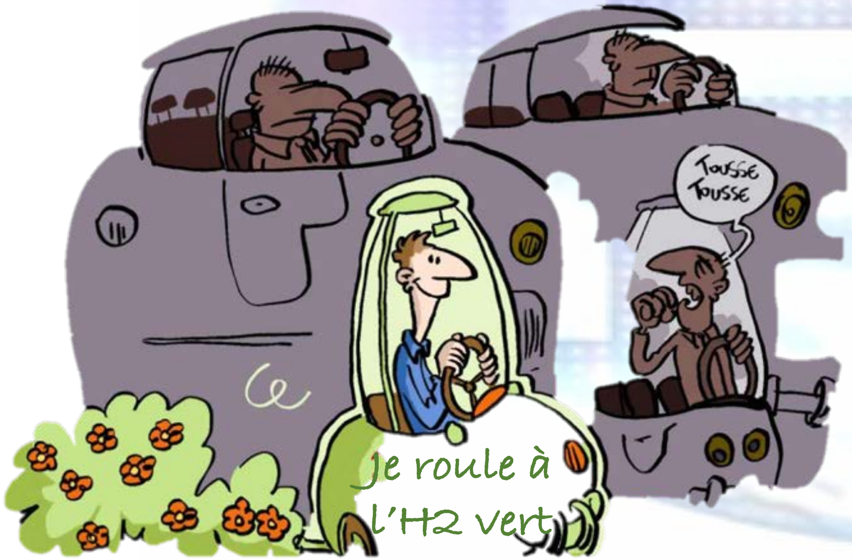
Microbiologie et transition énergétique, l'exemple de la production de bioH2 à partir de déchets ménagers



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