LIÈGE université

Welcome by Prof. Vincent Lemort

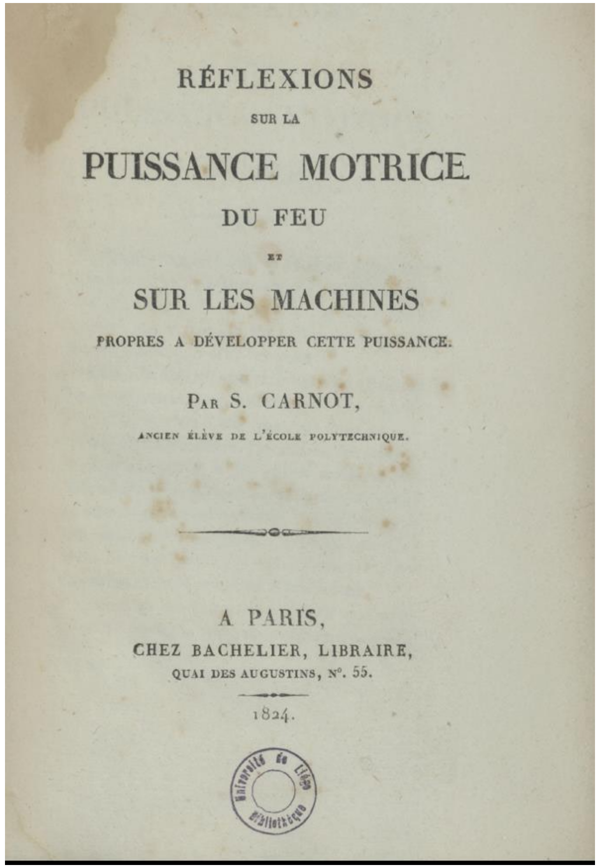
Carnot 2024 Liège, BE

Welcome to all Thermodynamics Enthusiasts to Liège!

- *Students*
- *Close colleagues*
- *Past and current research partners*
- *Former PhD students*
- *Future research partners?*
- *Industrial partners*
- …

- Some of you have traveled very long distances to reach Liège

What do we celebrate?



RÉFLEXIONS
SUR LA
PUISSANCE MOTRICE
DU FEU
ET
SUR LES MACHINES
PROPRES A DÉVELOPPER CETTE PUISSANCE.
PAR S. CARNOT,
ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE.

A PARIS,
CHEZ BACHELIER, LIBRAIRE,
QUAI DES AUGUSTINS, N°. 55.
1824.

A book published 200 years ago and the scientist who wrote it

Sadi Carnot en uniforme d'élève de l'Ecole Polytechnique, 1813. Peinture sur huile de Louis-Léopold Boilly.

Why do we celebrate Carnot in this room, in Liège, Belgium?

To bring together all Belgian thermodynamicists

Both “Belgian” and “thermodynamicists” have to be understood in a broad sense

- Researchers developing/practicing/teaching thermodynamics, with different backgrounds (physics, chemistry, mechanical engineering)
- Researchers in **fundamental sciences** and in **engineering schools**
- Engineers in **companies** developing products using thermodynamics (but not only)
- How could we connect thermodynamics with **other disciplines** to extend research and development?
- Specialists in different subfields of thermodynamics: classical, statical, stochastic, irreversible, finite-time, technical/applied, chemical…

Organizing this event has been the opportunity to discover many people and teams in Belgium!

To bring together all Belgian thermodynamicists

- Anyone with a **special connection with Belgium** or simply interested in exploring the R&D activities in Belgium (and presenting their own research)
  - North and the South of the Country
  - Luxembourg
  - Belgian leaving abroad
  - Former researchers having lived in Belgium…

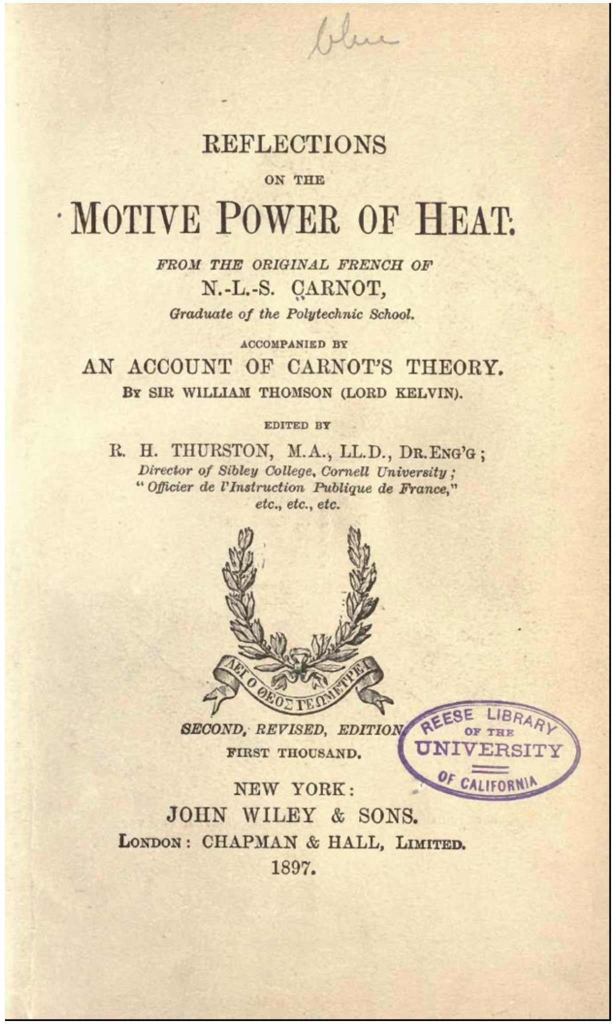
Welcome by Prof. Eric J.-M. Delhez, Dean of the Engineering School

From Sadi Carnot to thermodynamics in Belgium

Vincent Lemort

Thermodynamics Laboratory

« Reflections on the motive power of fireand on Machines Fitted to Develop that Power »


REFLECTIONS

ON THE

MOTIVE POWER OF HEAT.

FROM THE ORIGINAL FRENCH OF

N.-L.-S. CARNOT,

Graduate of the Polytechnic School.

ACCOMPANIED BY

AN ACCOUNT OF CARNOT'S THEORY.

BY SIR WILLIAM THOMSON (LORD KELVIN).

EDITED BY

R. H. THURSTON, M.A., LL.D., DR.ENG'G;

Director of Sibley College, Cornell University;

"Officier de l'Instruction Publique de France,"

etc., etc., etc.

ΑΕΙ Ο ΘΕΟΣ ΓΕΩΜΕΤΡΕΙ

SECOND, REVISED, EDITION.

FIRST THOUSAND.

NEW YORK:

JOHN WILEY & SONS.

LONDON: CHAPMAN & HALL, LIMITED.

1897.

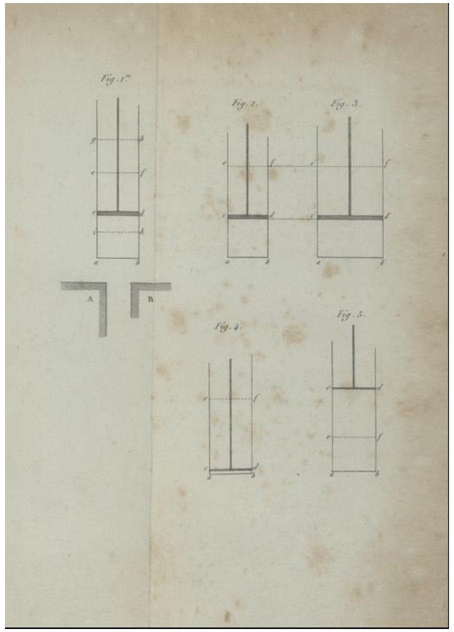
Published 200 years ago by Sadi Carnot (28 years old), an engineer graduated from Ecole Polytechnique (Paris)

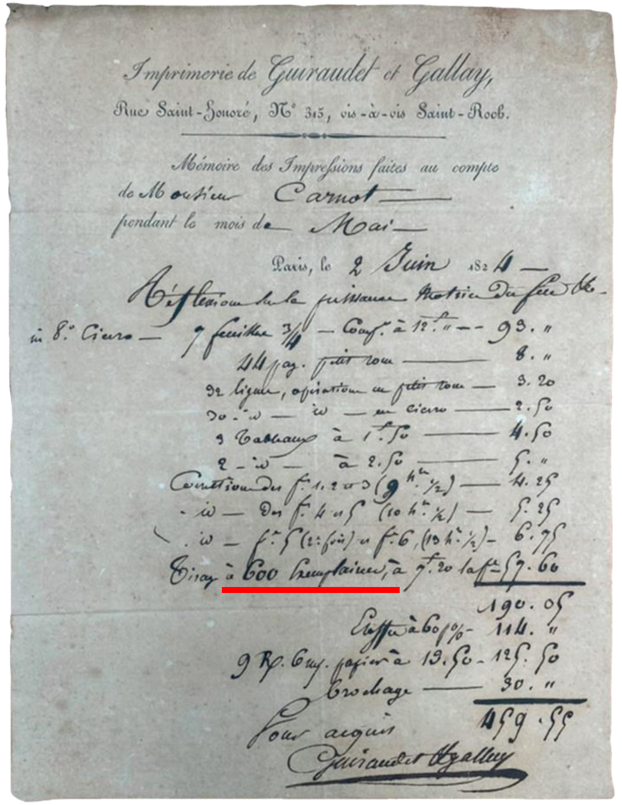
- Very short military career
- Took a “sabbatical” leave to study sciences in Paris (CNAM)
- He investigated steam engines to understand what could maximize their performance (and if a limit does exist)
- Carnot was impressed by the technological leadership of England versus France

Woolf steam engine 1858 (licensed under the Creative Commons Attribution-Share Alike 2.5 Generic license)

« Reflections on the motive power of fire »

- 120 pages + 5 figures (few equations)
- Limited diffusion (600 printed copies, paid by Carnot himself)
- Latter recognized as the foundation of the 2nd Law of thermodynamics





Imprimerie de Guiraudet et Gallay,
Rue Saint-Honoré, N° 315, vis-à-vis Saint-Roch.

