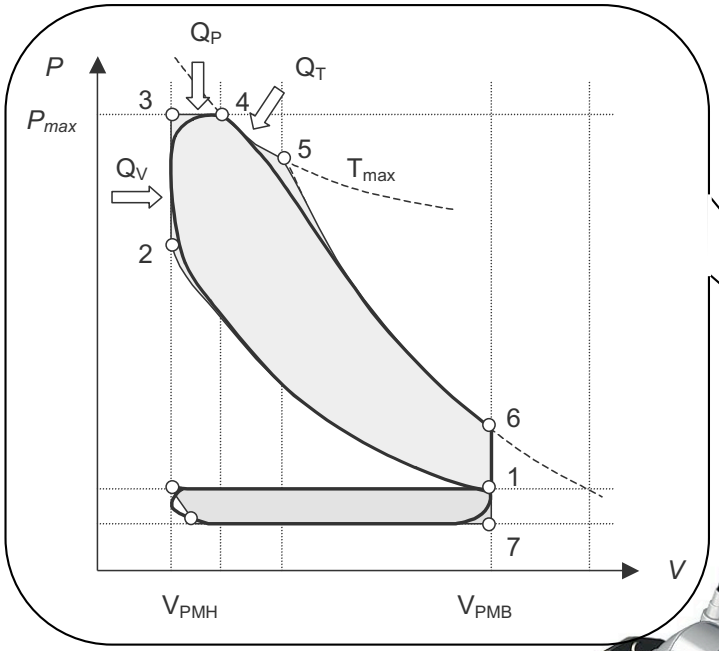
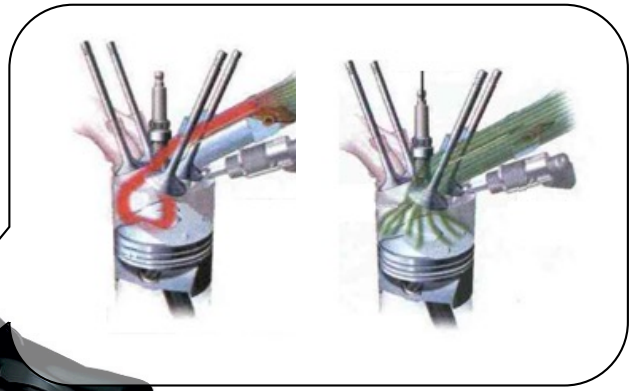
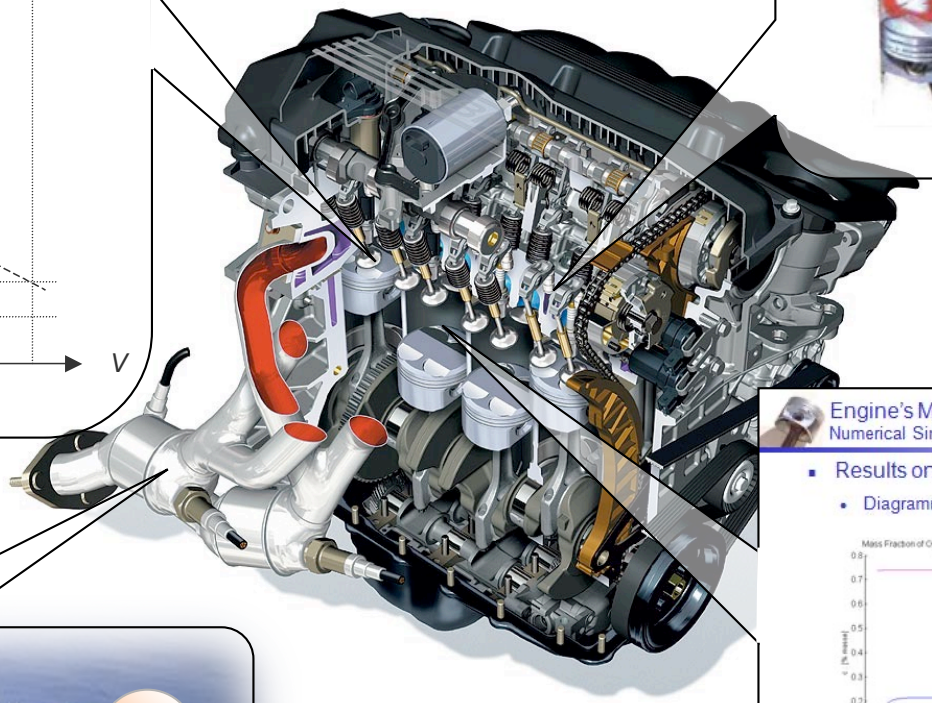