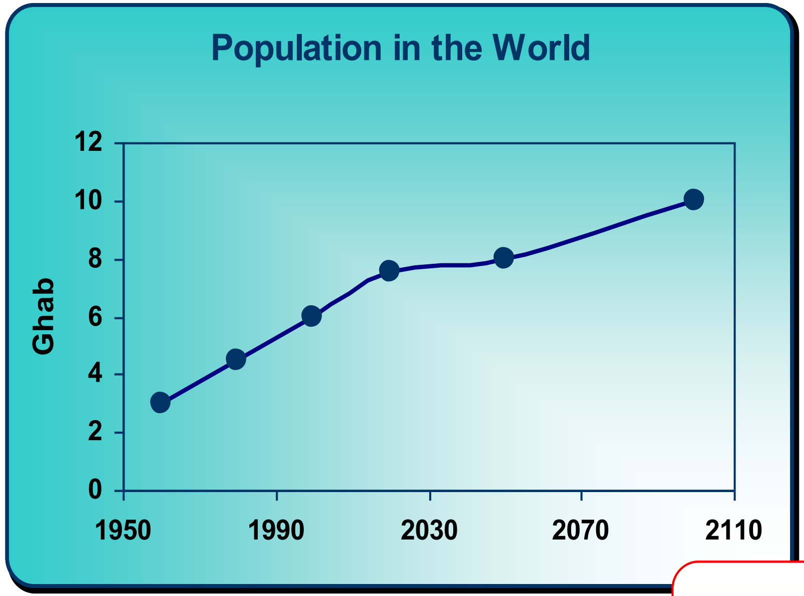
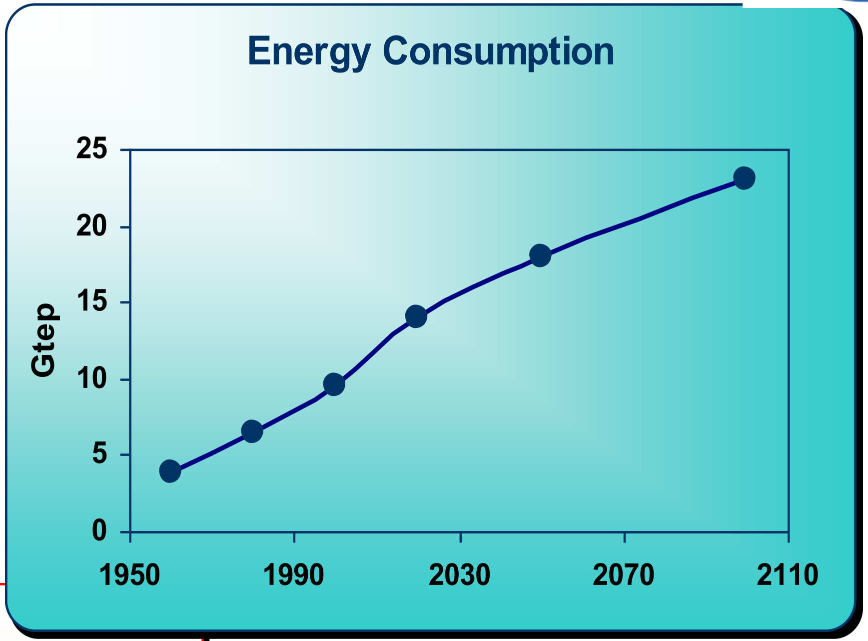
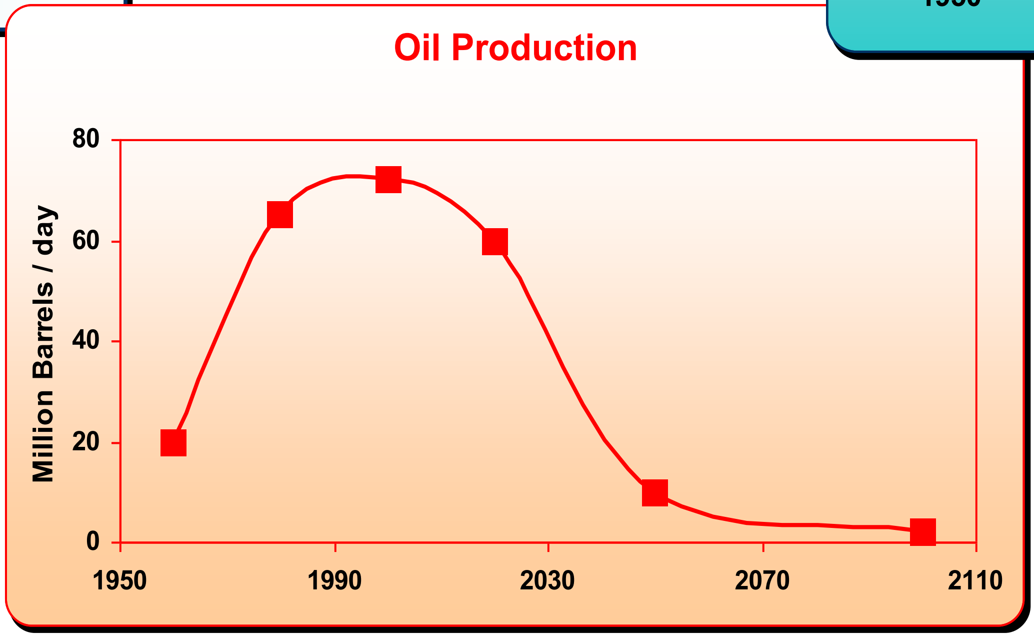
OHM Bassin minier de Provence

