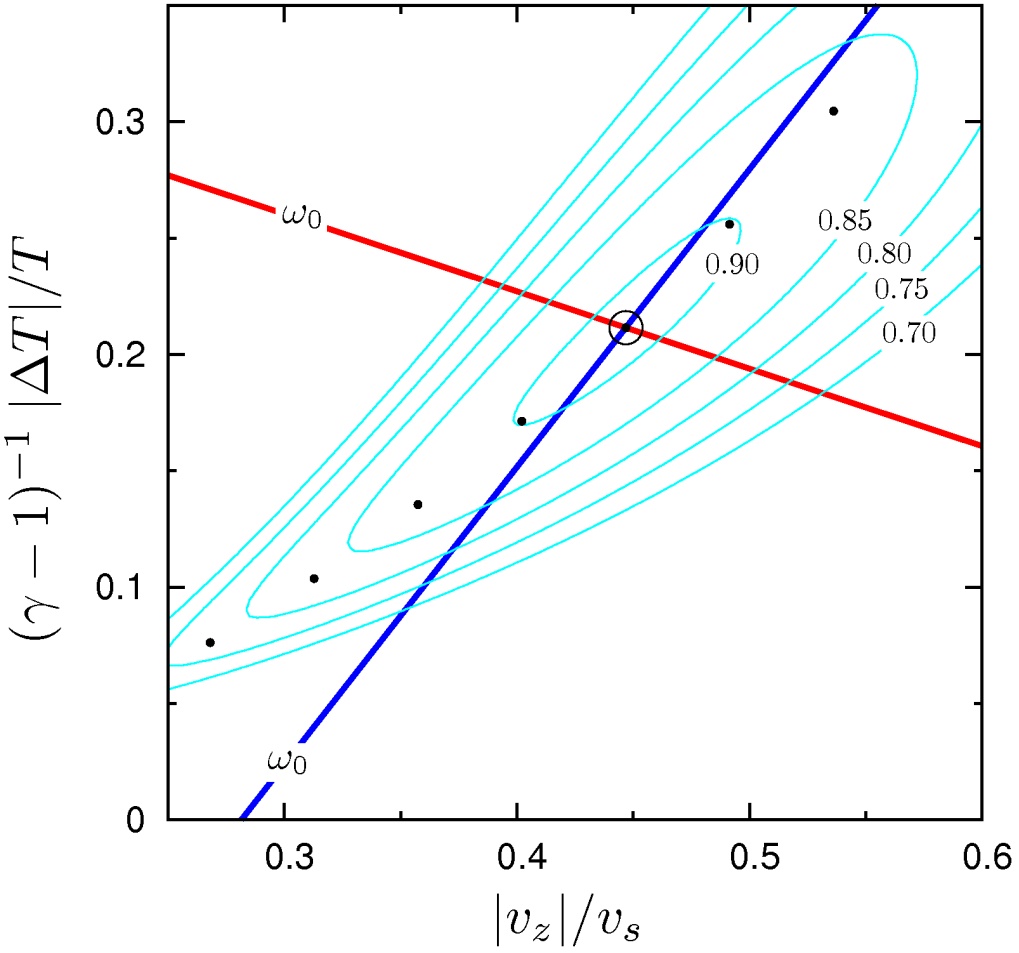


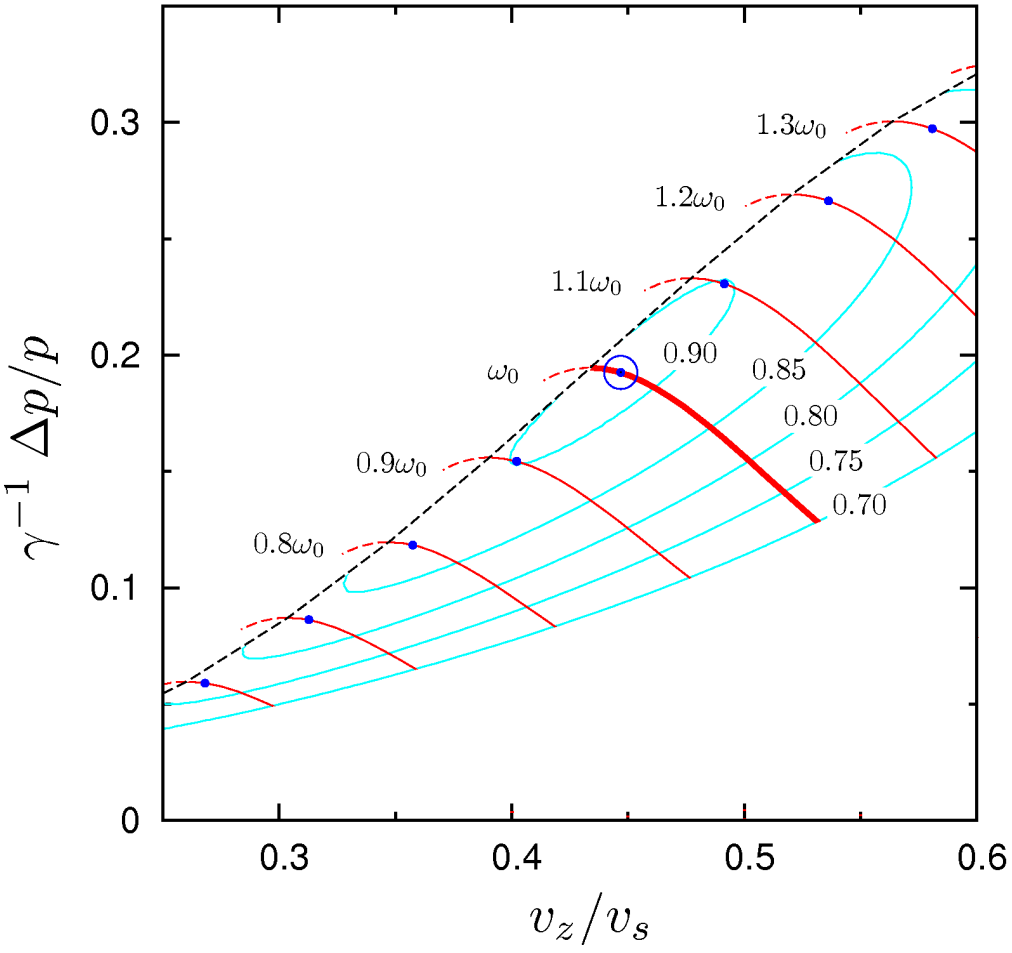
$\dot{S}$ = Entropy Creation Rate
$\dot{\nu}$ = Molar Flow Rate
T = Kelvin Temperature
p = Pressure
R = Gas Constant
γ = Specific Heat Ratio

… That Oppose and Slow Down Flow in a Reciprocating Fashion ...