Mémoire des Impressions faites au compte
de Monsieur Carnot
pendant le mois de Mai

Paris, le 2 Juin 1824

Pour acquit
Guiraudet Gallay

Facture de Réflexion sur la puissance motrice du feu chez la Maison de l'Éditeur, 459,99 F (2 juin 1824)
Source: Archive privée de la famille Carnot, France | Very kindly authorized by the Carnot family

« Reflections on the motive power of fire »

What does this book teach us?

« Reflections on the motive power of fire »

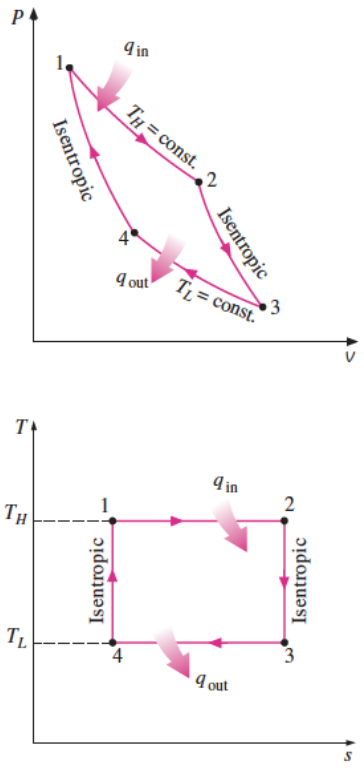


FIGURE 9–6

P-v and *T-s* diagrams of a Carnot cycle.

- Neither the T-s diagram nor the “Carnot formula” can be found in « Réflexions »

Chapter 9 | 491

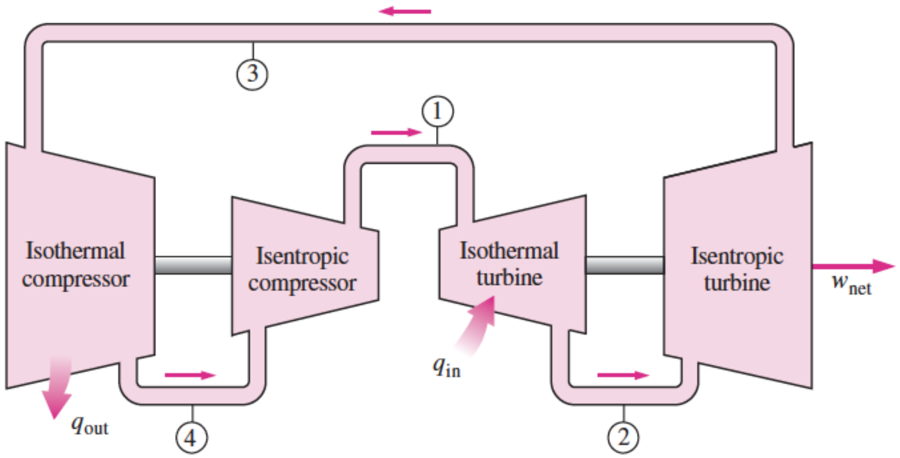


FIGURE 9–7

A steady-flow Carnot engine.

be utilized as the working fluid. The Carnot cycle is the most efficient cycle that can be executed between a heat source at temperature T_H and a sink at temperature T_L, and its thermal efficiency is expressed as

$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H} \qquad (9\text{–}2)$$

From Çengel, Y. A., and Boles, M. A. (2006). Thermodynamics, An Engineering Approach. 5th Edition. McGraw-Hill Higher Education.

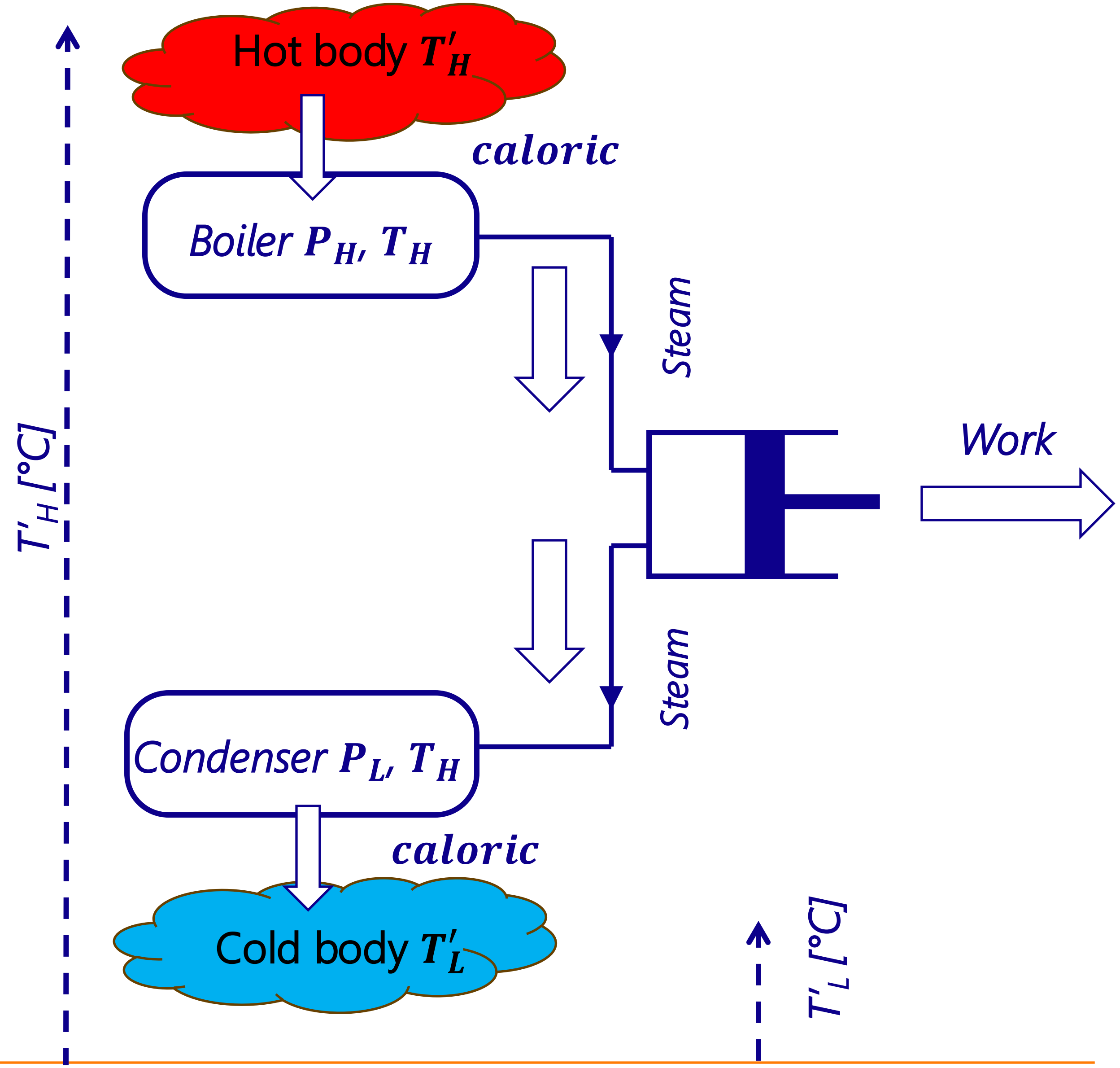
« Reflections »

The contributions of the book

Contribution #1: the maximum of work depends on the difference of temperature (but not the pressures) (very good intuition)

“fall of height of the caloric” = difference between the temperature of the hot body and that of the cold body

> *« The matter here dealt with being entirely new, we are obliged to employ expressions not in use as yet, and which perhaps are less clear than is desirable »*



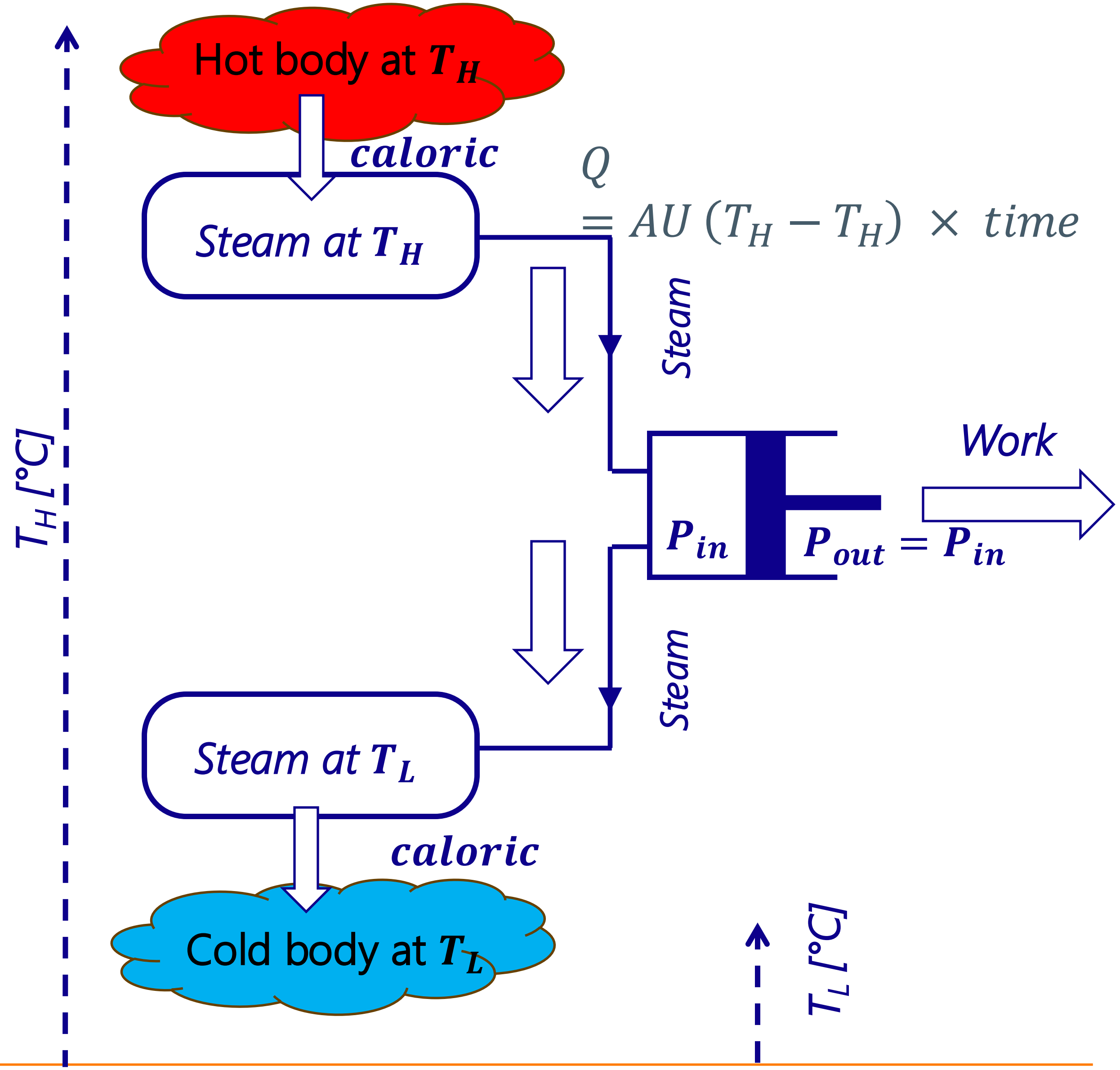
« Reflections »
The contributions of the book