Séminaire 2023 de l'OHM BMP
et Transition énergétique en région Sud-PACA
Meyreuil, 9 et 10 Novembre 2023

Our present and our future…





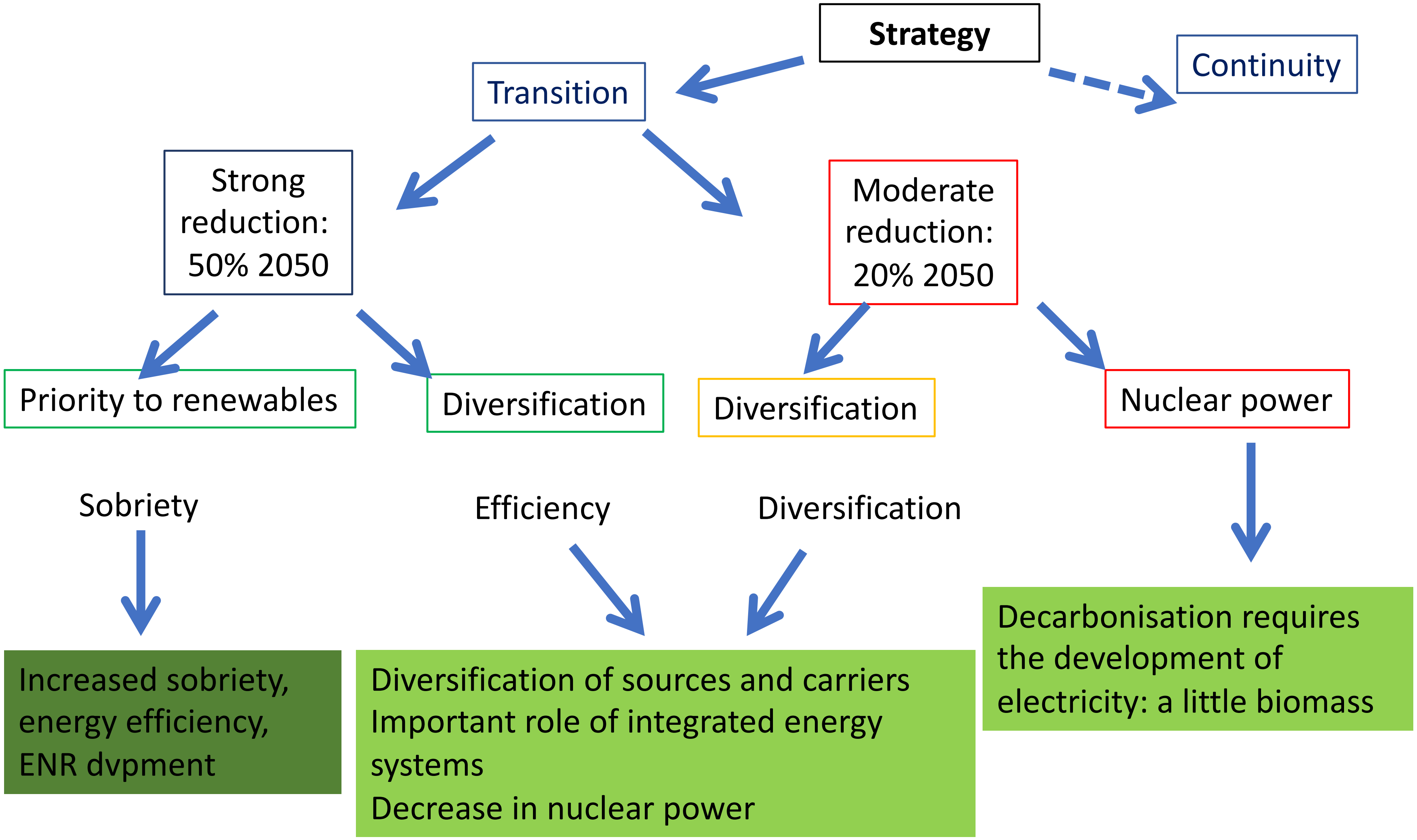


Our future…

alternative energies to limit

- Dependence on fossil fuels
- Greenhouse gas emissions

Examples of Scenarii for the energy transition (source report for energy transition)



H2: a green energy

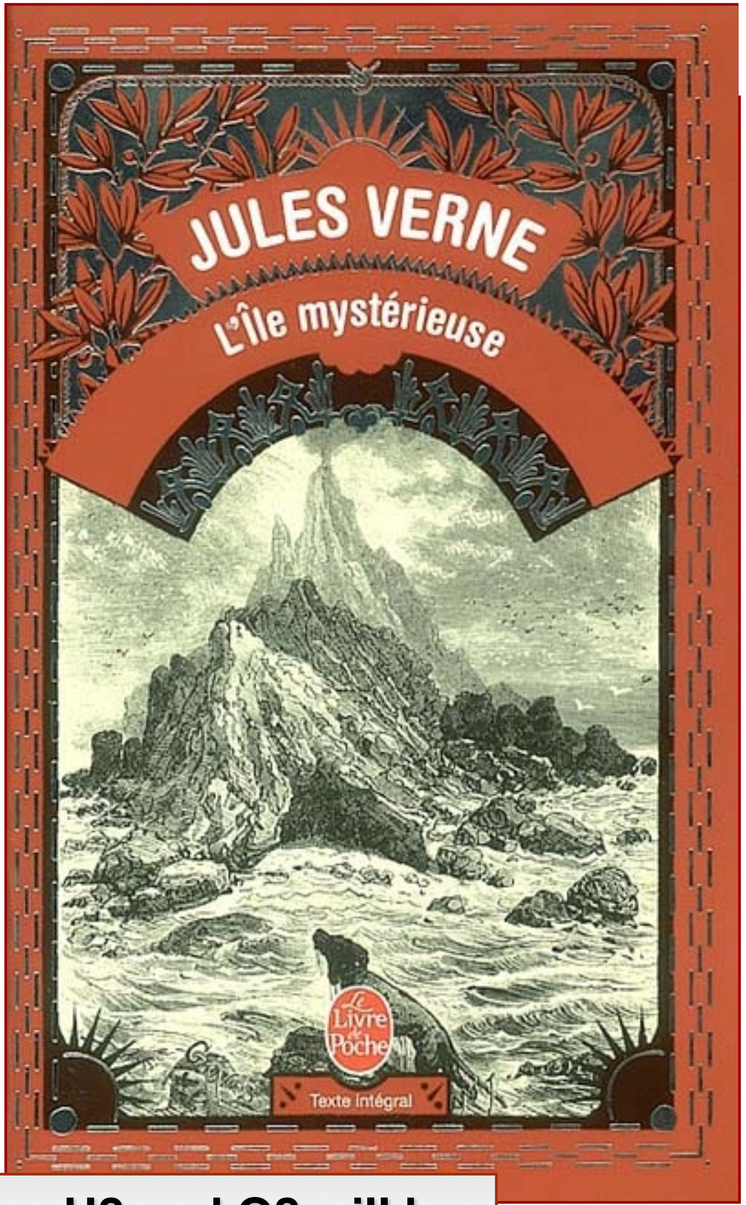
Most common element in the world
but not in a 'free' form