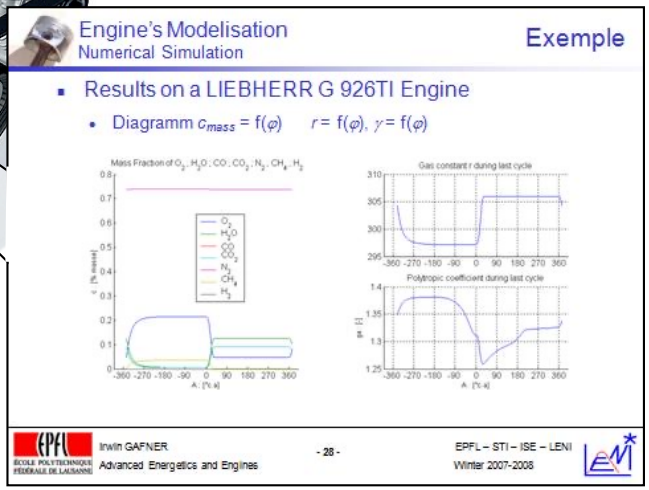
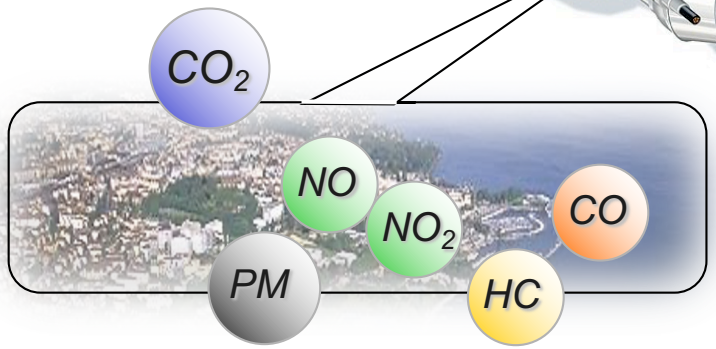
# Engines