Contribution #2: The **reversible** heat engine is introduced

- **No temperature difference** associated with the heat transfer (ideal but impossible)
- Pressures on both sides of piston are equal

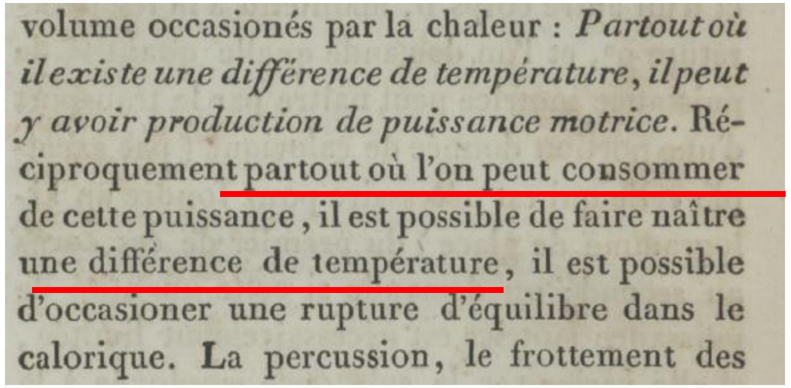
=> The machine functioning is **infinitely slow.**

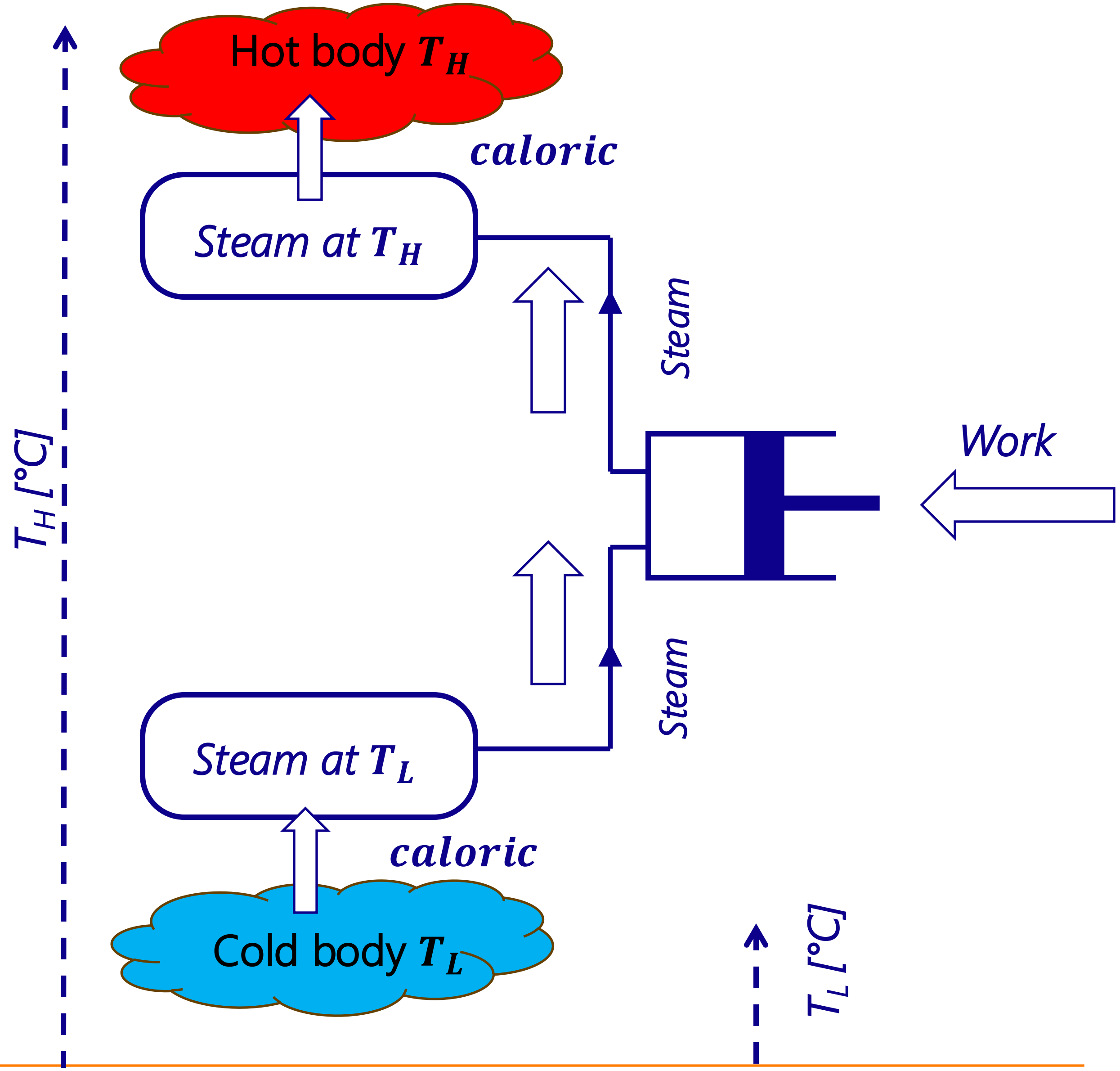
- No caloric loss to the environment.



« Reflections »
The contributions of the book

The motor being reversible, it could be inverted …
=> Carnot anticipated the working principle of the **heat pump**.

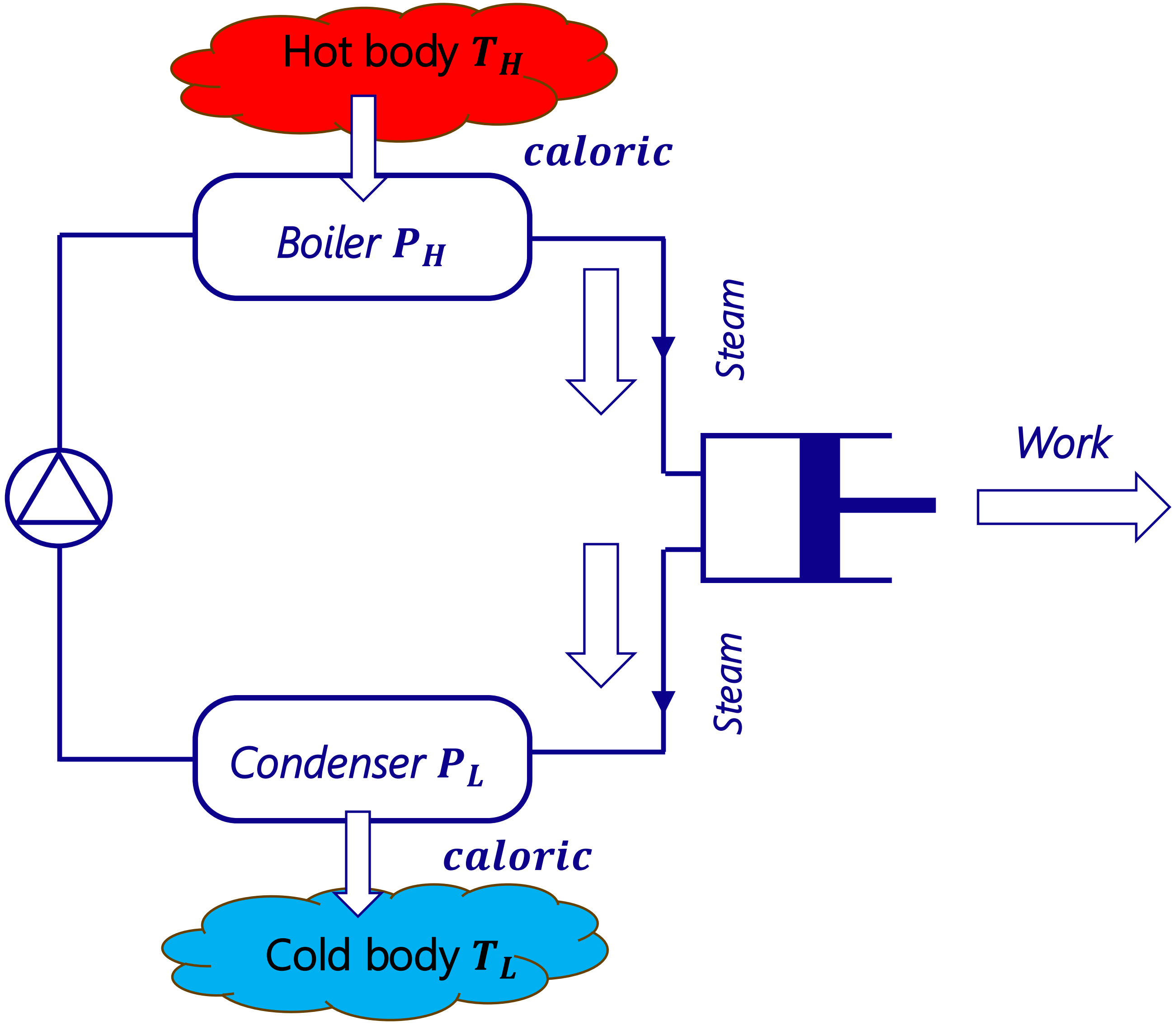

volume occasionés par la chaleur : *Partout où il existe une différence de température, il peut y avoir production de puissance motrice.* Réciproquement partout où l'on peut consommer de cette puissance, il est possible de faire naître une différence de température, il est possible d'occasioner une rupture d'équilibre dans le calorique. La percussion, le frottement des



