Working Paper No. **HDH-08-05**
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RESEARCH PROGRAM ON AN EMISSIONS TEST PROCEDURE FOR HEAVY DUTY HYBRIDS (HDH)

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WP3: Non-electric HDHs

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  - Method/Analysis
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  - Method/Analysis
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Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

3. Extension of HILS to non-electrical hybrids, which are currently not covered by Kokujikan No.281.

To May 2012 the following WP is to be carried out.

- Overview of possible other types of hybrids of interests and issues for HILS testing will be investigated. Information gathering. Proposal of which non-electric hybrids to include in the HILS method.
- Evaluate, using software models and simulation the possibilities of using HILS for assessment of quality factors of these hybrids.

Tasks and timeplan

	Work task description	***Period (Start-end)***
WP 3	Extension to non-electrical hybrids	
WT 3.1	Technology overview and selection of scope	06/2011-10/2011
WT 3.2	Development of HIL elements (models) for non-electrical hybrids	10/2011-01/2012
WT 3.3	Test methods for input data to non-electrical component models	01/2012-02/2012
WT 3.4	Definition of control signals	01/2012-02/2012
WT 3.5	Alignment with HILS for HEV and verification	03/2012-04/2012

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WT 3-1: Technology overview and selection of scope

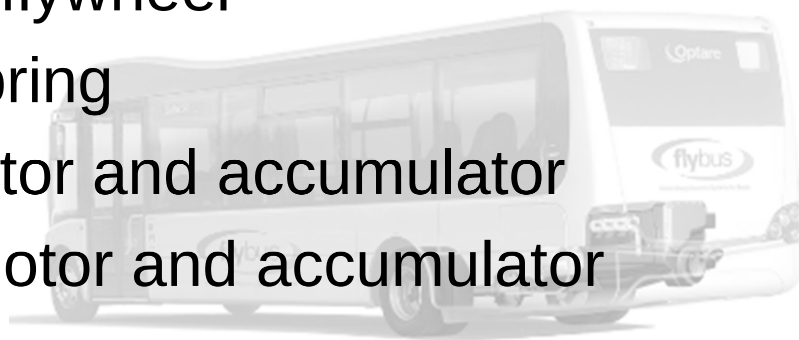
- Detailed analysis on what non-electric hybrid systems/components to be included in the HILS method. Review of non-electric hybrid topologies proposed in the literature, by OEMs and others. Review of non-electric components, such as flywheels, accumulators etc, used in non-electric powertrains proposed in the literature, by OEM and others. Together with OEMs and other partners decide which topologies that should be covered. Meetings with OEMs, will be co-planned with TU Graz and TU Wien in relation to WP 1-4 (TU Graz and TU Wien offer).

- The preliminary result is a list of non-electric powertrain topologies and a list of components that needs to be modeled.

