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« EMR-based Scaling of Fuel Cells for on-road heavy-duty electrified vehicles»

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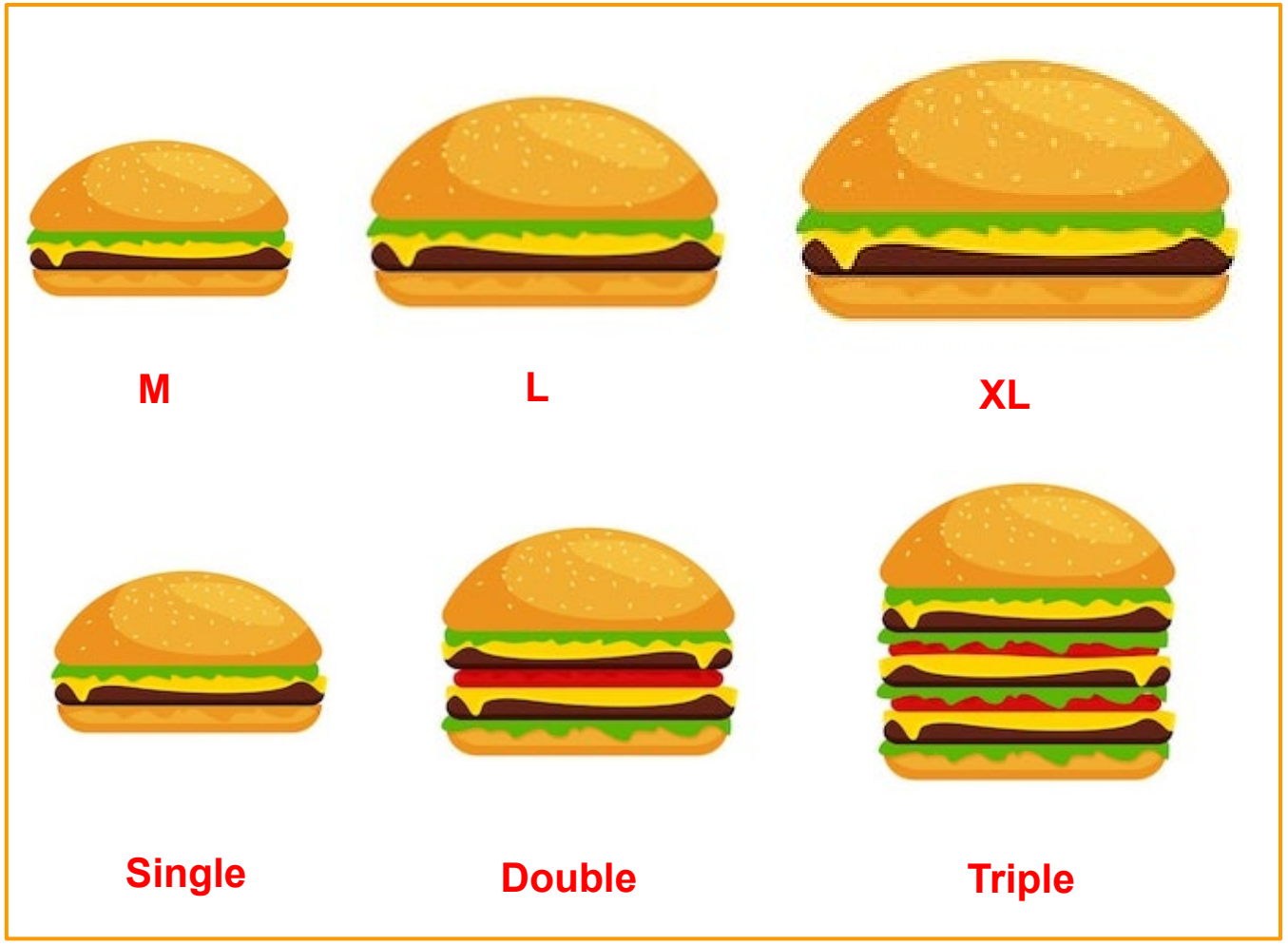
- Outline -

1. Context
2. Single fuel cell modeling
3. Global EMR and Fitting Results
4. Conclusion and Perspectives

«Context »