« Reflections »
The contributions of the book

Contribution #3: the system Boiler-Expander-Condenser-Pump vs Expander alone

=> The concept of cycle is introduced



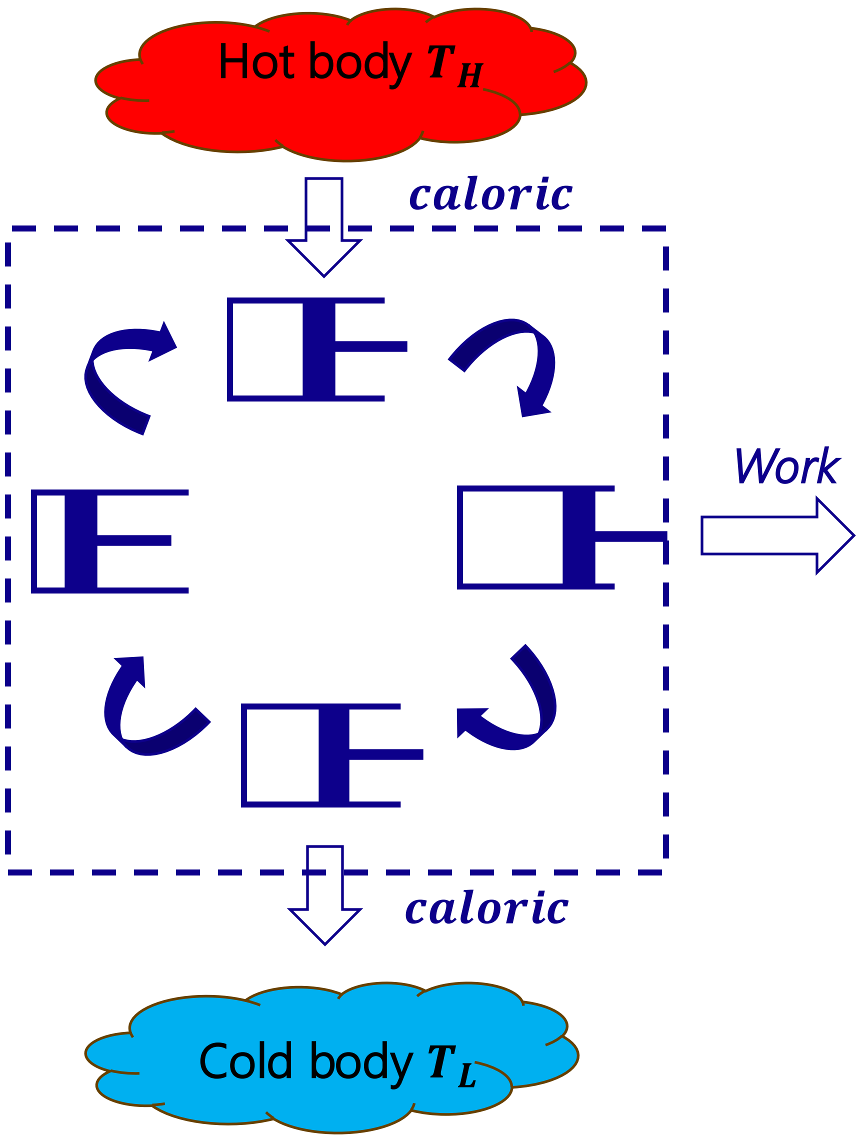
« Reflections »

The contributions of the book

Contribution #4: the maximum power of a heat engine is independent of the fluid and technological aspects. It only depends on temperatures.

The formula $\boldsymbol{\eta = 1 - T_L/T_H}$ appears in the 1850s, but Carnot showed (p. 72-3) that

$$W_{max}(1\ to\ 0°C) > W_{max}(101\ to\ 100°C)$$



« Reflections »

The reception of the book

- The book was presented in Academy of Sciences in June 1824
- The book didn't receive a lot of success
    - ✓ Not enough practical for engineers
    - ✓ Didn't meet the standards of academia
- Carnot died from cholera in 1832, his papers were burned
- Notes written at the end of his life were made public by his brother in 1878 (designs of experiments that would have certainly demonstrated the mechanical equivalent of heat)

Portrait of Sadi Nicolas Léonard Carnot (1796-1832), as an adult around 1830
Source: Académie François Bourdon, Le Creusot

The re-discovery of the book by Clapeyron, Thomson and Clausius

- **Clapeyron** discovered the book and introduced more mathematics and the P-v diagram (1834)
- **Thomson** read Clapeyron, found Carnot's book and wrote 2 books (1848 and 1849): Reflections « **as one the greatest scientific works ever written** » (Translation of Reflections by Robert Fox in 1986)
- **Clausius** wrote many books from 1850 to 1869. He proposed a new state variable (**entropy**) proposing the canvas of modern classical thermodynamics

> Je crois qu'il est de quelque intérêt de reprendre cette théorie; M. S. Carnot, évitant l'emploi de l'analyse mathématique, arrive par une série de raisonnemens délicats et difficiles à saisir, à des résultats qui se déduisent sans peine d'une loi plus générale, que je vais chercher à établir. Mais avant d'entrer en matière, il est utile de revenir sur

$$\Delta E = Q_{in} - Q_{out} + W_{in} - W_{out} + \sum m_{in} h_{in} - \sum m_{out} h_{out}$$

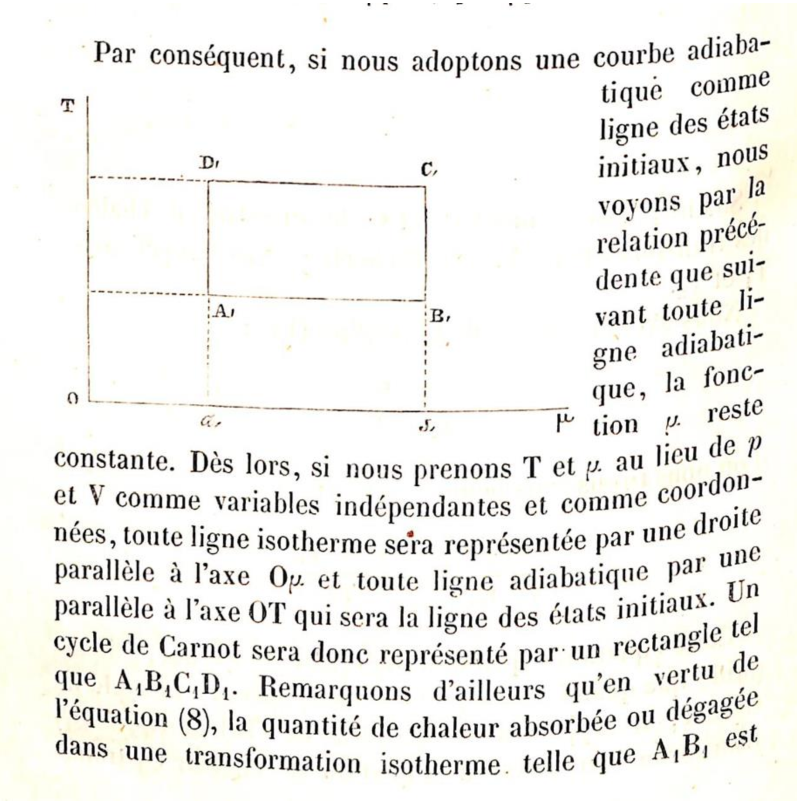
$$\Delta S = \underbrace{\sum Q_k/T_k + \sum m_{in} s_{in} - \sum m_{out} s_{out}}_{\text{Entropy transfer}} + \underbrace{S_{gen}}_{\text{Entropy generation } (\geq 0)}$$

Entropy transfer   Entropy generation (≥ 0)

Théodore Belpaire and the temperature-entropy diagram

Théodore Belpaire (1848-1893), a Belgian engineer graduated from Ghent university, proposed to use T and s rather than P and v to represent the Carnot cycle.

The **first rectangular Carnot cycle diagram** was published in a Belgian journal in 1872.



Par conséquent, si nous adoptons une courbe adiabatique comme ligne des états initiaux, nous voyons par la relation précédente que suivant toute ligne adiabatique, la fonction μ reste constante. Dès lors, si nous prenons T et μ au lieu de p et V comme variables indépendantes et comme coordonnées, toute ligne isotherme sera représentée par une droite parallèle à l'axe $O\mu$ et toute ligne adiabatique par une parallèle à l'axe OT qui sera la ligne des états initiaux. Un cycle de Carnot sera donc représenté par un rectangle tel que $A_1B_1C_1D_1$. Remarquons d'ailleurs qu'en vertu de l'équation (8), la quantité de chaleur absorbée ou dégagée dans une transformation isotherme telle que A_1B_1 est

Théo BELPAIRE, « Note sur le second principe de la thermodynamique, » *Bulletins de l'Académie Royale des Sciences, des Lettres, et des Beaux-Arts de Belgique*, 34, 1872, p. 509-10

Jules Boulvin and the entropy diagram

Jules Boulvin (1855-1920), professor at Ghent University, generalized the use of the entropy diagram to other engines and refrigeration cycles

LE DIAGRAMME ENTROPIQUE

ET SES APPLICATIONS

Par **M. J. Boulvin**, Professeur à l'Université de Gand.

Remarquons toutefois que la chaleur abandonnée au réfrigérant se compose des deux parties *bb'c'c* et *cdd'c'* ; la dernière portion, abandonnée à la température T_2 du réfrigérant, ne peut plus être utilisée, mais la première, rigoureusement égale à celle nécessaire pour accomplir la transformation *da*, pourrait être tenue en réserve, et être communiquée au fluide pour le ramener gratuitement à l'état initial. Les deux adiabatiques du cycle de Carnot seraient ainsi remplacées par les deux transformations *bc*, *da*, qui n'emprunteraient rien au foyer, et le rendement d'un pareil cycle, formé de deux isothermiques et de deux transformations qui se compensent, nommées *isodiabatiques* par Rankine, serait égal au rendement du cycle de Carnot.