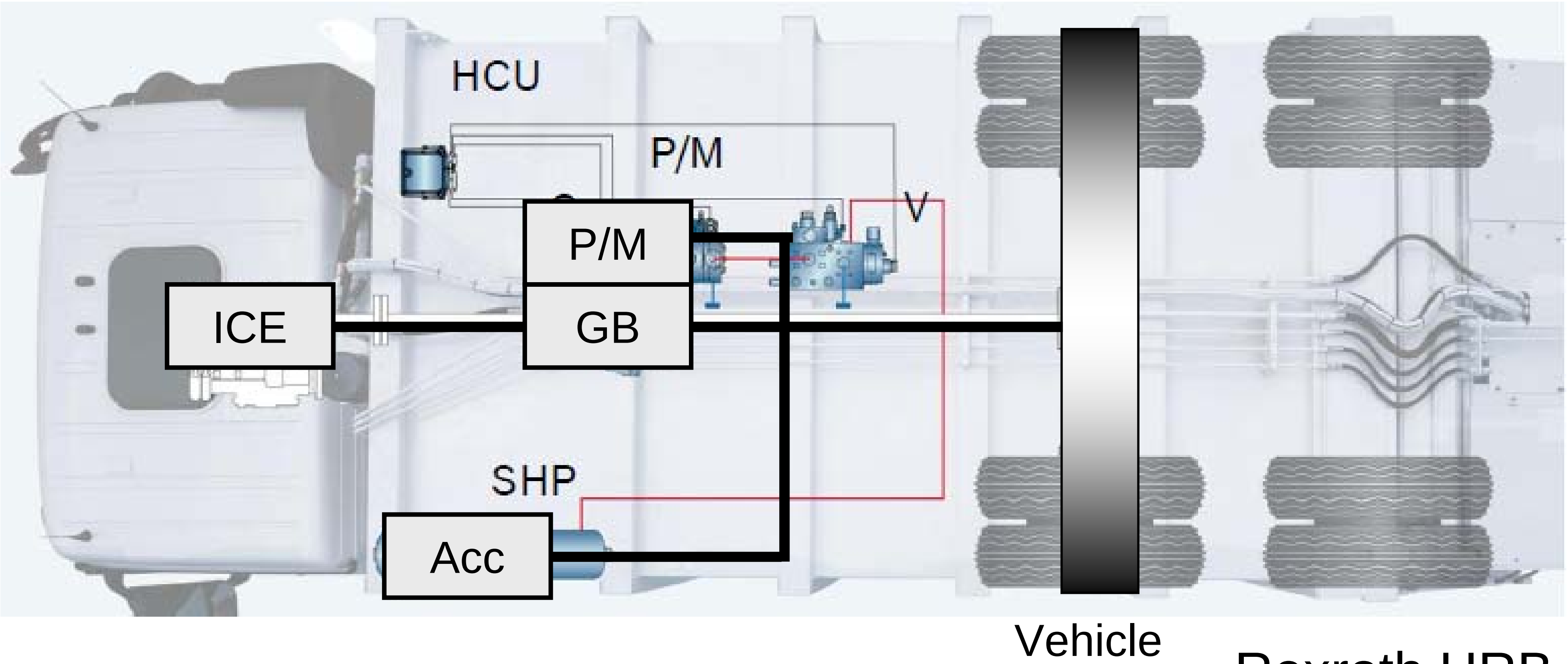
Hybrid Powertrain Principles

Energy storage and converter

- Electrochemical, generator/motor and battery
- Electrostatic, generator/motor and supercapacitor
- Electromagnetic, generator/motor and superconductor coil
- Kinetic, CVT and flywheel
- Kinetic, motor/generator and flywheel
- Potential, CVT and torsion spring
- Potential, hydraulic pump/motor and accumulator
- Potential, pneumatic pump/motor and accumulator