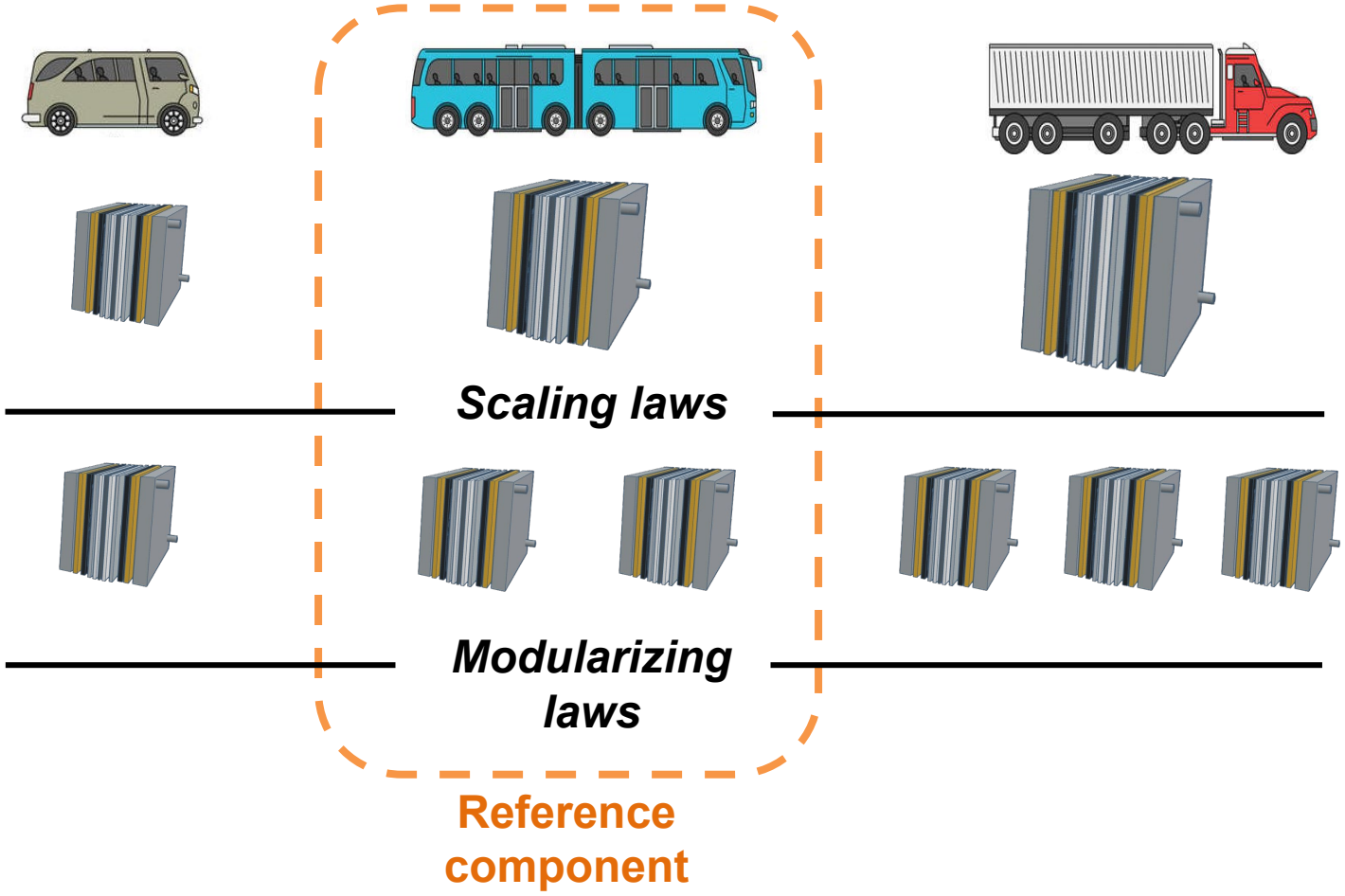


[FREEPIK]

- Easily scalable (Same ingredients)
- **Modular toppings** (cheese, salad, steak…)

A Burger Analogy: Scalability in HDVs

Can design knowledge from one application be transferred to others ?



Objective : Develop a generic method for scaling and modularizing laws using the EMR formalism that allow for up- or down-sizing reference fuel cells for on-road HDVs.

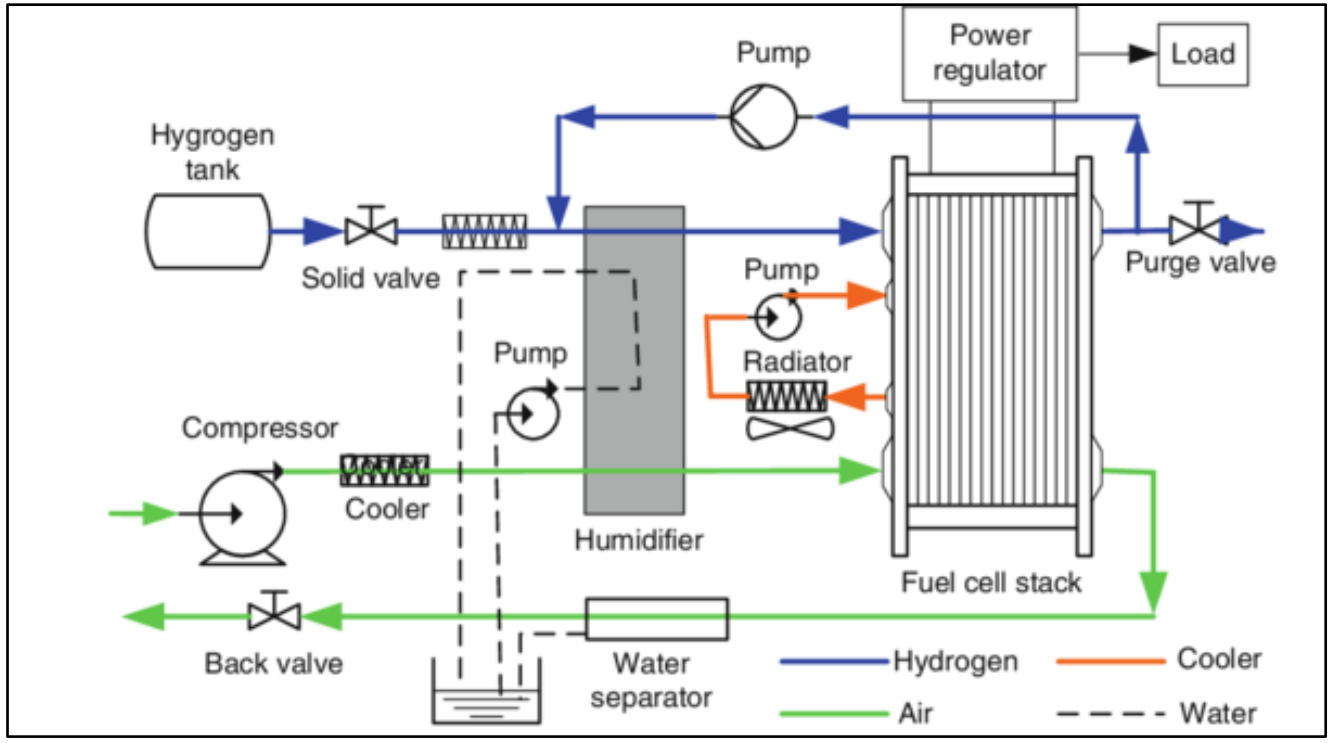
What is a PEM Fuel Cell?

- Fuel cell is an electrochemical devices.

$$H_2 + \frac{1}{2}\,O_2 \rightarrow H_2O + energy(electrical + thermal)$$

Why PEMFC in Vehicles?