Examinons comment les deux transformations *bc*, *da*, peuvent se compenser :

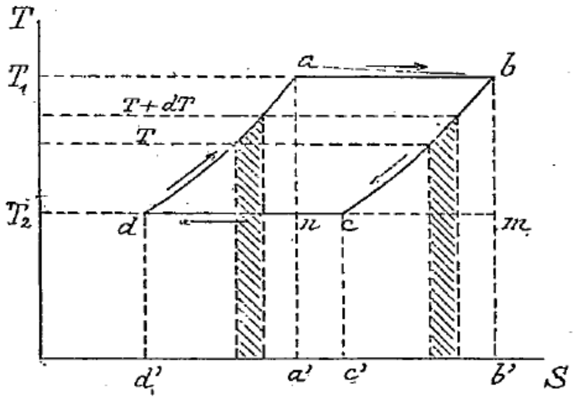


FIG. 7.

In *Revue de Mécanique*, 1897, pp. 22-33

Carnot 2024 Liège, BE

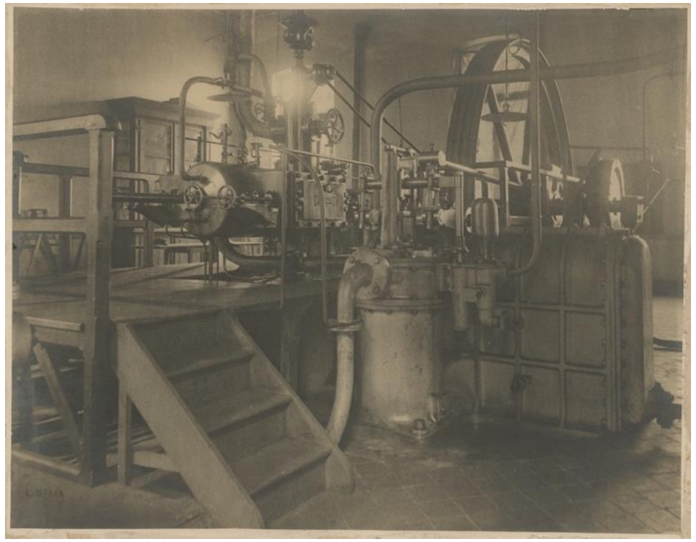
Victor Dwelshauvers-Dery and the experimental research

Victor Dwelshauvers-Dery (1855-1920), professor at Liege University, popularized the experimental research in mechanical engineering in academia.

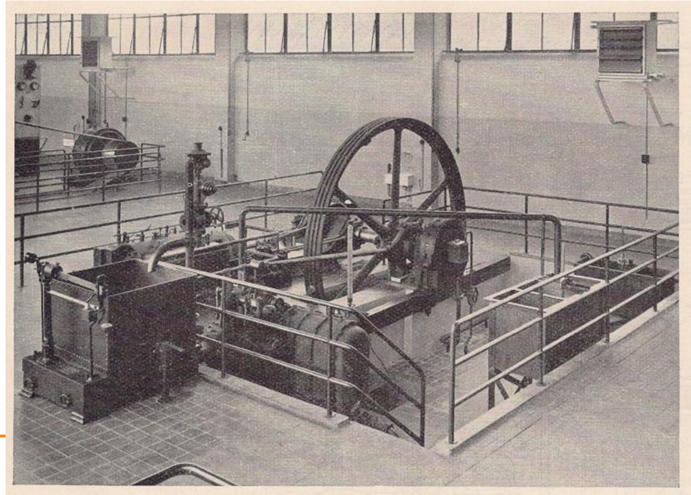
He established the Thermodynamics laboratory (1887) with the strong support of Hirn.

He investigated heat transfer between expander wall and steam.

The experimental practice in our lab has been carried on to this day (Hubert, du Chesne, Danze, Burnay, Fafchamps, Buchet, Hannay, Lebrun)



View of steam engine in Mechanics Laboratory.
© Musée Wittert ULiège

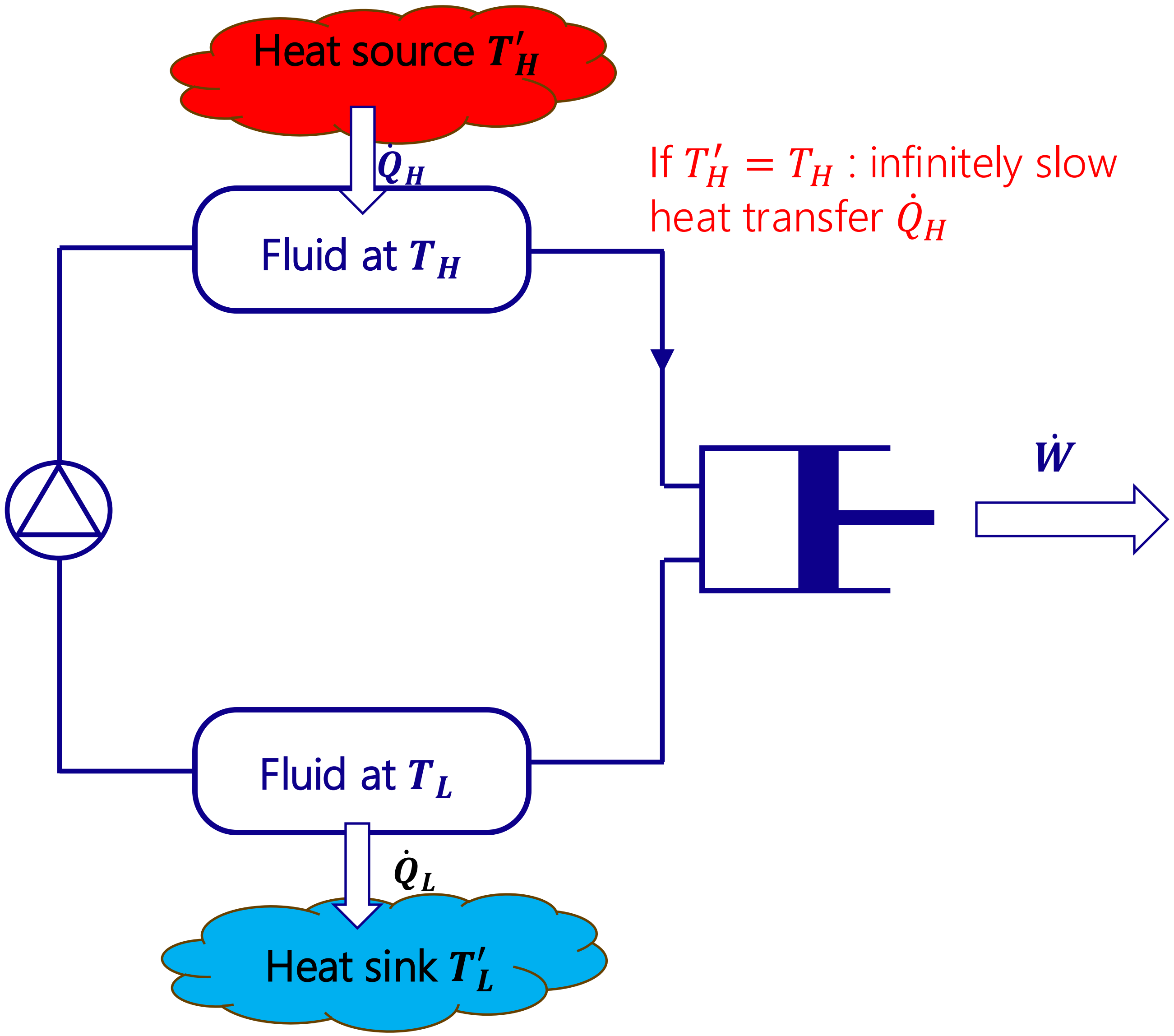


View of the steam engine in the new Thermodynamics Laboratory in Val-Benoît ca. 1937.

Chambadal, Reitlinger and the Finite-Time Thermodynamics

The Carnot heat engine is not practical since it takes an infinite time to produce a finite quantity of work.

What is the temperature T_H of the fluid maximizing $\dot{W}$ and what is the engine efficiency?



Chambadal, Reitlinger and the Finite-Time Thermodynamics

Curzon and Ahlborn demonstrated in a seminal paper of 1974 that the efficiency of an endoreversible heat engine at maximum power is given by

$$\eta_{CA} = 1 - \sqrt{\frac{T'_L}{T'_H}}$$

« nice radical function »

AJP Volume 43

Efficiency of a Carnot Engine at Maximum Power Output

F. L. CURZON
B. AHLBORN
Department of Physics
University of British Columbia
Vancouver, B.C., Canada
(Received 9 November 1973; revised 14 May 1974)

The efficiency of a Carnot engine is treated for the case where the power output is limited by the rates of heat transfer to and from the working substance. It is shown that the efficiency, η, at maximum power output is given by the expression $\eta = 1 - (T_2/T_1)^{1/2}$ where T_1 and T_2 are the respective temperatures of the heat source and heat sink. It is also shown that the efficiency of existing engines is well described by the above result.

To obtain a finite power output the cycle is speeded up. However, to drive the heat flux during the isothermal expansion of the working substance, the substance must be colder than the heat source. Conversely, during the isothermal compression the working substance cannot reject heat to the sink unless it is hotter than the sink. Ultimately, the two isothermal stages take place with no change in temperature of the working substance, so that heat flows straight from the source to the sink, and no mechanical work is performed by the engine. Hence the power output is zero and the engine has zero efficiency. Somewhere between these two extremes of zero power (i.e., optimum or zero efficiency) the engine clearly has a maximum power output. The efficiency under conditions of maximum power output is evaluated below.

Chambadal, Reitlinger and the Finite-Time Thermodynamics

It has been found later that Chambadal, a French engineer graduated from Ghent University and working at EDF, already used that efficiency in 1949. A Russian researcher, Novikov also demonstrated this relationship in 1957*.