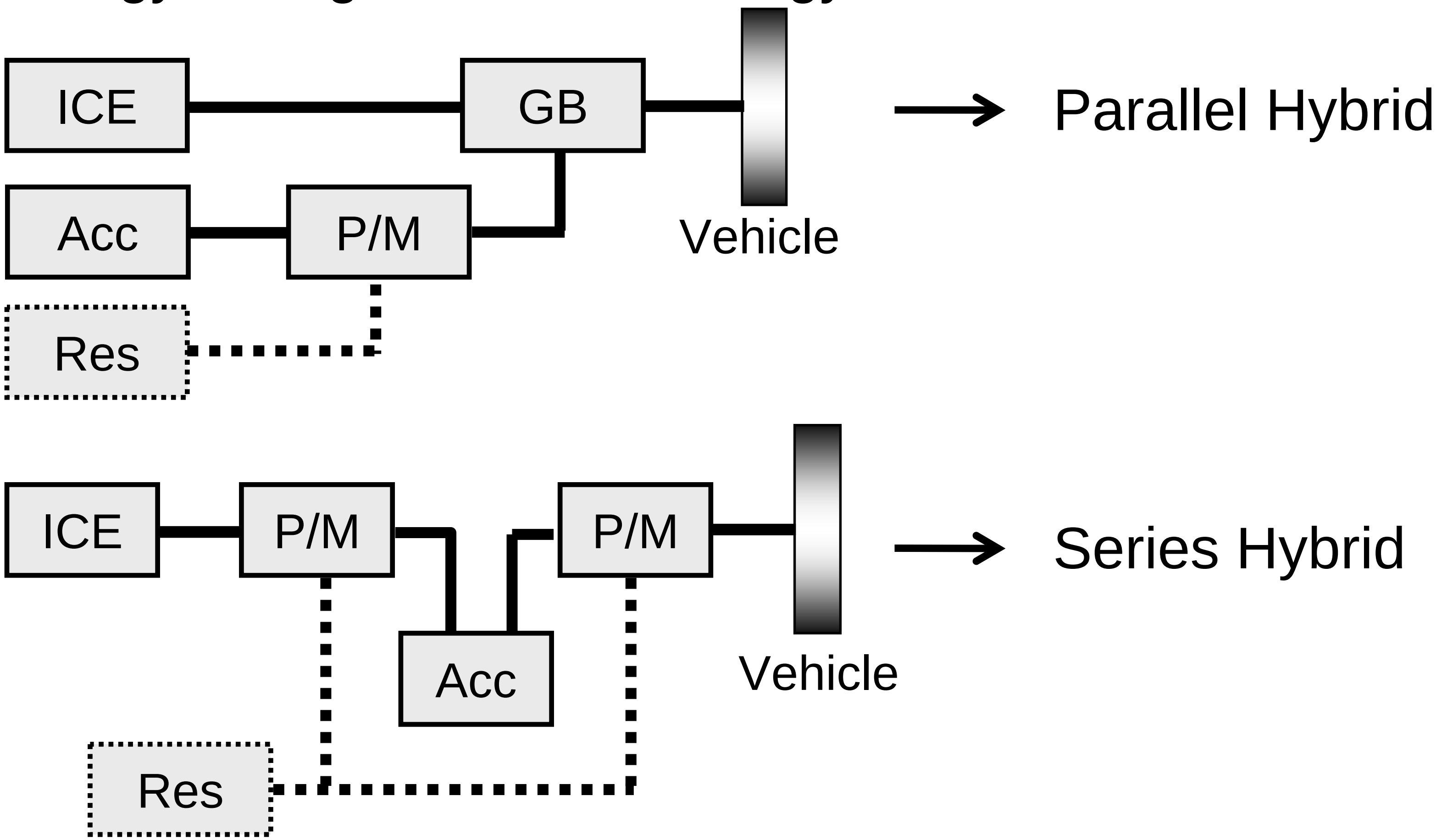
Hydraulic pump/motor and accumulator



Rexroth HRB

Hydraulic pump/motor and accumulator

- Energy storage: Potential energy

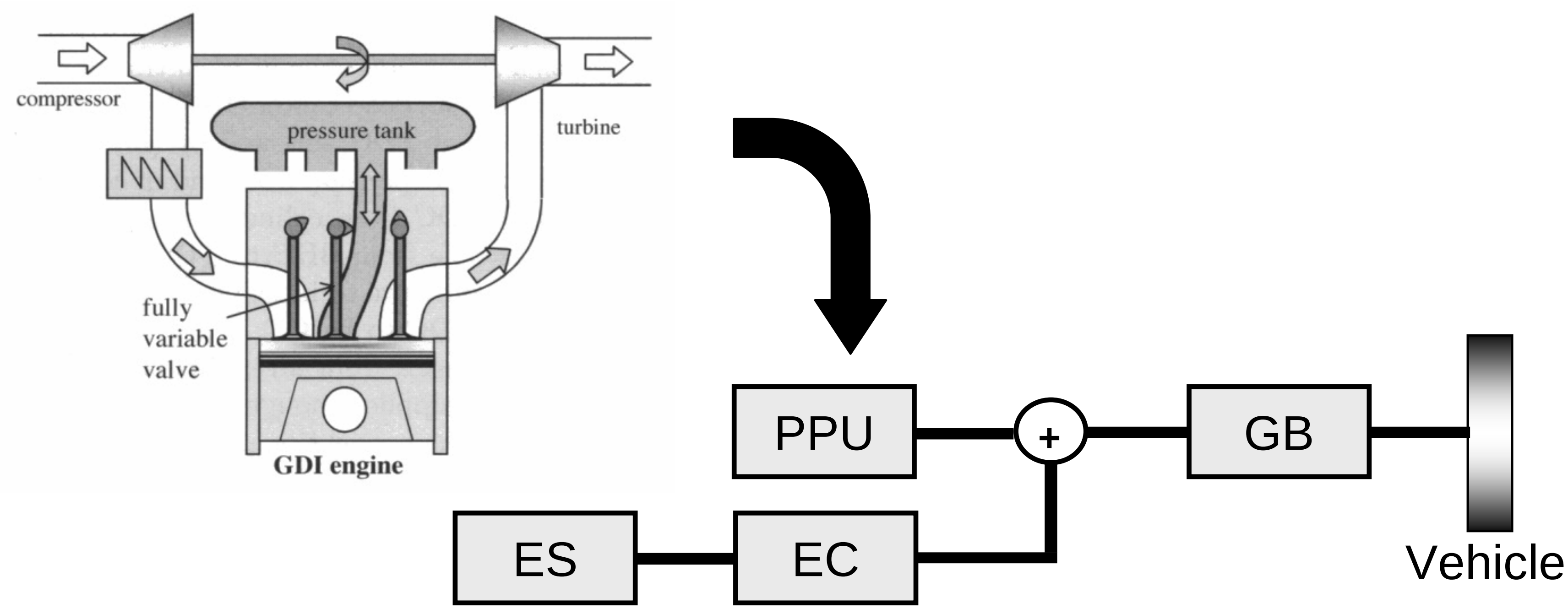


Hydraulic pump/motor and accumulator

- Ford F150 and F350 Hydraulic Hybrid (Parallel)
- Eaton, Hydraulic Launch Assist (Parallel and Series)
- NRG Dynamix (Parallel and Series)
- Innas, Netherlands, (Series)
- Parker, Runwise system, (Parallel and Series)
- Bosch Rexroth, HRB (Parallel and series)
- Poclain Hydraulics, ADDIDRIVE Assist (Series, addon to non-driven wheels)

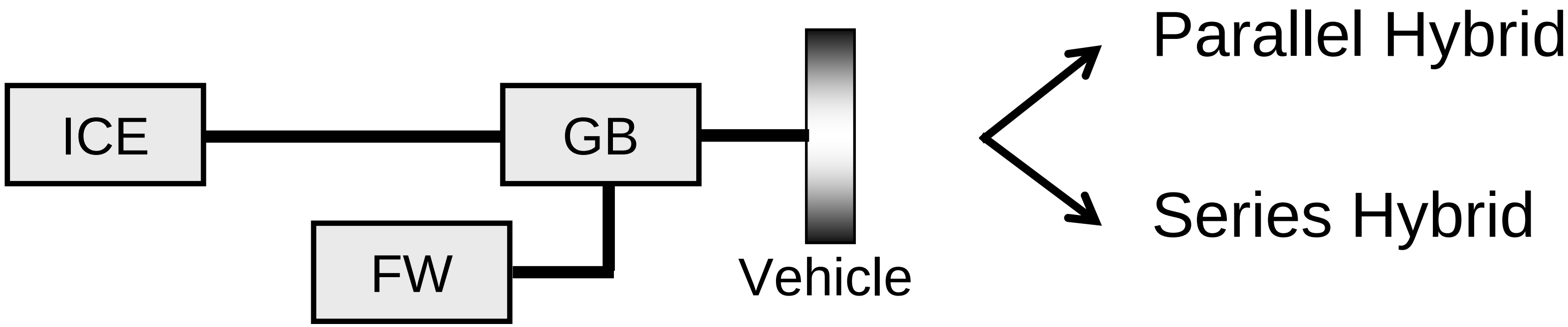
Pneumatic pump/motor and accumulator

- Enery storage: Potential energy
  - Principle could be similar as for hydraulic hybrids
- Alternative: Hybrid engine concept:

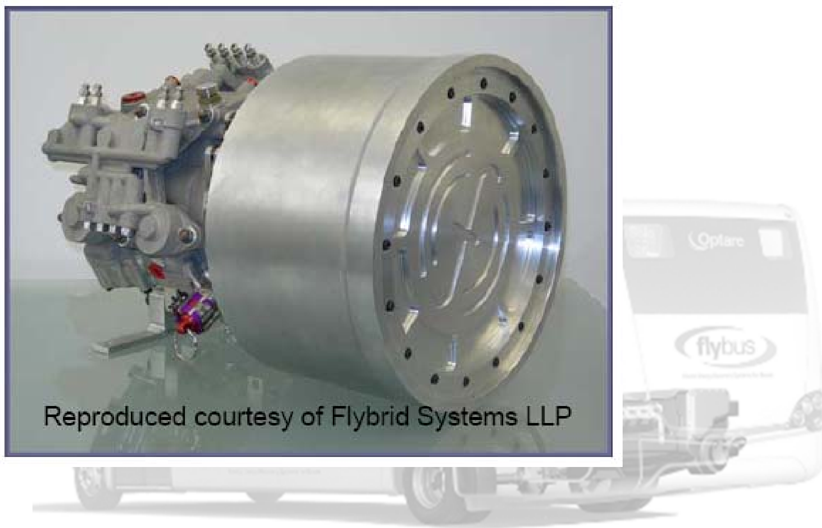


CVT and flywheel

- Energy Storage: Kinetic energy



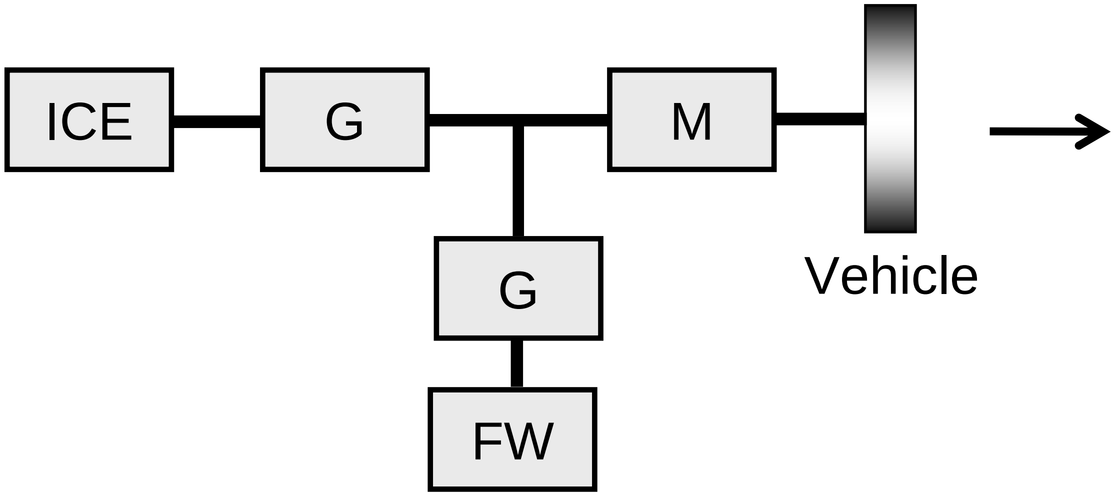
- Examples:
  - Formula 1
  - Flybrid
  - Torotrack for city bus



Reproduced courtesy of Flybrid Systems LLP

Motor/generator and flywheel

- Energy storage: Kinetic energy



Series Hybrid

- Examples:
  - PhD thesis from Uppsala University, Sweden

Results

- Non-electric hybrid powertrain topologies (concepts) fits well into the same categories as for electric hybrid powertrains

- Non-electric hybrid powertrains can be divided into:
  - Series powertrain topologies
  - Parallel powertrain topologies
  - Split powertrain topologies

Interesting non-electric powertrain concepts:

- CVT and flywheel
- Motor/generator and flywheel
- Hydraulic or (pneumatic) pump/motor and accumulator

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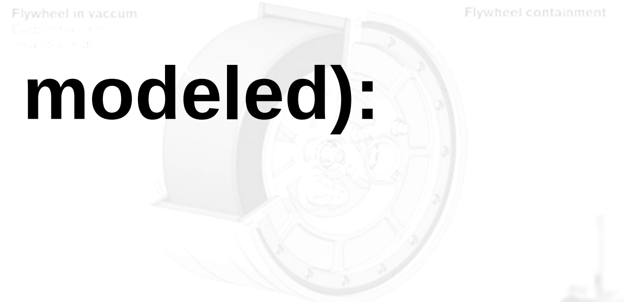
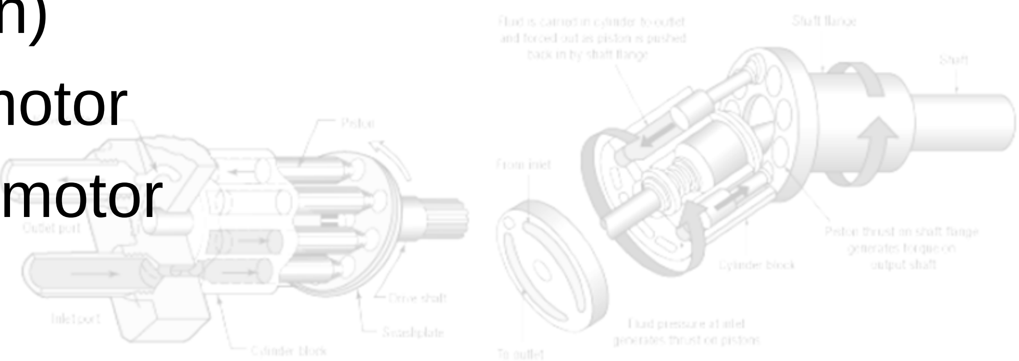
Results