- High Efficiency
- Operates at Low Temperatures
- On-road zero Emissions



[Guo 2013]

PEMFC Modeling Approaches

Theoretical

Based on fundamental physical laws

Specific phenomena, Design

High accuracy

hard-to-obtain parameters

Semi-Empirical

Hybrid models combining physics and experimental fitting

Vehicle performance, Control

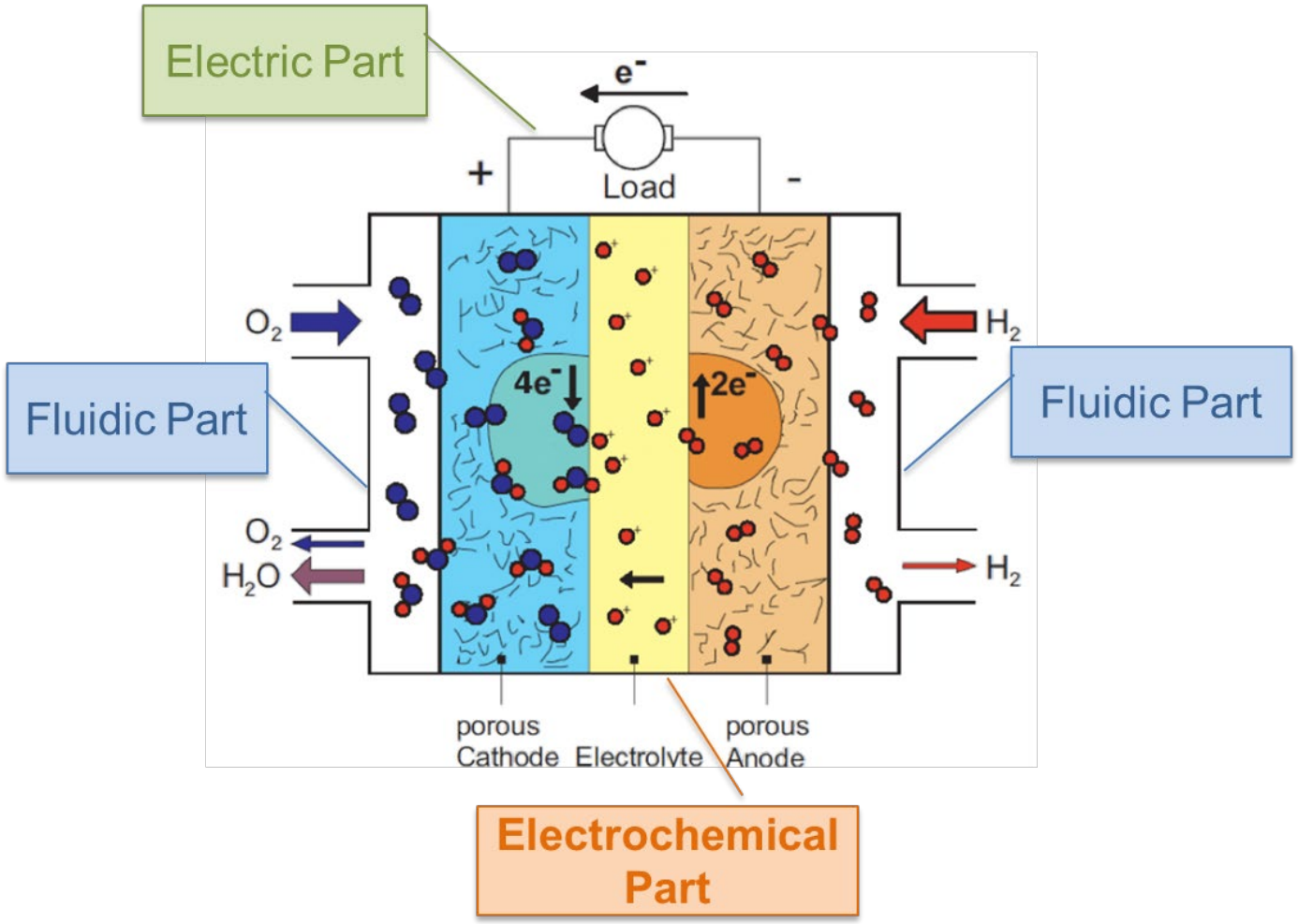
Simpler setup, good balance of accuracy

[Labach 16]

«Single fuel cell modeling »

from the PhD thesis of Loïc Boulon

Domains & Assumptions

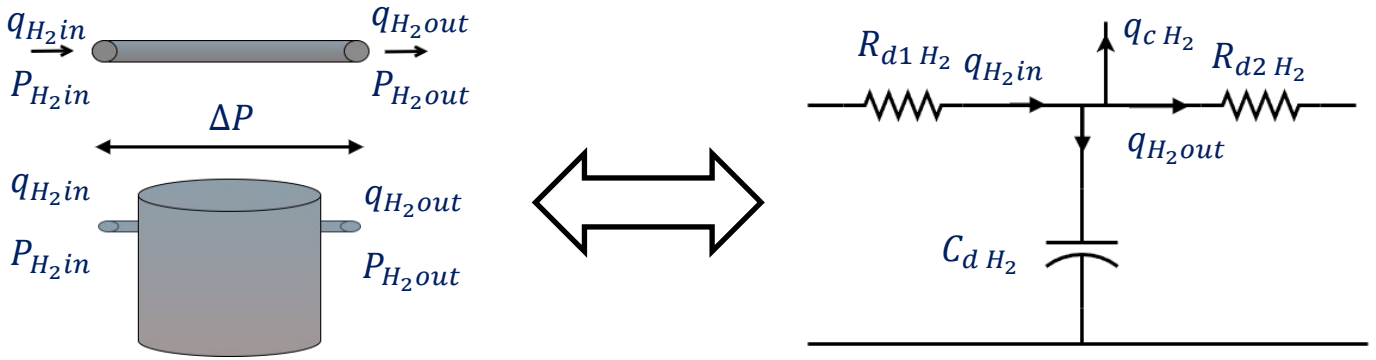


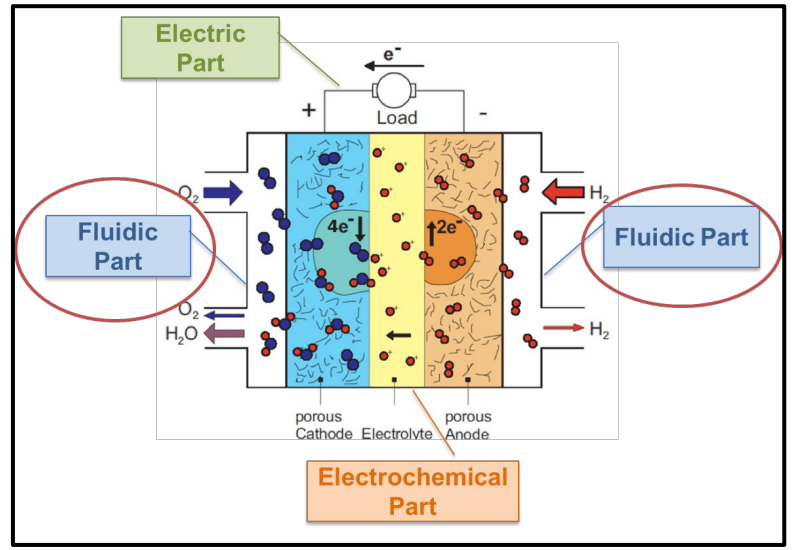
Assumptions:

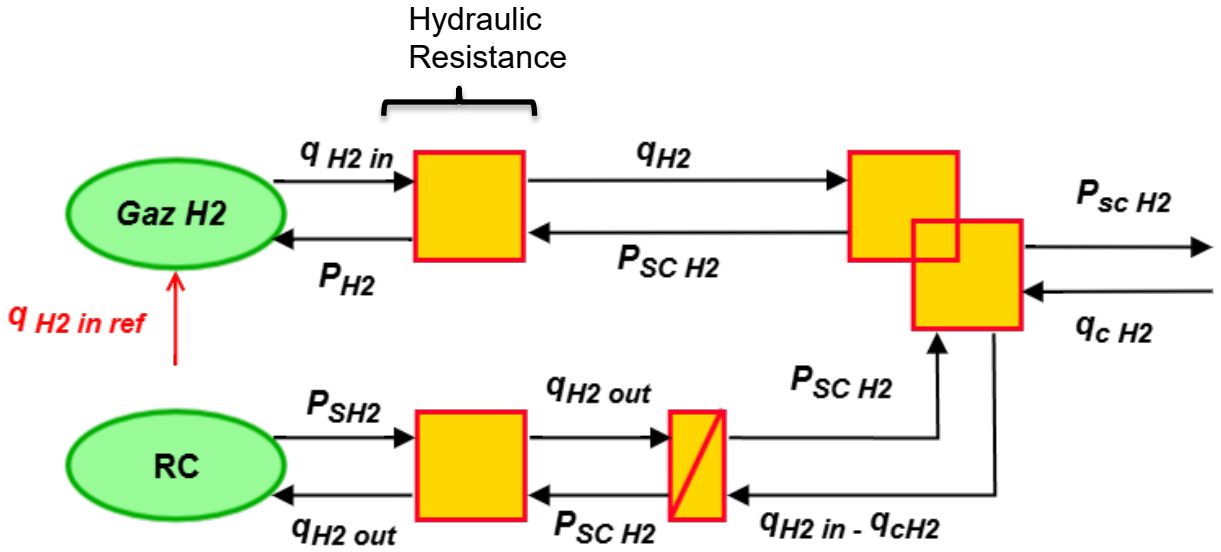
- Constant and uniform temperature
- Liquid water formation
- Ideal gas behavior

Fluidic Modeling

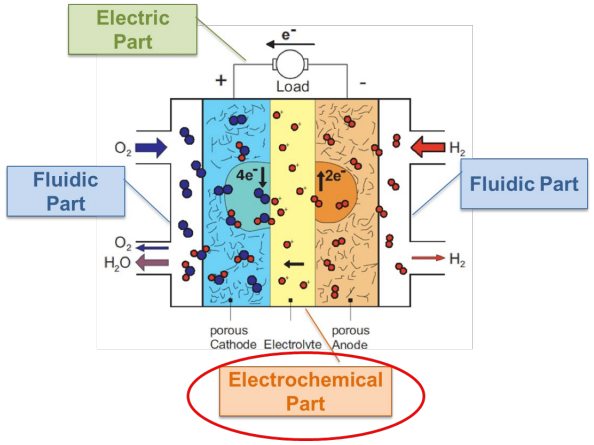
The fluidic behavior of a single fuel cell is modeled using an electrical circuit analogy