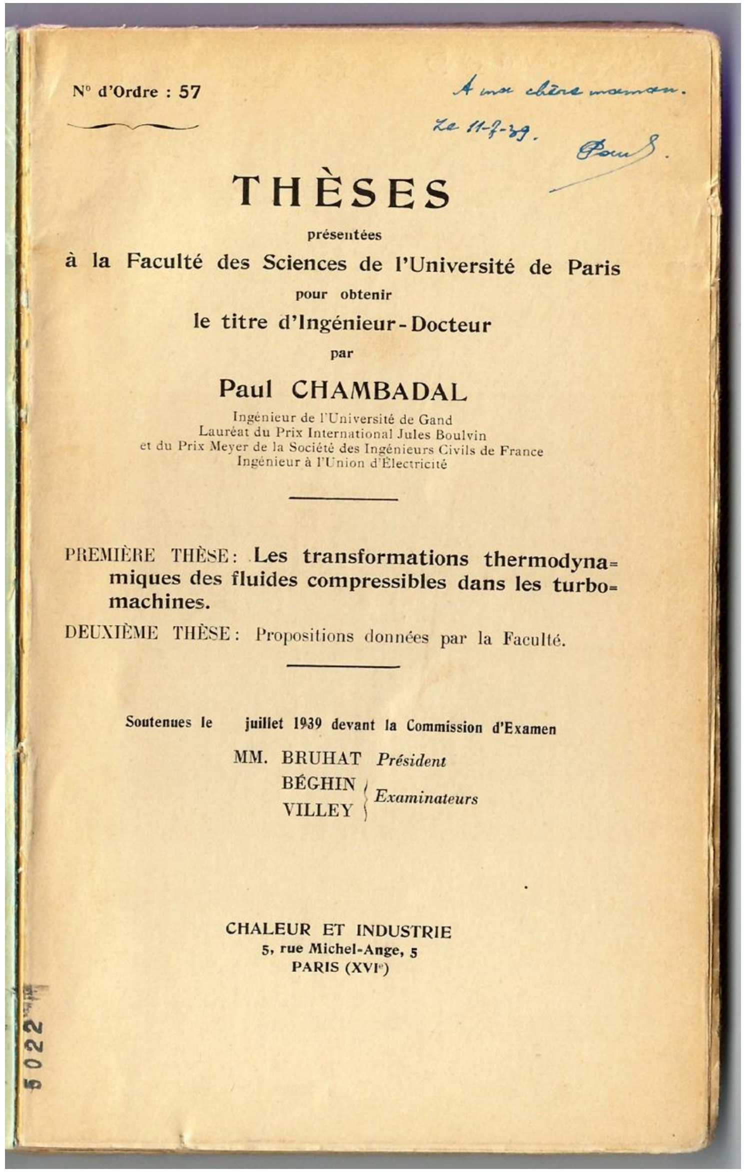
Adrian Bejan prosed to call this efficiency the *Chambadal-Novikov-Curzon-Ahlborn efficiency*

1N

$$\eta_{CNCA} = 1 - \sqrt{\frac{T'_L}{T'_H}}$$

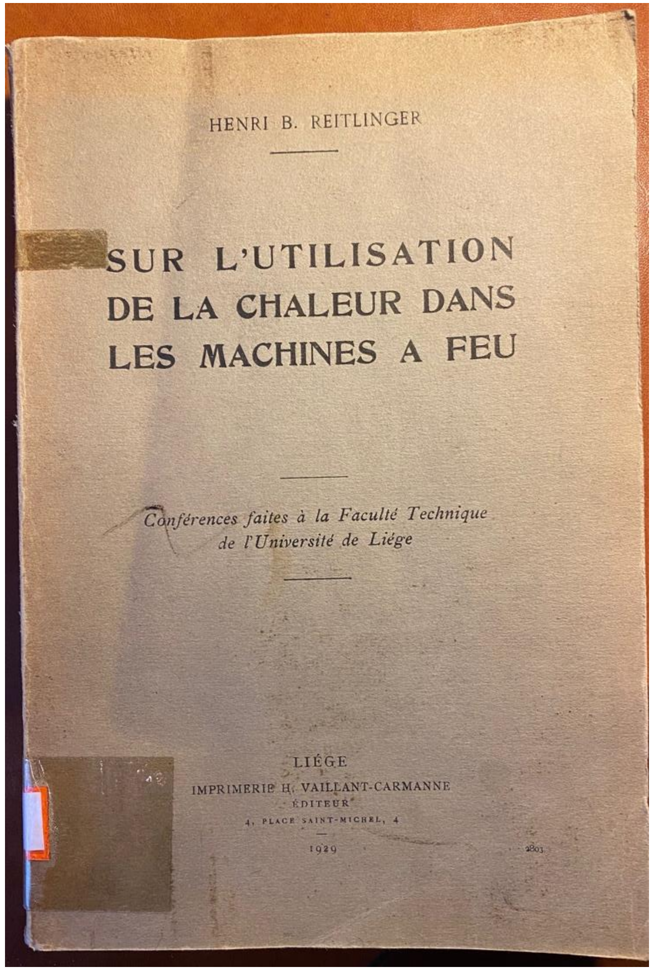
But*…

*See: Vaudrey, Alexandre & Lanzetta, François & Feidt, Michel. (2014). H. B. Reitlinger and the origins of the Efficiency at Maximum Power formula for Heat Engines. Journal of Non-Equilibrium Thermodynamics. 39. 199-203.



Courtesy of Prof. François Lanzetta

Chambadal, Reitlinger and the Finite-Time Thermodynamics

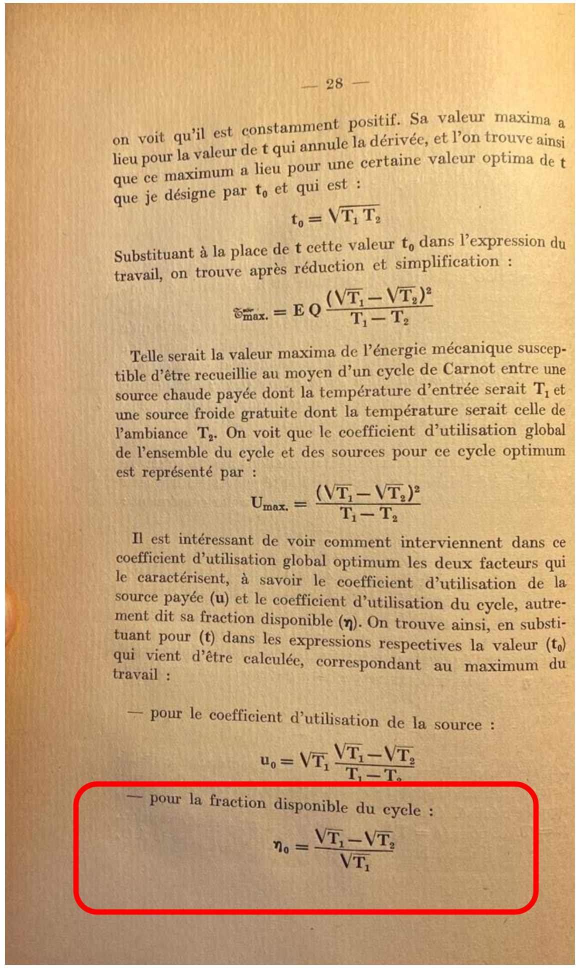


HENRI B. REITLINGER

SUR L'UTILISATION DE LA CHALEUR DANS LES MACHINES A FEU

Conférences faites à la Faculté Technique de l'Université de Liége

LIÉGE
IMPRIMERIE H. VAILLANT-CARMANNE
ÉDITEUR
4, PLACE SAINT-MICHEL, 4
1929



— 28 —

on voit qu'il est constamment positif. Sa valeur maxima a lieu pour la valeur de t qui annule la dérivée, et l'on trouve ainsi que ce maximum a lieu pour une certaine valeur optima de t que je désigne par t_0 et qui est :

$$t_0 = \sqrt{T_1 T_2}$$

Substituant à la place de t cette valeur t_0 dans l'expression du travail, on trouve après réduction et simplification :

$$\mathfrak{T}_{max.} = E\,Q\,\frac{(\sqrt{T_1} - \sqrt{T_2})^2}{T_1 - T_2}$$

Telle serait la valeur maxima de l'énergie mécanique susceptible d'être recueillie au moyen d'un cycle de Carnot entre une source chaude payée dont la température d'entrée serait T_1 et une source froide gratuite dont la température serait celle de l'ambiance T_2. On voit que le coefficient d'utilisation global de l'ensemble du cycle et des sources pour ce cycle optimum est représenté par :

$$U_{max.} = \frac{(\sqrt{T_1} - \sqrt{T_2})^2}{T_1 - T_2}$$

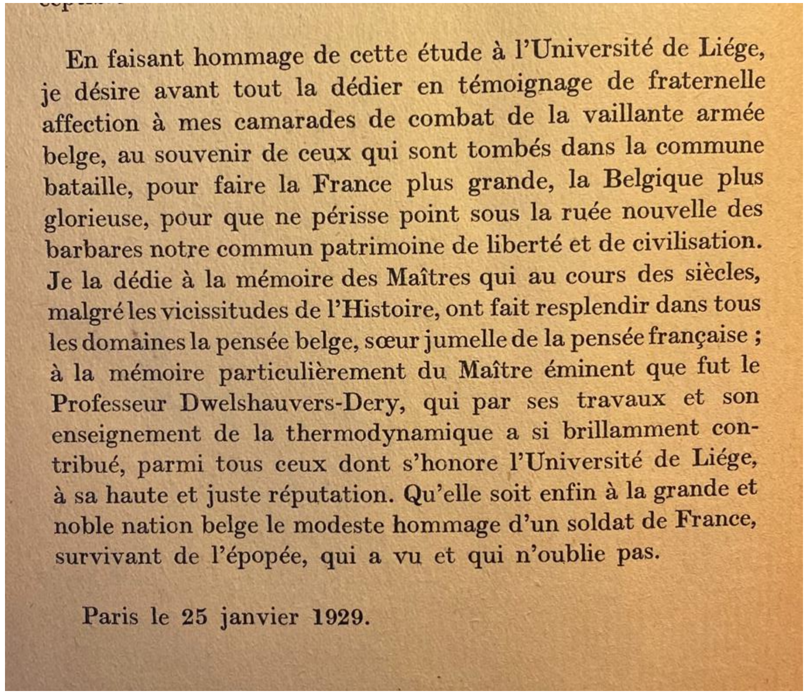
Il est intéressant de voir comment interviennent dans ce coefficient d'utilisation global optimum les deux facteurs qui le caractérisent, à savoir le coefficient d'utilisation de la source payée (u) et le coefficient d'utilisation du cycle, autrement dit sa fraction disponible (η). On trouve ainsi, en substituant pour (t) dans les expressions respectives la valeur (t_0) qui vient d'être calculée, correspondant au maximum du travail :