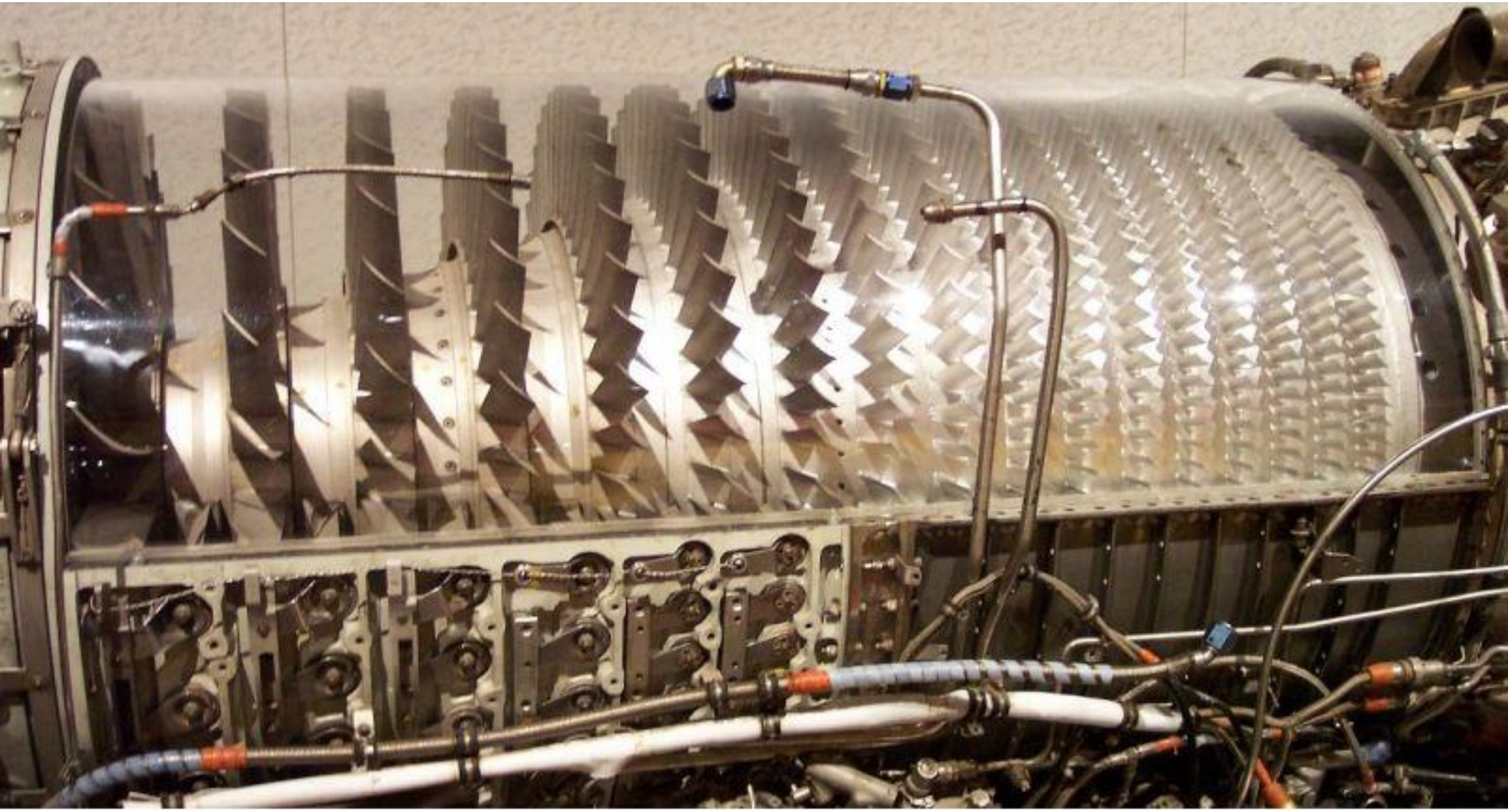


… That Then Push the Compressor Toward