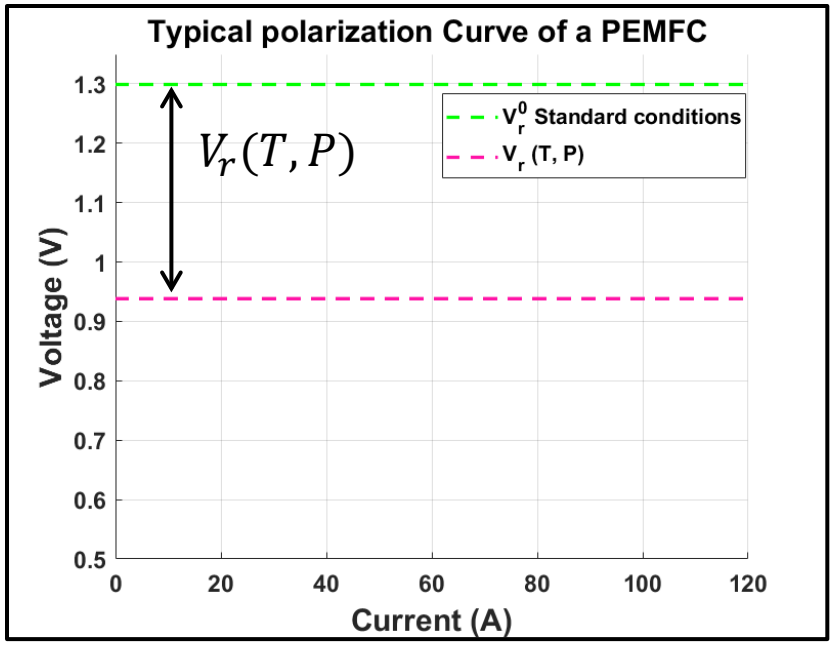






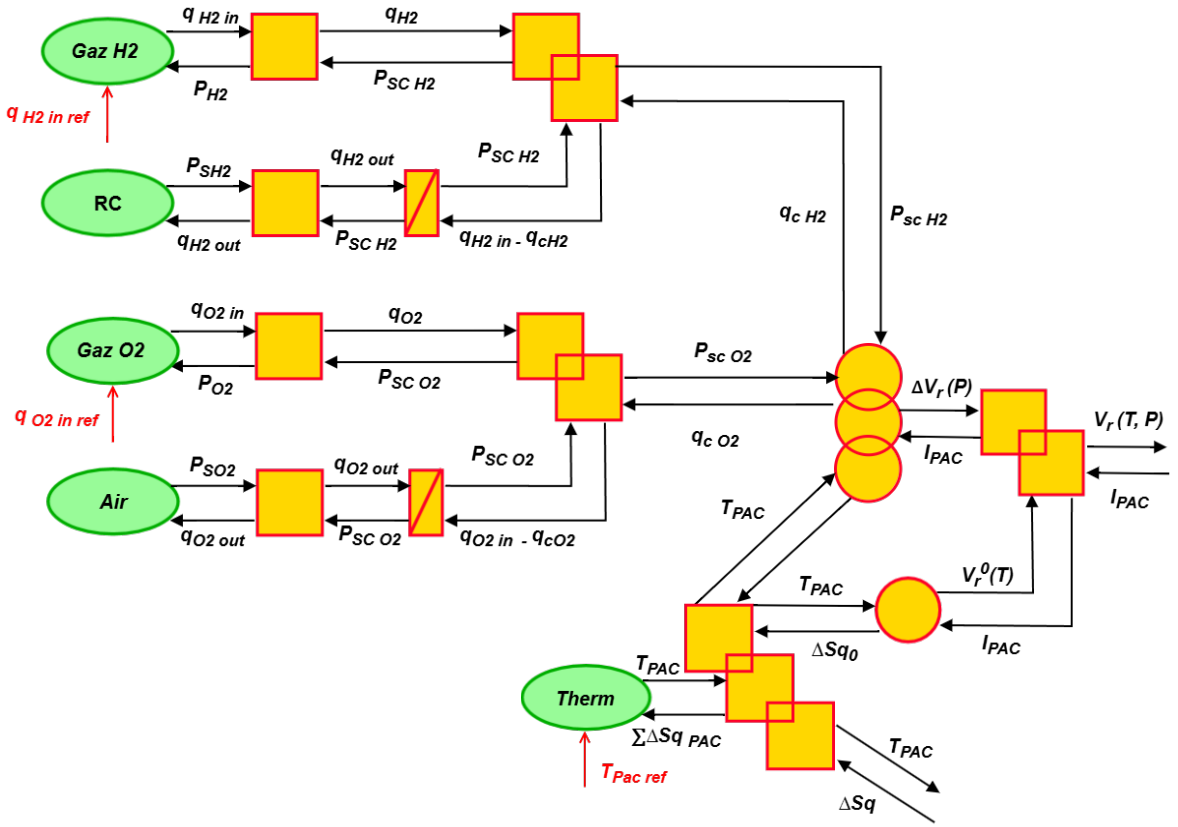
Electrochemical Modeling





Nernst-Based Voltage Equation :