— pour le coefficient d'utilisation de la source :

$$u_0 = \sqrt{T_1}\,\frac{\sqrt{T_1} - \sqrt{T_2}}{T_1 - T_2}$$

— pour la fraction disponible du cycle :

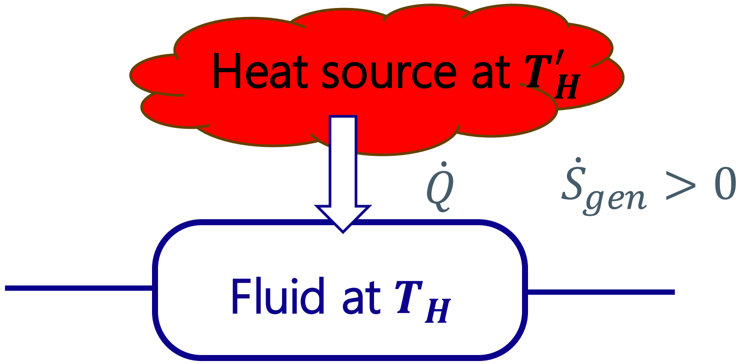
$$\eta_0 = \frac{\sqrt{T_1} - \sqrt{T_2}}{\sqrt{T_1}}$$



En faisant hommage de cette étude à l'Université de Liége, je désire avant tout la dédier en témoignage de fraternelle affection à mes camarades de combat de la vaillante armée belge, au souvenir de ceux qui sont tombés dans la commune bataille, pour faire la France plus grande, la Belgique plus glorieuse, pour que ne périsse point sous la ruée nouvelle des barbares notre commun patrimoine de liberté et de civilisation. Je la dédie à la mémoire des Maîtres qui au cours des siècles, malgré les vicissitudes de l'Histoire, ont fait resplendir dans tous les domaines la pensée belge, sœur jumelle de la pensée française ; à la mémoire particulièrement du Maître éminent que fut le Professeur Dwelshauvers-Dery, qui par ses travaux et son enseignement de la thermodynamique a si brillamment contribué, parmi tous ceux dont s'honore l'Université de Liége, à sa haute et juste réputation. Qu'elle soit enfin à la grande et noble nation belge le modeste hommage d'un soldat de France, survivant de l'épopée, qui a vu et qui n'oublie pas.

Paris le 25 janvier 1929.

De Donder, Prigogine, Nicolis and thermodynamics of irreversible processes



- Entropy production rate $\dot{S}_{gen}$ expressed as **the product of a flux by a force**. For instance, in the case of heat transfer

$$\dot{S}_{gen} = \dot{Q} \times \left(\frac{1}{T_H} - \frac{1}{T'_H}\right) > 0$$

- This approach can be **generalized to many physical processus:** piston movement under a difference of pressure, electric current through a resistance, diffusion due to concentration gradients, flow in a porous medium due to pressure gradient…

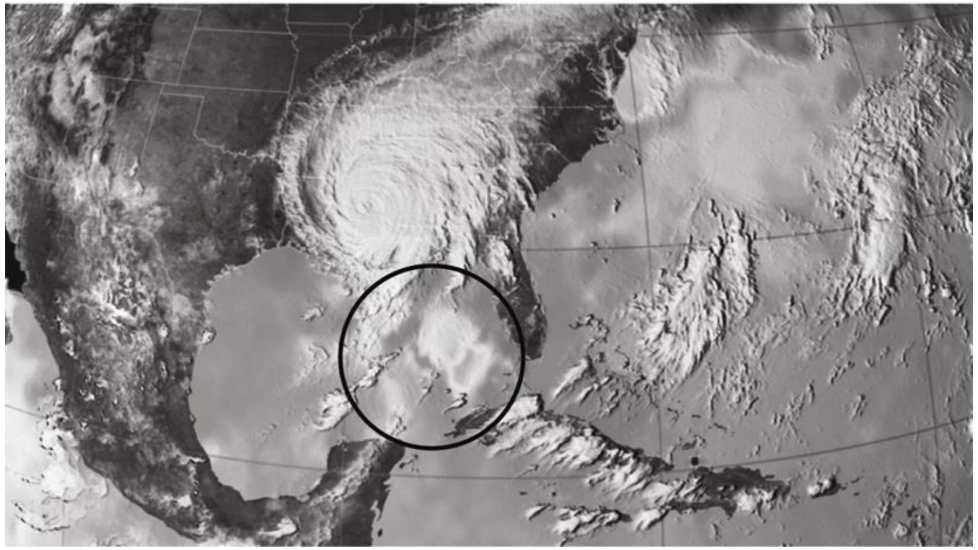
- At equilibrium: no force=> no flux.

De Donder, Prigogine, Nicolis and thermodynamics of irreversible processes

- **Close to equilibrium** (forces are weak), the formulation can be linearized. In the case of the heat transfer, the approach yields Fourrier's law of conduction (1822)

- **Far from equilibrium**, the system can evolve towards an organized and stationary structure, creating a lot of entropy provided it is fed by energy and mass = **dissipative structure**

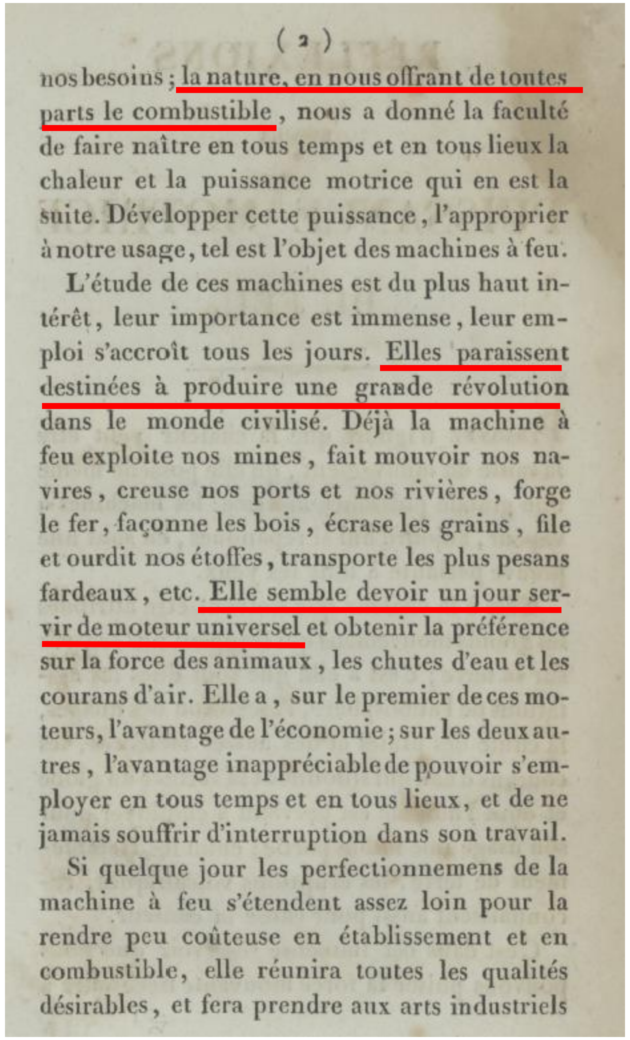
"The destruction of order prevails in the neighborhood of equilibrium. Creation of order may occur far from equilibrium provided the system obeys to nonlinear laws of a certain type." (Nicolis and Prigogine, 1977)



"Cold water trail left by Hurricane Katrina in 2005"
Source: Tiezzi et al., Dissipative structures in nature and human systems, WIT Transactions on Ecology and the Environment, Vol 114, 2008

What is the legacy of Carnot?

Universal engine + infinite fuel = large revolution



(2)

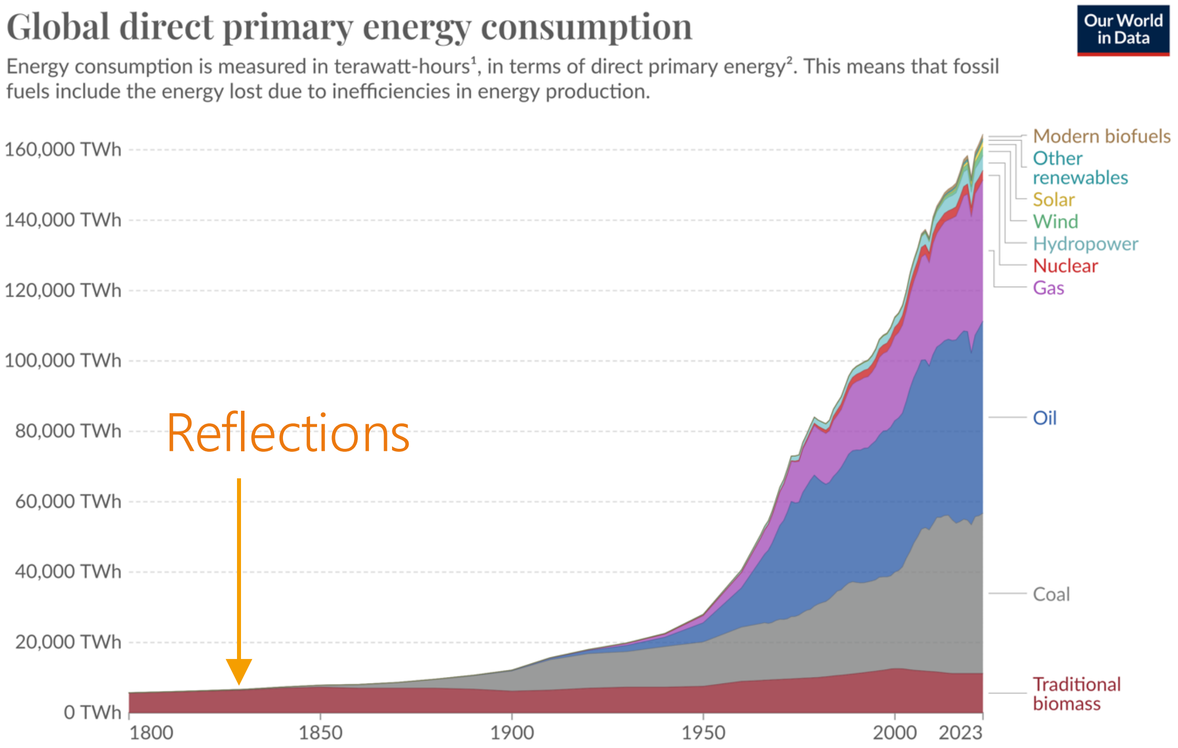
nos besoins ; la nature, en nous offrant de toutes parts le combustible, nous a donné la faculté de faire naître en tous temps et en tous lieux la chaleur et la puissance motrice qui en est la suite. Développer cette puissance, l'approprier à notre usage, tel est l'objet des machines à feu.