Component list (to be modeled):

- Energy storages:
  - Flywheel
  - Hydraulic accumulators
  - Pneumatic accumulators
- Energy converters
  - CVT (transmission)
  - Hydraulic pump/motor
  - Pneumatic pump/motor




(a) Swash-plate type, inline axial-piston type (b) Bent-axis type, axial-piston type

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WT 3-2: Development of HIL elements for non-electrical hybrid systems/components

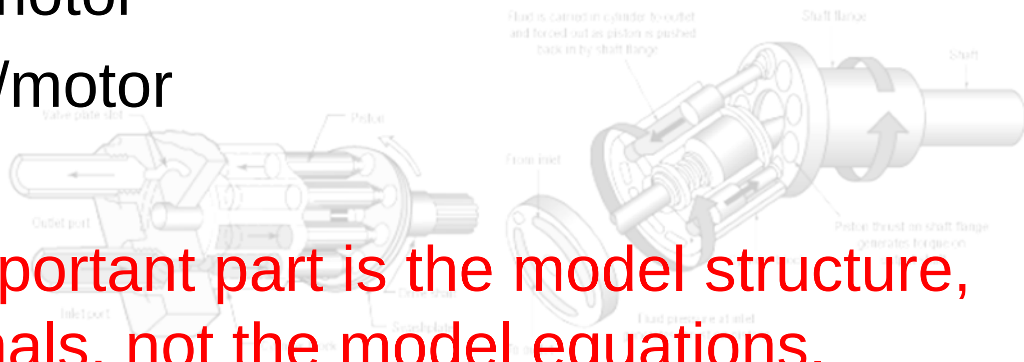
- Based on the list of topologies and components in WP 3-1, develop simple, representative mathematical models of the different powertrain components, such as actuators and energy buffers. The models will be implemented in a simulation software. All models will be documented.

- The result is a set of simulation models of non-electric powertrain components, which are suitable to use in a HILS setup.

Components

- Energy storages:
  - Flywheel
  - Hydraulic accumulators
  - Pneumatic accumulators
- Energy converters
  - CVT (transmission)
  - Hydraulic pump/motor
  - Pneumatic pump/motor

- Notice: The most important part is the model structure, the input-output signals, not the model equations.



(a) Swash-plate type, inline axial-piston type (b) Bent-axis type, axial-piston type

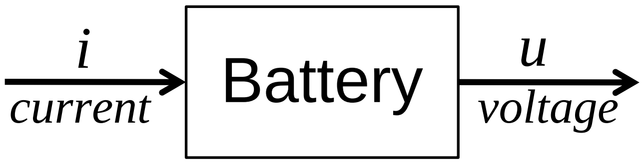
Energy storages

- Flywheel
- Accumulators

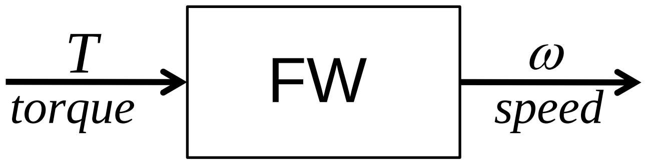
- Notice: The similarity to the electric energy storage

Flywheel

Electric battery:



Flywheel:



State-of-Charge

$$C \frac{dSOC}{dt} = -i$$

$$J \frac{d\omega}{dt} = -T - T_{loss}(\omega)$$

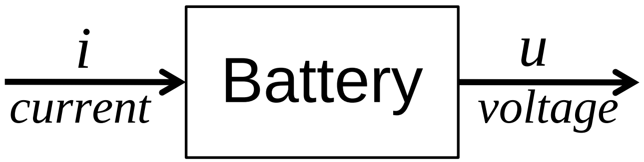
losses

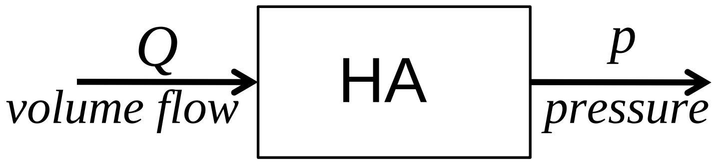
$$u = u_{OCV}(SOC) - Ri$$

$T_{loss}(\omega)$ - Lookup table

Accumulator

Electric battery:





State-of-Charge

$$C\frac{dSOC}{dt} = -i$$

$$\frac{dV_g}{dt} = Q$$ (mass balance)

losses

$$u = u_{OCV}(SOC) - Ri$$

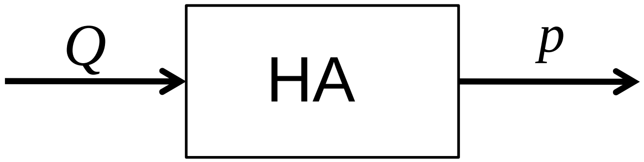
Temperature

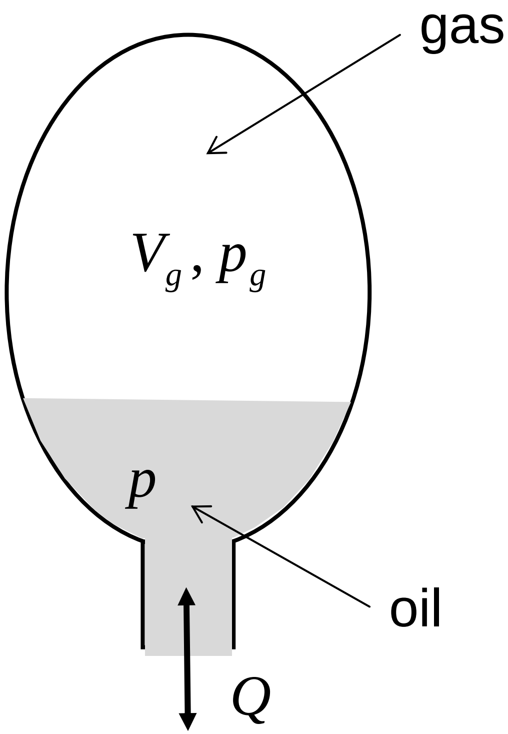
$$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)}$$ (ideal gas law)

$$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

(energy balance)

Accumulators





State-of-Charge

Mass balance: $$\frac{dV_g}{dt} = Q$$

Temperature

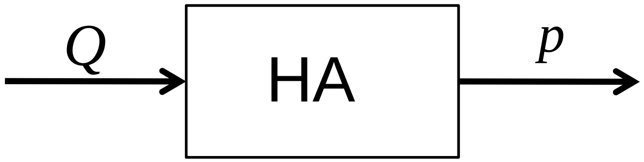
Ideal gas law: $$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)}$$

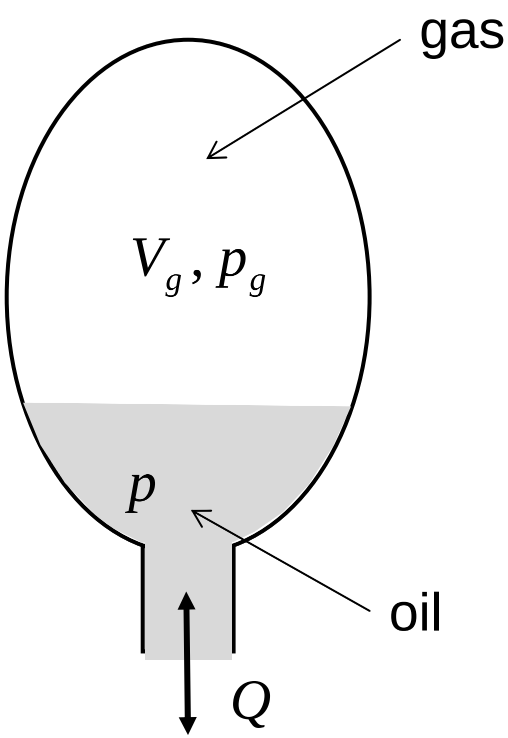
Assumption ([1]): $p \approx p_g$

Energy balance: $$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

[1] Guzzella and Sciarretta, Vehicle Propulsion Systems, Springer, 2007

Accumulators





State-of-Charge

Mass balance: $$\frac{dV_g}{dt} = Q$$

Temperature

Ideal gas law: $$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)}$$

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Energy balance: $$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

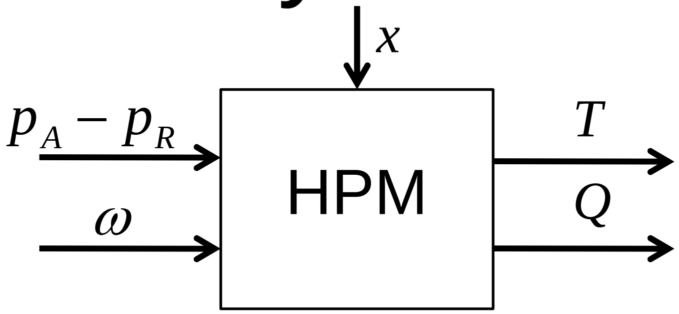
[1] Guzzella and Sciarretta, Vehicle Propulsion Systems, Springer, 2007

Energy converters

- Hydraulic pump/motor
- CVT

- Notice: The similarity to the electric energy converter

Hydraulic Pump/Motor



	Pump:	Motor:
Volumetric flow rate:	$Q = \eta_v x D \omega$	$Q = x D \omega / \eta_v$
Torque:	$T = \eta_t x D (p_A - p_R)$	$T = x D (p_A - p_R) / \eta_t$

Efficiencies:

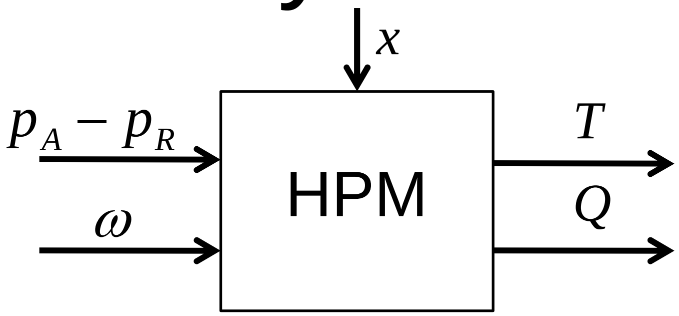
$$\eta_v = 1 - \frac{C_s}{xS} - \frac{p_A - p_R}{\beta} - \frac{C_{st}}{x\sigma}$$

laminar loss, compressibility loss, turbulent loss

$$\eta_t = 1 - \frac{C_s S}{x} - \frac{C_f}{x} - C_h x^2 \sigma^2$$

viscous loss, friction loss, hydrodynamic loss

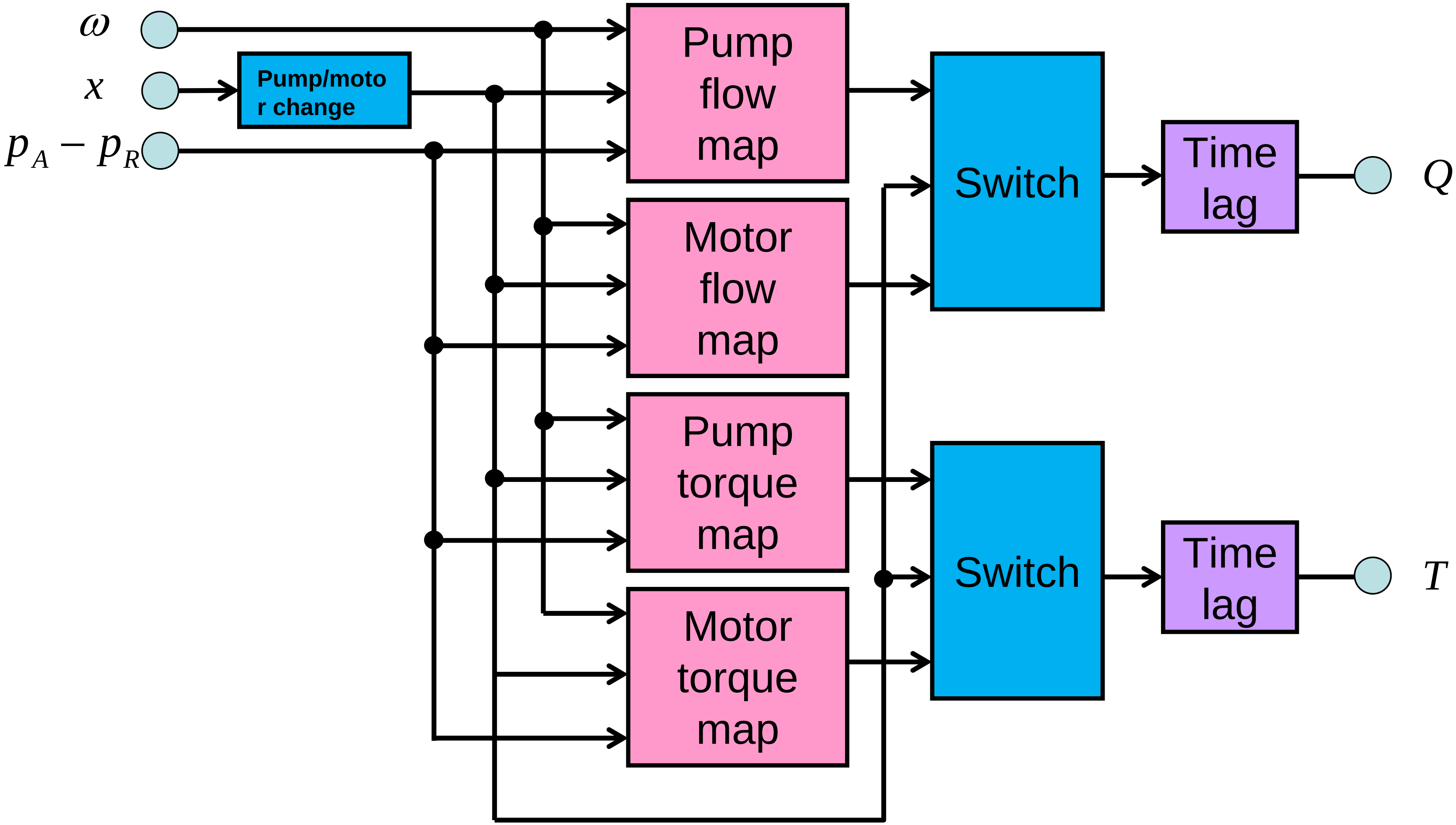
Hydraulic Pump/Motor



	Pump:	Motor:
Volumetric flow rate:	$Q = \eta_v x D \omega$	$Q = x D \omega / \eta_v$
Torque:	$T = \eta_t x D (p_A - p_R)$	$T = x D (p_A - p_R) / \eta_t$
Efficiencies:	$\eta_v = f(x, p_A - p_R, \omega)$	$\eta_t = f(x, p_A - p_R, \omega)$