P
V
$Q_P$
$Q_T$
$Q_V$
$P_{max}$
$T_{max}$
1
2
3
4
5
6
7
$V_{PMH}$
$V_{PMB}$






Engine's Modelisation
Numerical Simulation
Exemple
Results on a LIEBHERR G 926TI Engine
Diagramm $c_{mass}$ = f($\varphi$) r = f($\varphi$), $\gamma$ = f($\varphi$)
Irwin GAFNER
Advanced Energetics and Engines
- 28 -
EPFL – STI – ISE – LENI
Winter 2007-2008


$CO_2$
NO
$NO_2$
CO
PM
HC

# Engines – preamble

- Reference books:

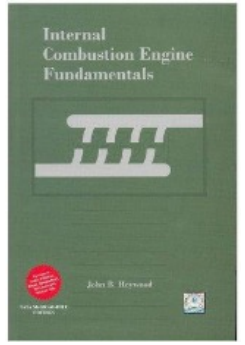
  A) Thermodynamique & Energétique 1, *L. Borel / D. Favrat*

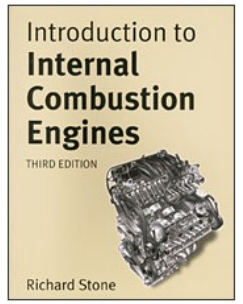
  B) Internal Combustion Engine Fundamentals, *John B. Heywood* (1988)

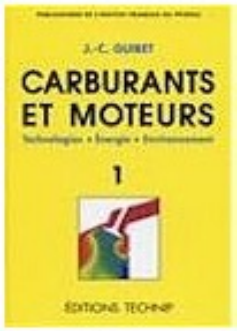
  C) Introduction to Internal Combustion Engines, *R. Stone* (SAE, 2012)

  D) Carburants & moteurs (2 books), J-C Guibet (Ed. Technip, IFP)

  **E) V Ganesan, IC Engines, 4th Ed. McGraw Hill, 2016**



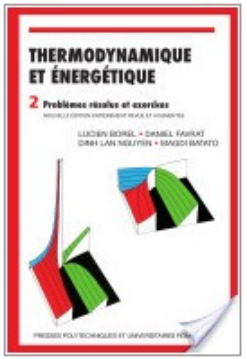




- Prerequisite:

  Thermodynamique & Energétique I & II

  *(Sophia Haussener, Jan Van herle)*

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*Martin.Gay@epfl.ch*
*Simon.Dorthe@epfl.ch*

# Engines – preamble

- Course support – moodle:
  - Slides (ppt/pdf)
  - Animation videos
  - Exercises
  - Video recording of lectures
  - Formulae mementos (=> exam in January session)

- Potential invited seminar(s) – *depending on external lecturers*
  - Dr Jean-François Tissot (Acceleron, Baden (AG) : diesel engines, turbochargers)
  - Liebherr Motors (Bulle, FR)
  - Dr Mardit Matian (EH Group, Nyon (VD) : fuel cell mobility)
  - Prof Dr David Hart (E4Tech, Lausanne : consulting studies fuel cells/electrolysis/H2)
  - Alexandre Closset (SolydEra, Yverdon : stationary fuel cells and steam electrolysers)

- Exam:

  January 2024, written (3h), 50% Engines, 50% Fuel Cells : calculation exercises. All material is allowed (open book). 60% of the final grade.

  Week 8 (Nov05): theory test on Engines (45'). Closed book. 1/6$^{th}$ of final grade.

  Week 14 (Dec17): theory test on Fuel Cells (45'). Closed book. 1/6$^{th}$ of final grade.

# Why ‘fuel cells’ & ‘engines in a shared course ?

| Similarities | Differences |
|---|---|
| Both use chemical fuel input (gas or liquid) | Engines : combustion (=>pollutants!)<br>FC : direct electrochemical conv. |
| Application: Mobility | ICE cars, trucks, ships, trains<br>FC electric (hybrid) cars, buses,… |
| Application: Stationary | Cogeneration engines : 0.1-10 MWe<br>FC cogeneration units : 1-1000 kWe |
| Complex, pluridisciplinary | Engines: mech. eng. focus<br>FC: chem.eng + mat.sci. focus |