$$V_r(T,P) = V_r^0(T) + \Delta V_r\left(T, P_{sc\ H_2}, P_{sc\ O_2}\right)$$

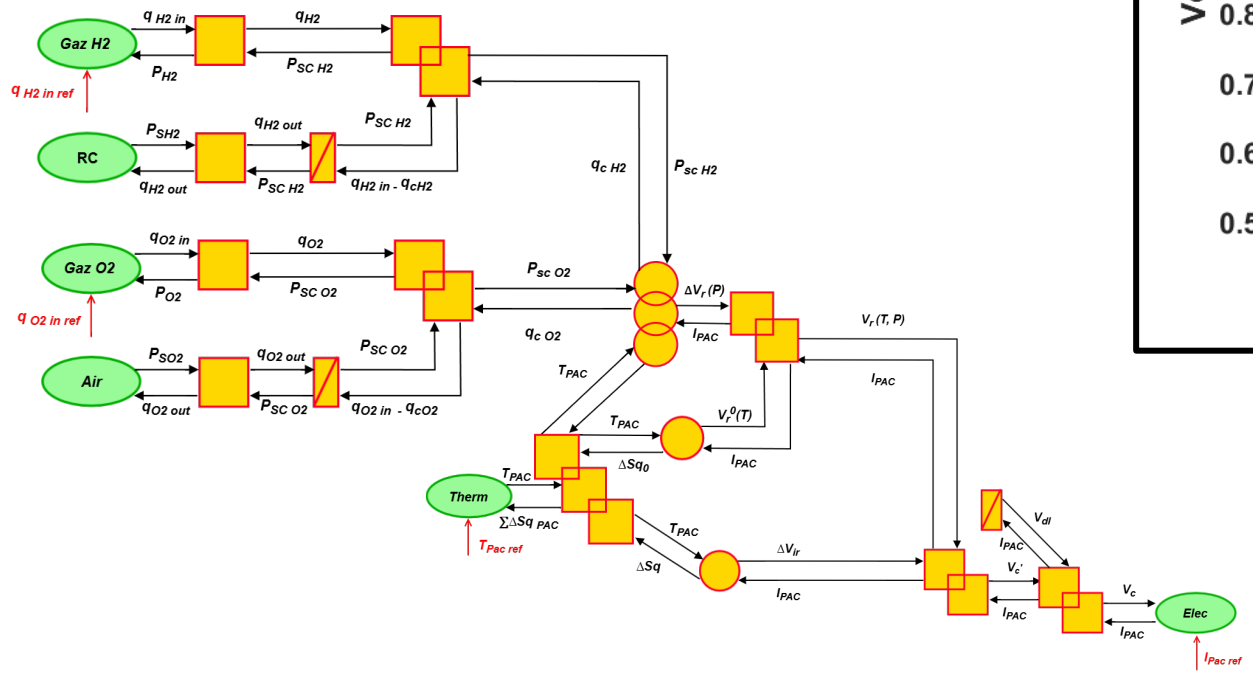


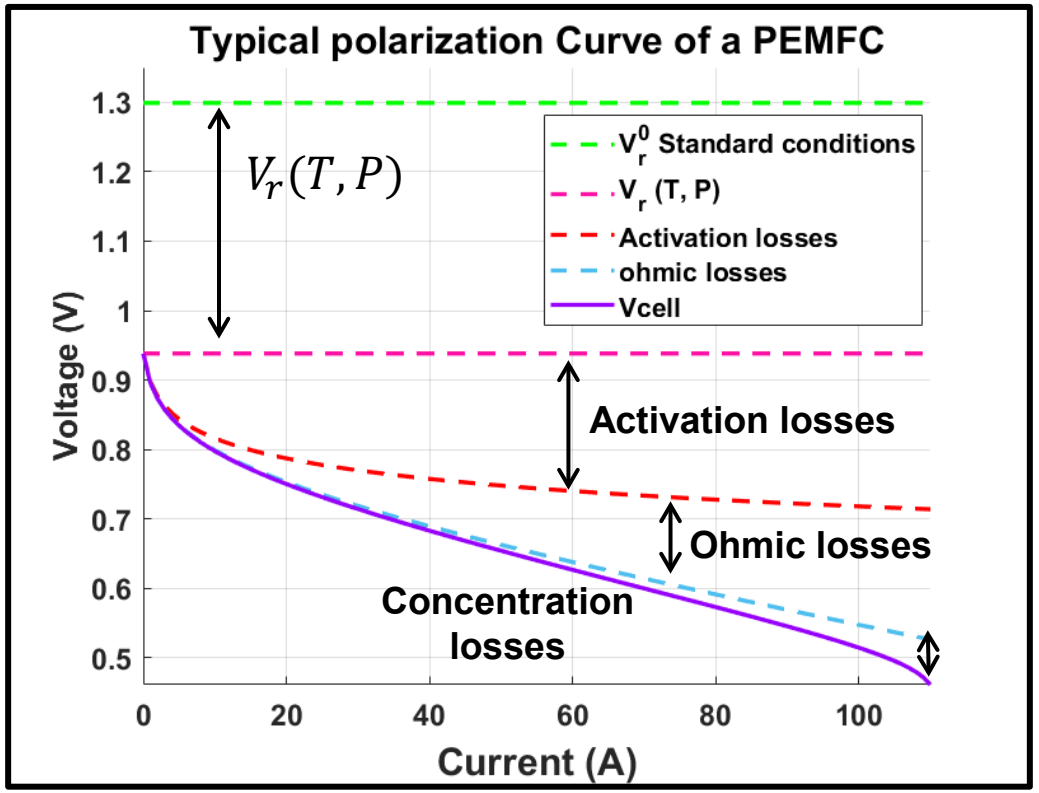
$$V_c' = V_r(P,T) - \Delta V_{ir}$$

Capacitive effect (double-layer phenomenon)

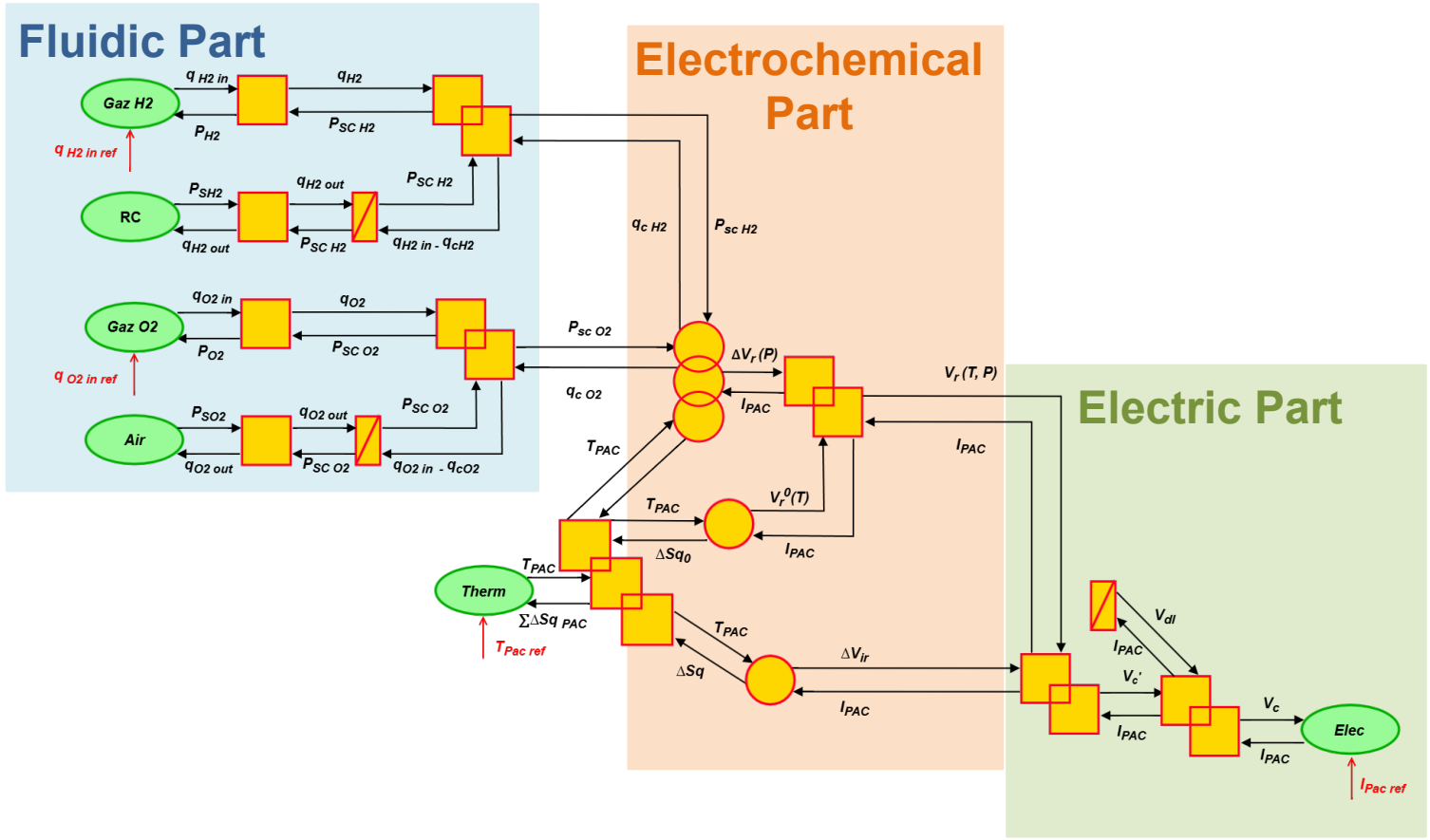
$$I_{PAC}(t) = C_{dl}\frac{dV_{dl}(t)}{dt} + \frac{V_{dl}(t)}{R_t}$$