Its Surge Line

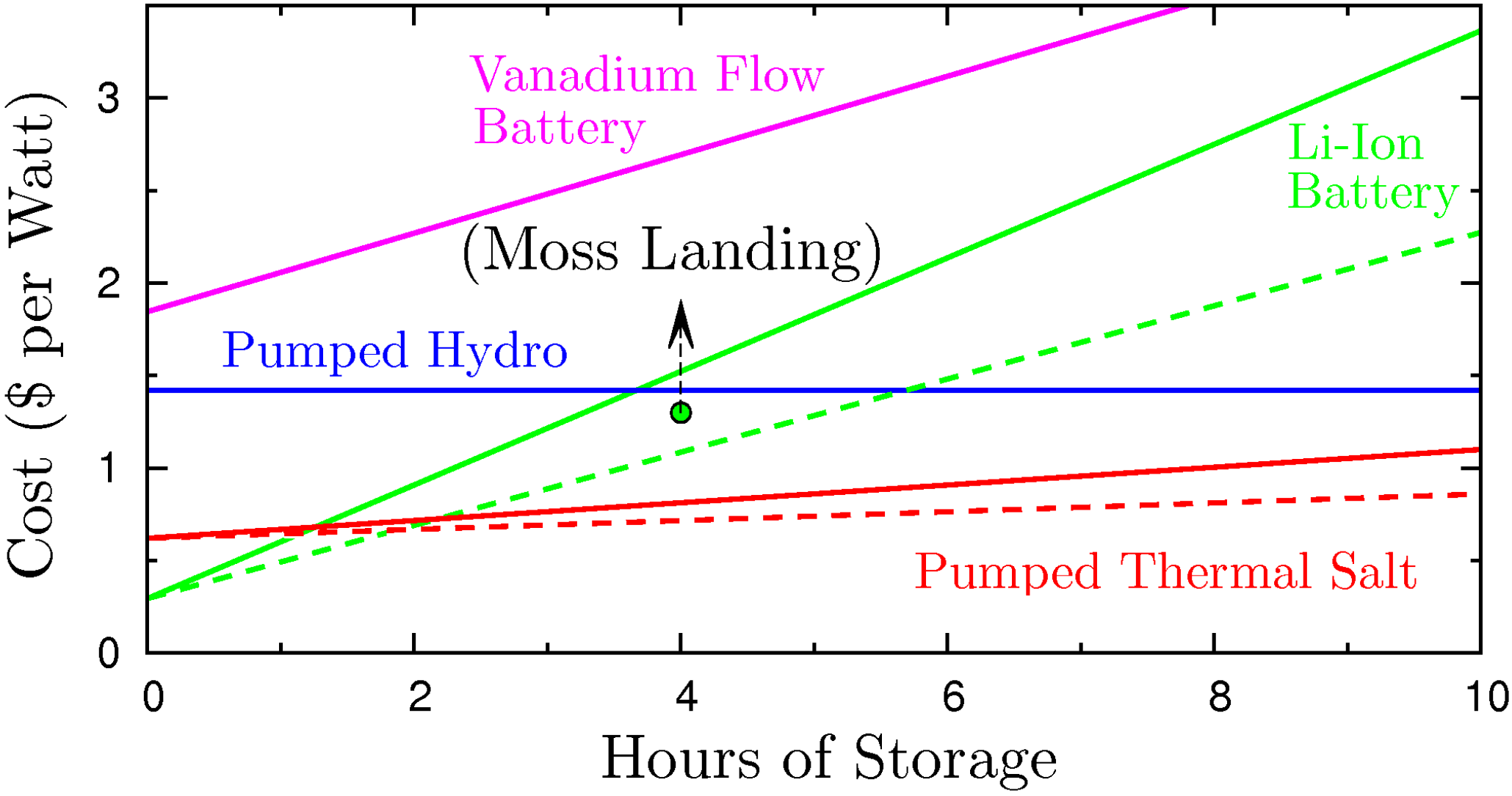




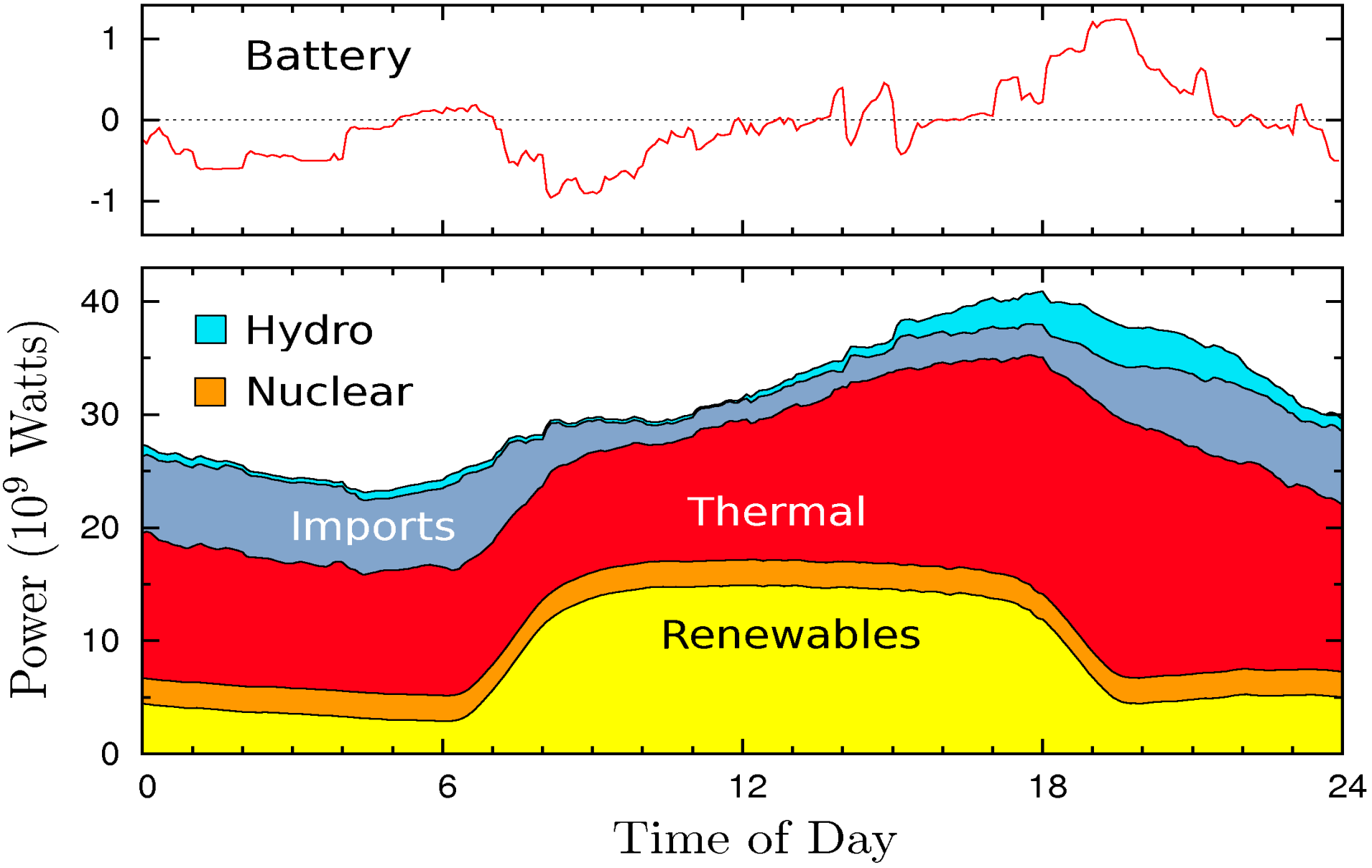
Thus No Good Solution Without Variable Blading – as in Aircraft