# Engines - Objectives

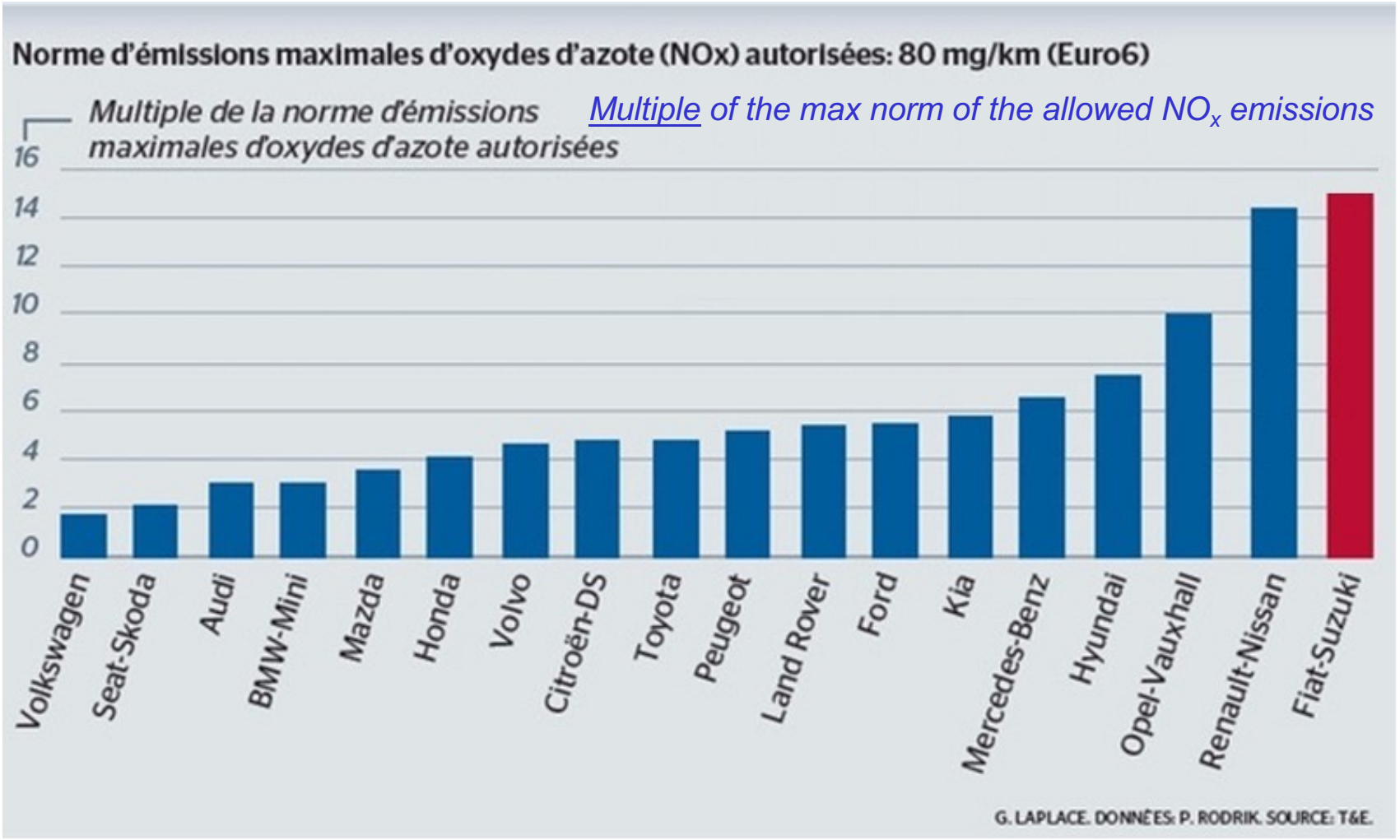
- Main objectives and targeted knowledge:

  ⇨ introduction to Internal Combustion Engines for transport and cogeneration applications

  ⇨ understand the main technological and methodological **options** in the design and use of internal combustion engines and exhaust gas treatment systems

  ⇨ understand the main technological **challenges** (trade-off) between mechanical, thermal, economical and environmental constraints

# ‘Dieselgate’




*Source: Article «24 heures», 20.09.2016*

# Engines – Course content (1/2)

## Week 1) Introduction to Internal Combustion Engines

- Description of the main components
- Operation principle (2 and 4-stroke, Diesel & Otto)
- Mechanical principles (incl. movies showing engine assemblies in 3D)
- Main material flows in an engine

10 sept

## Week 2) Thermodynamic Cycles

- Reminder of thermodynamic fundamentals
- Theoretical and real cycles

17 sept

## Week 3) Terminology and key values

- Engine cycle representation
- Engine operating characteristics
- Key factors and typical relations
- Efficiency definitions (from combustion to effective mech. power)
- Full load and operating map representation