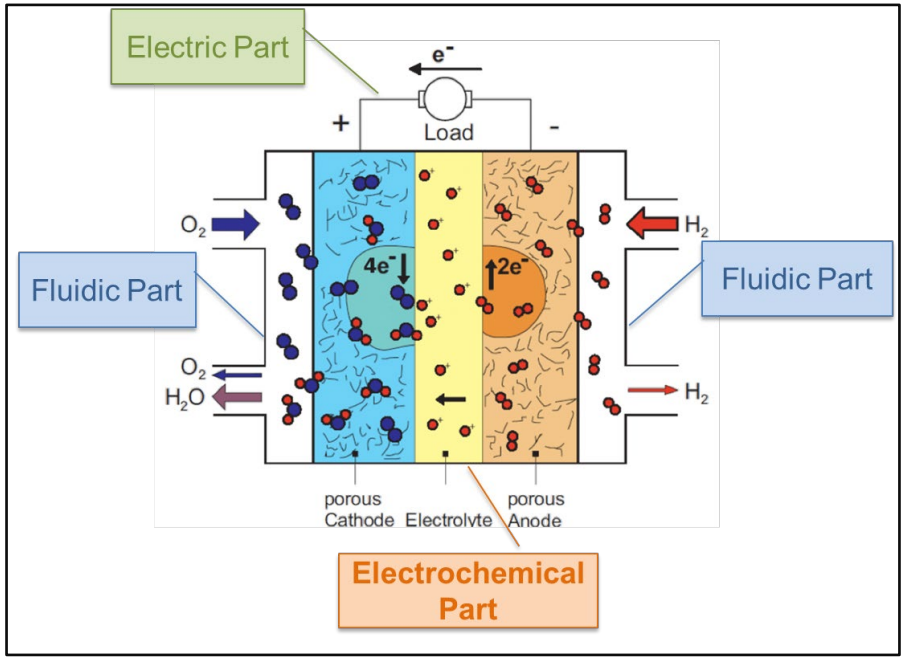
$$V_c = (V_{dl} + V_c')$$





Global EMR of a single cell



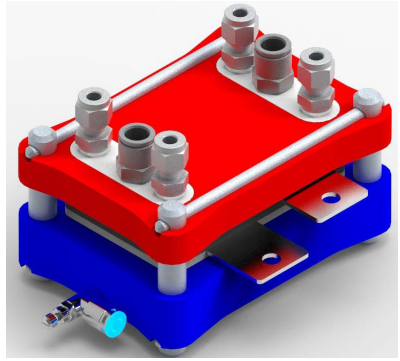


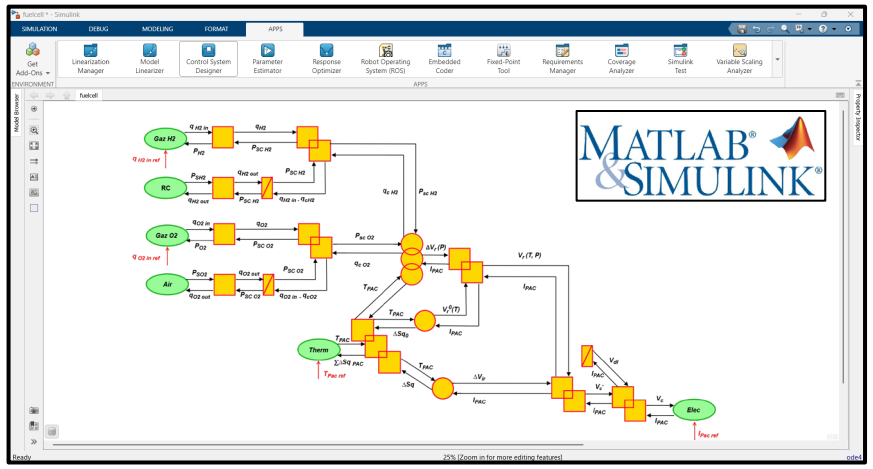
«Fitting Results »

Model Fitting to Experimental Data

Specifications :

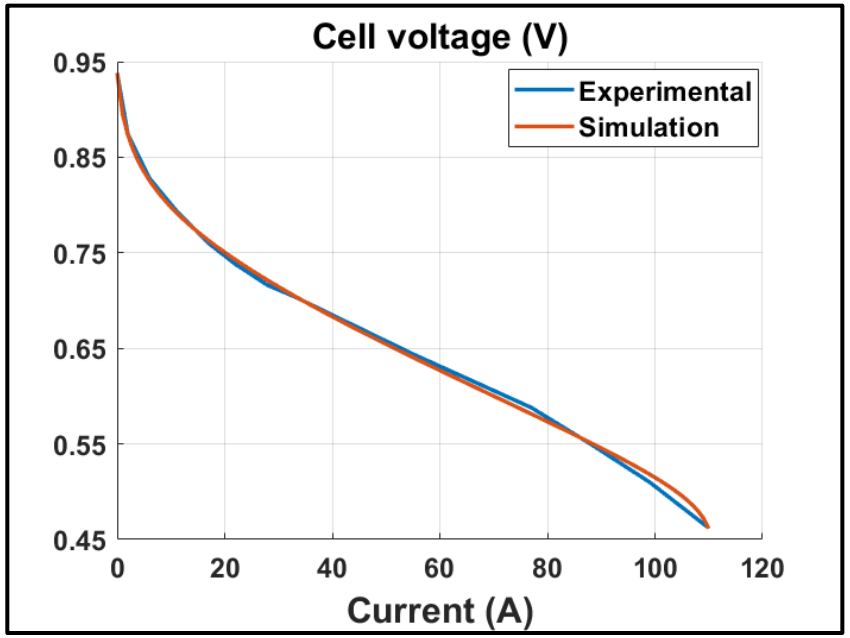
- **Active area:** 100 cm²
- **Nominal current:** 70 A
- **Maximal current:** 120 A
- **Operating temperature:** 60 °C