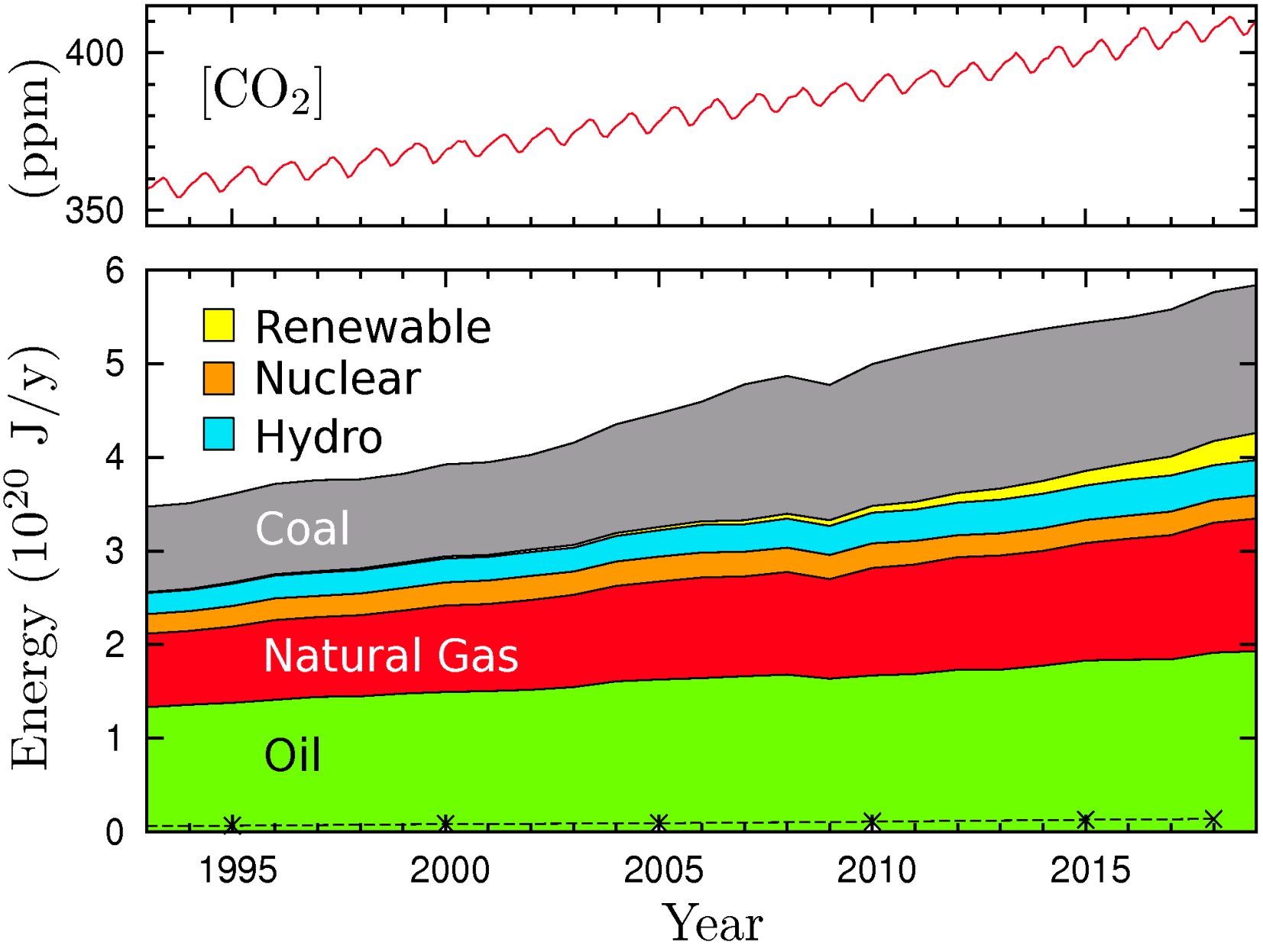
Part III - Redux

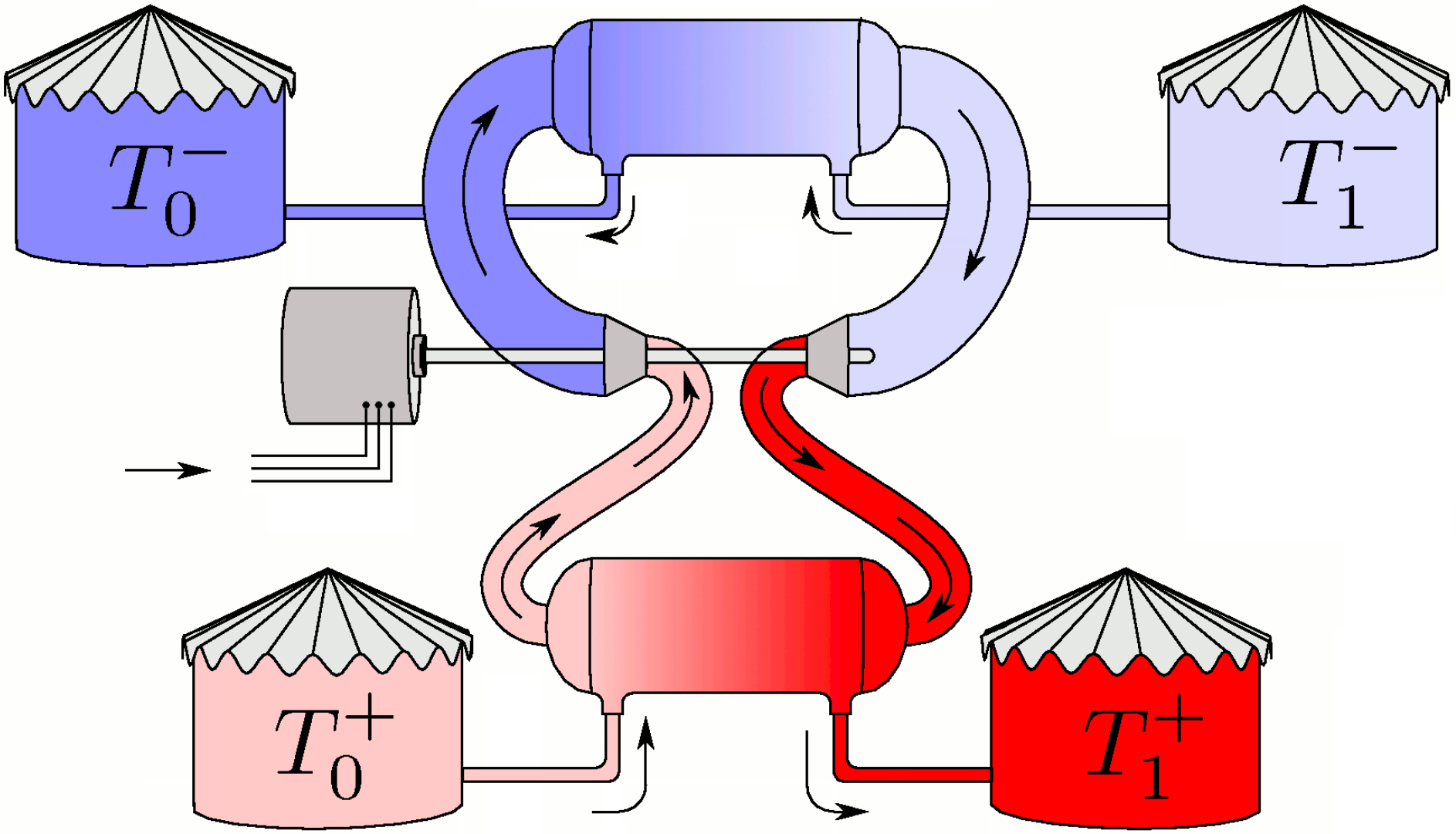


Part II - Redux



Part I - Redux


400
350
(ppm)
$[CO_2]$
6
5
4
3
2
1
0
Energy $(10^{20}$ J/y)
Renewable
Nuclear
Hydro
Coal
Natural Gas
Oil
1995
2000
2005
2010
2015
Year


T_0^-
T_1^-
T_0^+
T_1^+