L'étude de ces machines est du plus haut intérêt, leur importance est immense, leur emploi s'accroît tous les jours. Elles paraissent destinées à produire une grande révolution dans le monde civilisé. Déjà la machine à feu exploite nos mines, fait mouvoir nos navires, creuse nos ports et nos rivières, forge le fer, façonne les bois, écrase les grains, file et ourdit nos étoffes, transporte les plus pesans fardeaux, etc. Elle semble devoir un jour servir de moteur universel et obtenir la préférence sur la force des animaux, les chutes d'eau et les courans d'air. Elle a, sur le premier de ces moteurs, l'avantage de l'économie ; sur les deux autres, l'avantage inappréciable de pouvoir s'employer en tous temps et en tous lieux, et de ne jamais souffrir d'interruption dans son travail.

Si quelque jour les perfectionnemens de la machine à feu s'étendent assez loin pour la rendre peu coûteuse en établissement et en combustible, elle réunira toutes les qualités désirables, et fera prendre aux arts industriels

Global direct primary energy consumption

Energy consumption is measured in terawatt-hours[1], in terms of direct primary energy[2]. This means that fossil fuels include the energy lost due to inefficiencies in energy production.



Data source: Energy Institute - Statistical Review of World Energy (2024); Smil (2017) OurWorldinData.org/energy | CC BY
Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.

1. Watt-hour: A watt-hour is the energy delivered by one watt of power for one hour. Since one watt is equivalent to one joule per second, a watt-hour is equivalent to 3600 joules of energy. Metric prefixes are used for multiples of the unit, usually: - kilowatt-hours (kWh), or a thousand watt-hours. - Megawatt-hours (MWh), or a million watt-hours. - Gigawatt-hours (GWh), or a billion watt-hours. - Terawatt-hours (TWh), or a trillion watt-hours.

2. Primary energy: Primary energy is the energy available as resources – such as the fuels burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that the end user needs, in the form of electricity, transport and heating, plus inefficiencies and energy that is lost when raw resources are transformed into a usable form. You can read more on the different ways of measuring energy in our article.

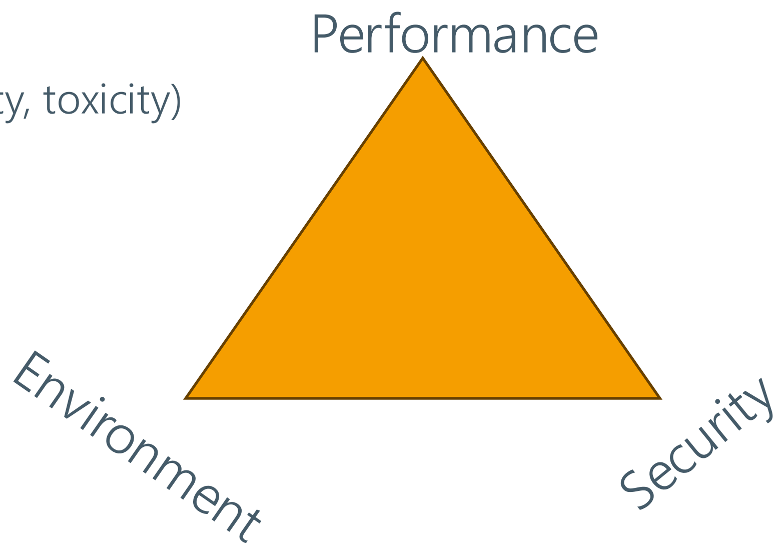
(See CHEVRIER, Joël, Sadi Carnot face à la fin de la civilisation thermo-industrielle, Le Creusot, 2024)

What is the legacy of Carnot? (limited to thermal engineering)

- Temperatures:
  - Temperature, temperature gradients, temperature lifts, temperature spread… are still key optimization variable
  - High temperature cooling and low temperature heating for efficient HVAC systems (better heat pump COP/ use of passive cooling)
  - High temperature heat pumps to replace gas boiler in industry
  - Techniques for low temperature waste heat valorization
  - Cryogenics (<120 K) for medical applications, gas liquefaction as well as research in space sciences and quantum physics $\left(COP_L = \frac{T_L}{T_H - T_L} = 0{,}00687 \; at \; T_L = 2K \; and \; T_H = 293K\right)$

What is the legacy of Carnot? (limited to thermal engineering)

- **Fluids**
  - "all fluids are good" but no fluid is perfect (GWP, TFA, flammability, toxicity)
  - Complex fluids: zeotropic mixtures, oil-fluid



- **Reversibility**
  - Heat pump + TES + heat engine = Carnot battery
  - Other hybridization of heat pumps and heat engines
- **Cycle vs component**
  - The design of machines is constrained by its components (f.i.: 2-phase compressors/expanders for new cycles, high temperature compressor for HT heat pumps)

Objectives of the conference

- Bridge researchers from different sub-fields of thermodynamics
- Discover new fields and applications of thermodynamics and learn about the state of knowledge
- Connect thermodynamics to other and younger fields of engineering and sciences: materials, manufacturing processes, AI, energy grids management,…
- Investigate thermodynamics at different scales going from fluids/materials to energy communities: how is it useful (or limited)?
- Exchange good practices for teaching thermodynamics
- …

Topics

- Day 1: Traveling between microscopic and macroscopic thermodynamics:

  Non-equilibrium, chemical thermodynamics (fluid and materials properties), fluid mechanics, heat engines (power plants, gas turbines, Stirling/Ericsson, ORC)

- Day 2: HVAC & refrigeration

  Heat pumps, passive cooling, high temperature heat pumps, not-in-kind cooling technologies, thermal storage, thermal energy transport

- Day 3: Thermodynamics and the energy transition

  Climatology, Carbon capture, power-to-fuel, energy transition scenarios, nuclear fusion

Many thanks to

- You for attending
- More than 110 people who prepared presentations of their work (40 speakers and 70 posters)
- My team who accepted to follow me in the idea of organizing a conference in 1 year.
- All reviewers
- …

Thank you to the organizations who endorsed this event

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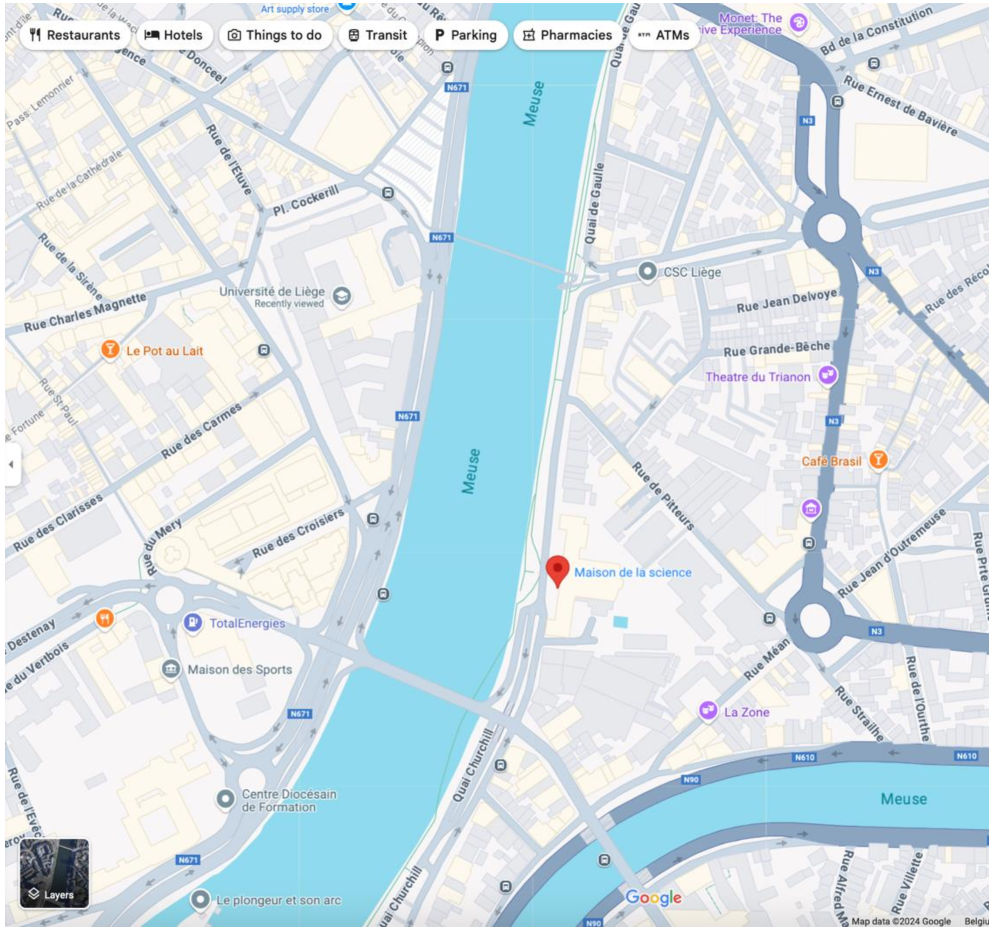
Housekeeping information

- Coffee breaks are organized in the ”Professor rooms” (climb 2 stairs) except tomorrow morning
- Cloak room
- Meeting room available (3/28b). Not very close from here but indicated
- Restrooms: go down the stairs
- Poster ID are already installed on panels. Material to fix the poster is available.

Housekeeping information

- Welcome drink – 18:15-22:00
- Maison de la science, Quai Edouard Van Beneden 22, 4020 Liège: House of Science - Google Maps
- Short conference by Prof. Raffaele Pisano, Université de Lille, France
- Free visit of Museum (with a temporary exhibition that will show case *Reflections*) and Aquarium



I wish you a very nice conference and fruitful exchanges!