Lookup table

Pump/motor Vs …



… Vs Electric Motor Model

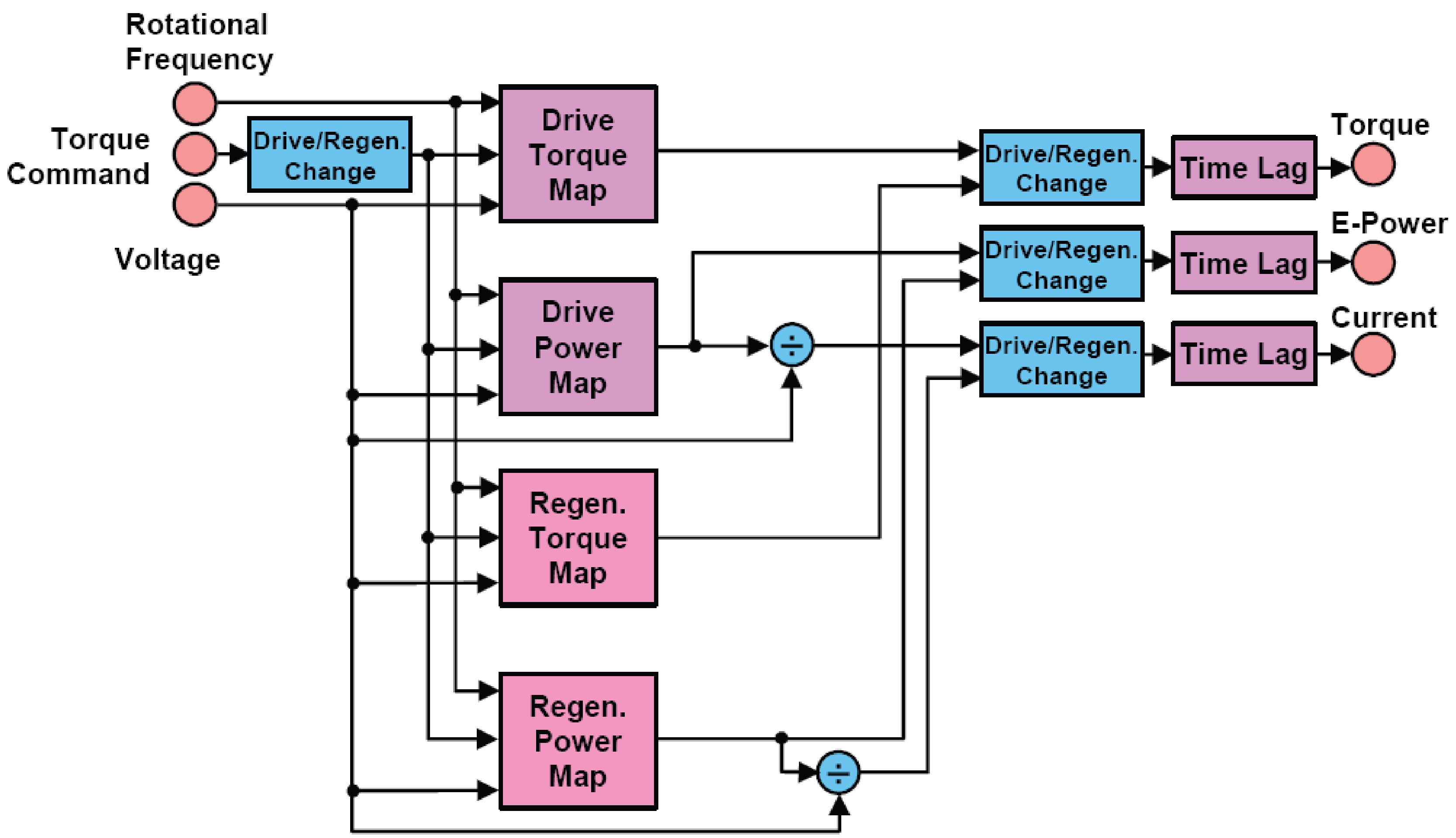
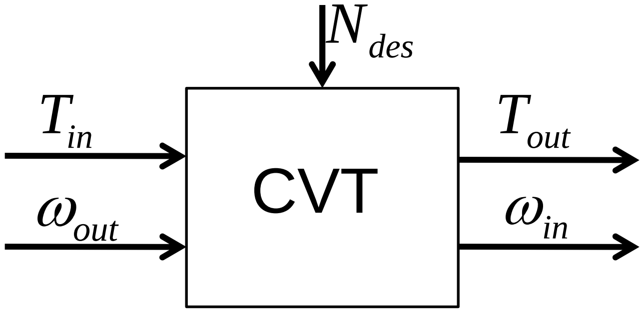


Fig. 3 Conceptual Diagram of Electric Motor Model

CVT



Torque: $$T_{out} = NT_{in}\eta$$

Efficiency: $$\eta = f(\omega_{out}, T_{out}, N)$$

Lookup table

Speed: $$\omega_{in} = N\omega_{out\,t}$$

Gear ratio: $$\frac{dN}{dt} = -\frac{1}{T}(N - N_{des})$$

Results

- Mathematical models for
  - Flywheel
  - Accumulator
  - Pump/Motor
  - CVT

Summary

- WT 3-1:
  - Non-electric hybrid powertrain topologies (concepts) fits well into the same categories as for electric hybrid powertrains

    → HILS should be possible for non-electric HDHs

- WT 3-2:
  - Mathematical models for:
    - Flywheel
    - Accumulator
    - Pump/Motor
    - CVT

    → Similar model structures as proposed in Kokujikan No. 281

- Work done according to time plan

Next...

- Implementation
  - MATLAB/Simulink (Started)
- Verification (WT 3.3)
  - Data (Need to get real model data from suppliers or OEMs to verify model structure)
- System modelling
  - Incorporate into the Japanese open-source model
  - Controller design (Started, a simple rule based controller)

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Thanks for your attention!

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