24 Sep

# Engines – Course content (2/2)

## Week 4) Compression-Ignition Engines (CI *or* Diesel Engines)

1 oct

- Fuel properties and combustion process
- Noise analysis and prevention
- Load regulation & supercharging
- Energy distribution

## Week 5) Spark-Ignition Engines (SI *or* Otto Engines)

8 oct

- Fuel properties and combustion process (ignition, knock limit)
- Load regulation
- New combustion concepts (mixed systems, direct gasoline injection)

## Week 6) Emission treatment systems

15 oct

- Characterization of combustion gases and origin of pollutants
- Pollutant formation
- Emission standards (On & Off-road engines)
- Upstream methods and means of emissions reduction
- Downstream methods (3 way-cat, SCR, DPF, NOx trap)

***Week 7 : Invited seminar***

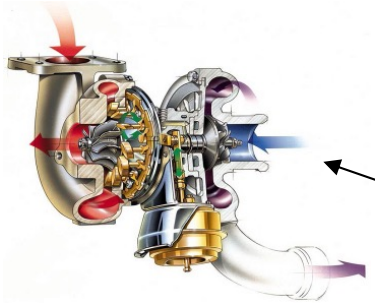
29 Oct

# Engines - course plan

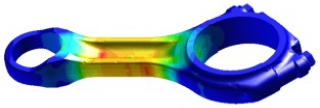
| Week | Date | *Content* | Hours | |
|---|---|---|---|---|
| | | | *Course* | *Exercise* |
| 1 | Sep-10 | Preambel<br>Week 1: General Introduction<br>Exercise 0 : simple num. examples of engine parameters | 2-3 | (intro) |
| 2 | Sep-17 | Week 2 : Themodynamic cycles<br>Exercise 1 :Thermodynamic cycle | 2 | 1 |
| 3 | Sep-24 | Week 3 : Therminology and Definitions<br>Exercise 2 : Gas engine | 2 | 1 |
| 4 | Oct-01 | Week 4 : Diesel Engines<br>Exercise 3 : Energy and exergy balance of a Diesel engine | 2 | 1 |
| 5 | Oct-08 | Week 5 : Otto Engines<br>Exercise 4 : Idle regulation of a S.I. Engine | 2 | 1 |
| 6 | Oct-15 | Week 6: Emission Treatment Systems<br>Exercise 5 : Selection of a cogeneration engine | 2 | - |
| 7 | Oct-22 | Semester break | | |
| 8 | Oct-29 | *Week 7 : Invited seminar* | 2 | 1 |
| 9 | Nov-05 | **16h15 : 45' theoretical exam on Engines part (closed book)** | 17h15 | 18h15 |

# Engines

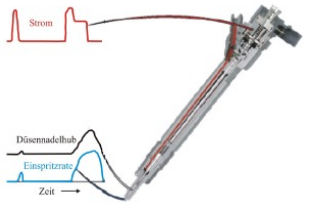
- Connection with other mech.eng. courses:



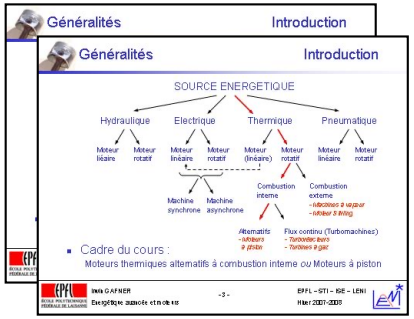
Thermal Turbomachines



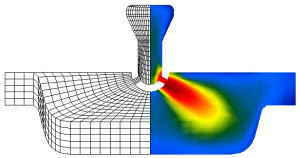
structural mechanics




Identification and control

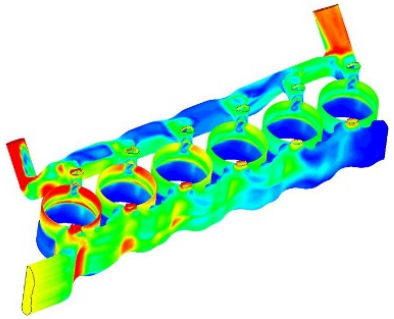



Numerical flow modelling

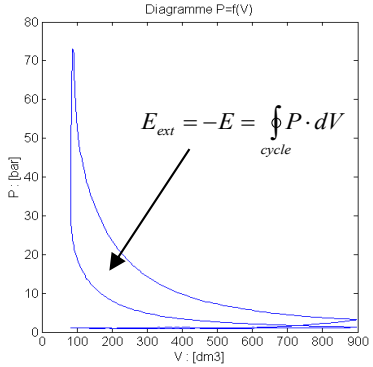


Mechanical design

Heat transfer



Thermodynamics



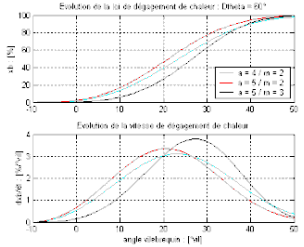

Modelling and optimization of energy systems

$$(a1)\quad \frac{dP}{P} - \frac{dT_u}{T_u} + \frac{dV_u}{V_u} = -\frac{dM_b}{M_u} + \frac{dr_u}{r_u}$$

$$(a2)\quad \frac{dP}{P} - \frac{dT_b}{T_b} - \frac{dV_u}{V_b} = +\frac{dM_b}{M_b} - \frac{dV}{V_b} + \frac{dr_b}{r_b}$$

$$(a3)\quad M_u \cdot \frac{du_u}{dT} \cdot dT_u + P \cdot dV_u = (u_u - h_u) \cdot dM_b + dQ_{u,parois}$$

$$(a4)\quad M_b \cdot \frac{du_b}{dT} \cdot dT_b - P \cdot dV_u = (h_u - u_b) \cdot dM_b - P \cdot dV + dQ_{b,parois} + dQ_{comb}$$

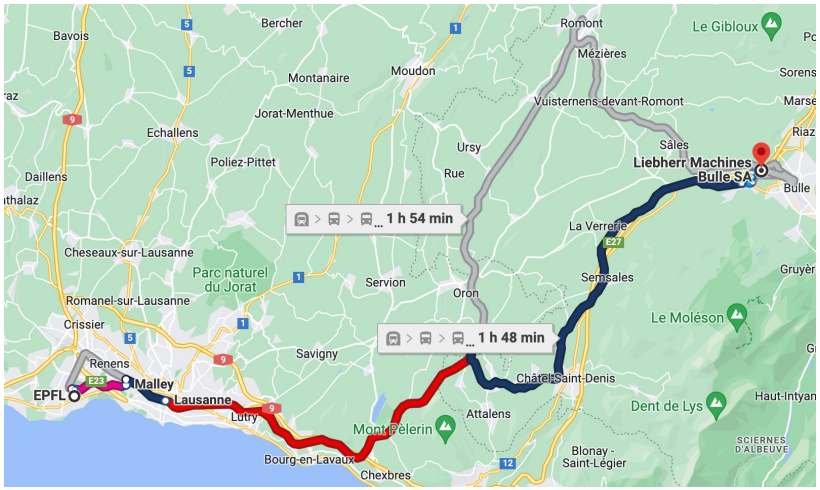


# Excursion during semester ?

- to Liebherr Engines factory, Bulle (FR)


https://youtu.be/yc2l0Azbgjk

Possible on Tue/Wed/Thu
Morning or afternoon
November or December
Max. 25 participants
Depends on personal interest