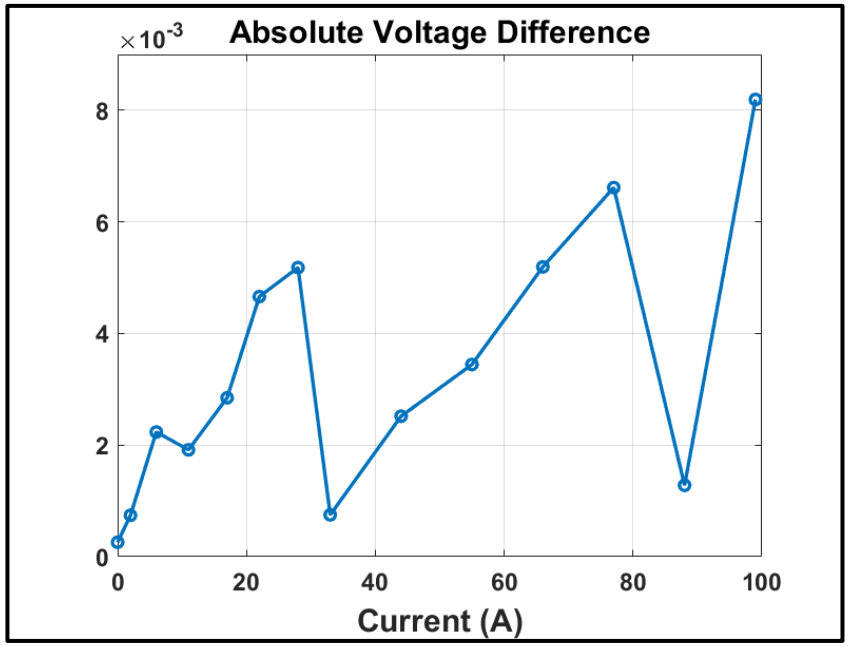




Missing parameters are obtained by fitting to experimental data.

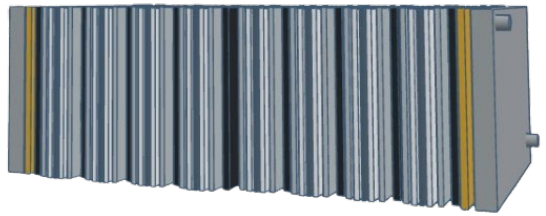
Fitting with nonlinear least squares method





Global EMR of a stack

$$q'_{H2\ in} = \frac{1}{N}\ q_{H2\ in}$$
$$P_{H2} = P_{H2}$$



Fluidic Part

Electrochemical Part

Electric Part

Gaz H2

Gaz O2

q H2' in

P H2' in

q H2 in

P H2 in

q H2 in ref

q O2' in

P O2' in

q O2 in

P O2 in

q O2 in ref

Vc

IPAC

VPAC

IPAC

Elec

I PAC ref

T

Therm

∑ΔSq PAC

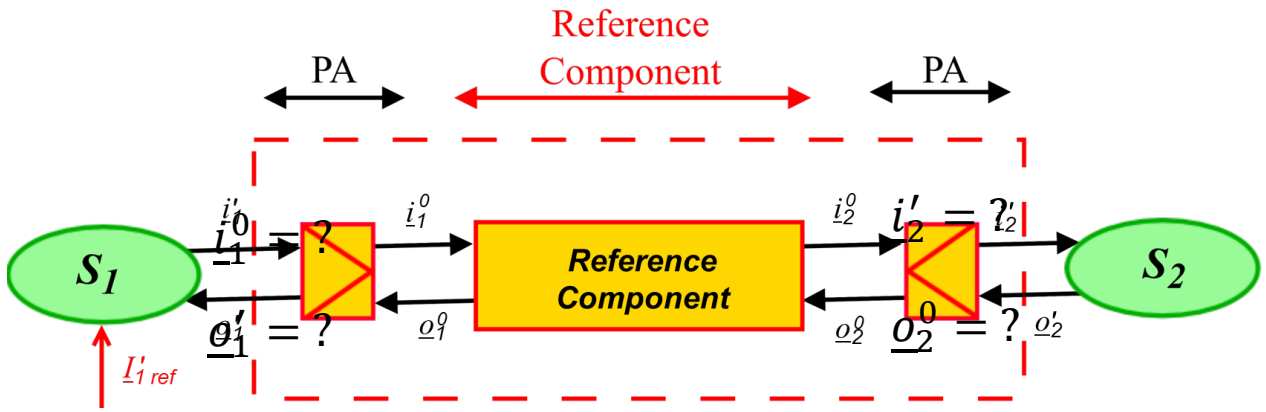
$$V_{PAC} = N\,V_c$$
$$I_{PAC} = I_{PAC}$$

«Conclusion and Perspectives »

Conclusion:

- ✓ The current EMR of the fuel cell model is based on the PhD thesis of Prof. Loïc Boulon.
- ✓ The model captures the main physical phenomena of fuel cells.
- ✓ It will serve as a basis for the next steps of our study.

Perspectives:



$\underline{x}'_x$ Reference component variables.

$\underline{x}^0_x$ Scaled component variables.

[Aroua 2023]

Thanks for your attention !

[Aroua 2023] A. Aroua, *Scalability of Electric Axles for System-Level Design in the Early Development Phases of Electric Vehicles*, Ph.D. dissertation, Univ. of Lille, France and Ghent Univ., Belgium, Dec. 2023.

[Boulon 2009] L. Boulon, *Modélisation multiphysique des éléments de stockage et de conversion d'énergie pour les véhicules électriques hybrides. Approche systémique pour la gestion d'énergie*, Ph.D. dissertation, Univ. de Franche-Comté, France, July 2009.

[Guo 2013] A. Guo, W. Chen, Q. Li, Z. Liu, and H. Que, "Air flow control based on optimal oxygen excess ratio in fuel cells for vehicles," *J. Mod. Transport.*, vol. 21, no. 2, pp. 79–85, Jun. 2013, doi: 10.1007/s40534-013-0009-8.

[Labach 2023] I. Labach, "Caractérisation et modélisation de piles à combustible et d'électrolyseurs PEM à conditions opératoires variables en vue de leur association".