# Past master semester projects at GEM

- 79. (JAN2020) Development of a pressure damping device for an evaporator coupled with a SOE
- 82. (JUN2020) PEFC electrochemical stack model
- 87. (JAN2022) Design exploration of a SOFC-battery hybrid supply for 50 pax electric aircraft
- 91. (JUN2022) Multi-objective optimization and economic analysis of SOFC-EV charging station
- 92. (JUN2022) Cooling strategies of a PEM fuel cell using CFD
- 96. (JUN2022) Anionic membranes screening and analysis / gas crossover
- 114. (JAN2024) Degradation analysis of single-cell accelerated stress tests via electrochemical impedance spectroscopy and distribution of relaxation time methods
- 115. (JAN2024) Minimizing Environmental Impact in Hydrogen Production Systems through Optimal Stack Module Sizing and Replacement Strategy
- 116. (JAN2024) Investigation of multiple scenarios for the exploitation of a SOFC-mGT system.
- 122. (JUN2024) Solid Oxide Electrolysers fault conditions footprint by using Electrochemical Impedance Spectroscopy (EIS) and Total Harmonic Distortion (THD)
- 123. (JUN2024) Performance and stability of metal-supported Solid Oxide Electrolysis Cells

# Past master thesis projects at GEM (1)

- 48. (SEP2020) **CGN-Lausanne**, Layout of a $H_2$-electrical propulsion for a 1.8 MW ship
- 49. (SEP2020) Using $NH_3$ in SOFC for Heavy Duty Transport (*publication*)
- 50. (MAR2021) **Retrofuture-EV** (F), Integration study of an energy converter to an electric traction system in an automotive retrofit.
- 51. (MAR2021) **RUAG** (CH), Trade-off, Design and Model-Based Performance and Safety Analysis of Energy Storage Subsystems for Spacecrafts.
- 53. (MAR2021) Etude de faisabilité et conception d'un banc d'essai moteur à hydrogène
- 56. (AUG2021) **Swisshydrogen**, Development of compact FC range extender for automotive application
- 59. (JAN2022) Modeling and experimental investigation of critical conditions in reversible solid oxide cells using State-of-Health online monitoring
- 60. (JAN2022) Design and optimisation of a heat exchanger network for an integrated reversible SOFC system
- 61. (FEB2022) **Stadler**, Development of a simulation tool to optimize the design of hybrid propulsion systems on railway vehicles, and application in a case study on shunting locomotives

# Past master thesis projects at GEM (2)

- 67. (AUG2022) **Michelin**, Modélisation d'une pile à combustible à membrane polymère PEMFC
- 68. (AUG2022) **Engie**, Thermodynamic modeling of Hydrogen Refueling Station
- 69. (SEP2022) **Liebherr**, THERMOMECHANICAL FATIGUE DAMAGE MODEL FOR ICE EXHAUST MANIFOLDS
- 74. (FEB2023) Two-Phase Simulation of AEM Electrolyser Flow Channels ***(=> Patent)***
- 75. (FEB2023) MEMBRANE ELECTRODE ASSEMBLY SIMULATION OF AEMEL
- 77. (MAR2023) **EH Group**, Modelling and dimensioning of a PEMFC active humidifier
- 80. (AUG2023) **Safran**, Instrumentation de pile à combustible PEMFC
- 81. (AUG2023) **Liebherr**, Engine Design modelling combining Statistical Approaches and AI
- 82. (AUG2023) **Stadler**, Electrical Modelling of the Auxiliary Consumptions in Trains
- 84. (Mar2024) **Garrett**, Design of a cooling system for a FS eMotor
- 89. (AUG2024) **Neology**, Optimization of an ammonia to hydrogen generation system
- 90. (AUG2024) **Beyond Aerospace**, Aviation Energy Efficiency: Hybridization Strategies for Battery and Fuel Cell Systems
- 91. (AUG2024) **SolydEra**, CFD modeling and analysis of ejectors for the recirculation of fuel in a SOC system
- 93. (AUG2024) Operating strategy of SOFC system for lifespan extension and performance optimization
- 94. (AUG2024) Characterisation and analysis of PEMFC cells and stacks