Non-toxic, invisible and odourless gas,

Lowest density
(1 l of petrol = 4.6 l H2 compressed to 700 bars)

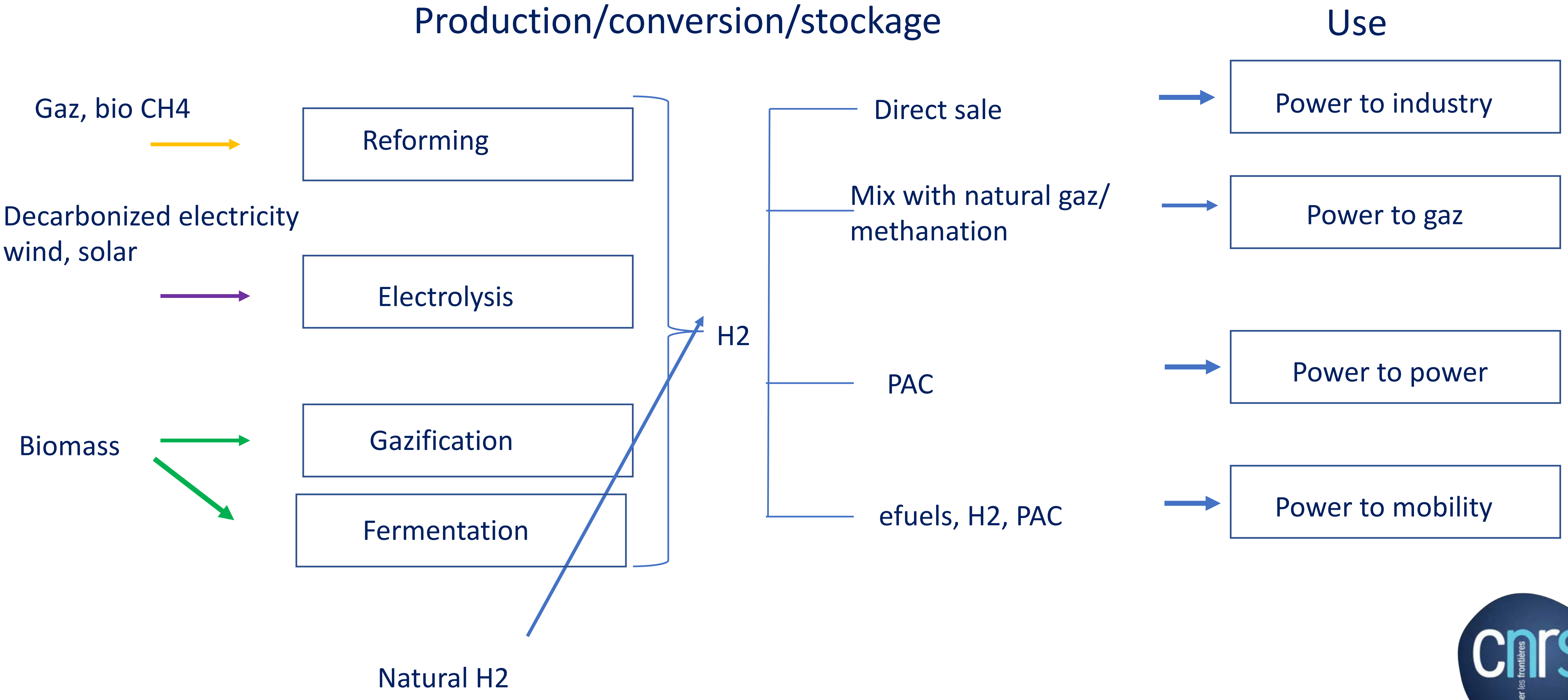
But the most energetic
(3 times more than petrol)

Its combustion releases only heat and water



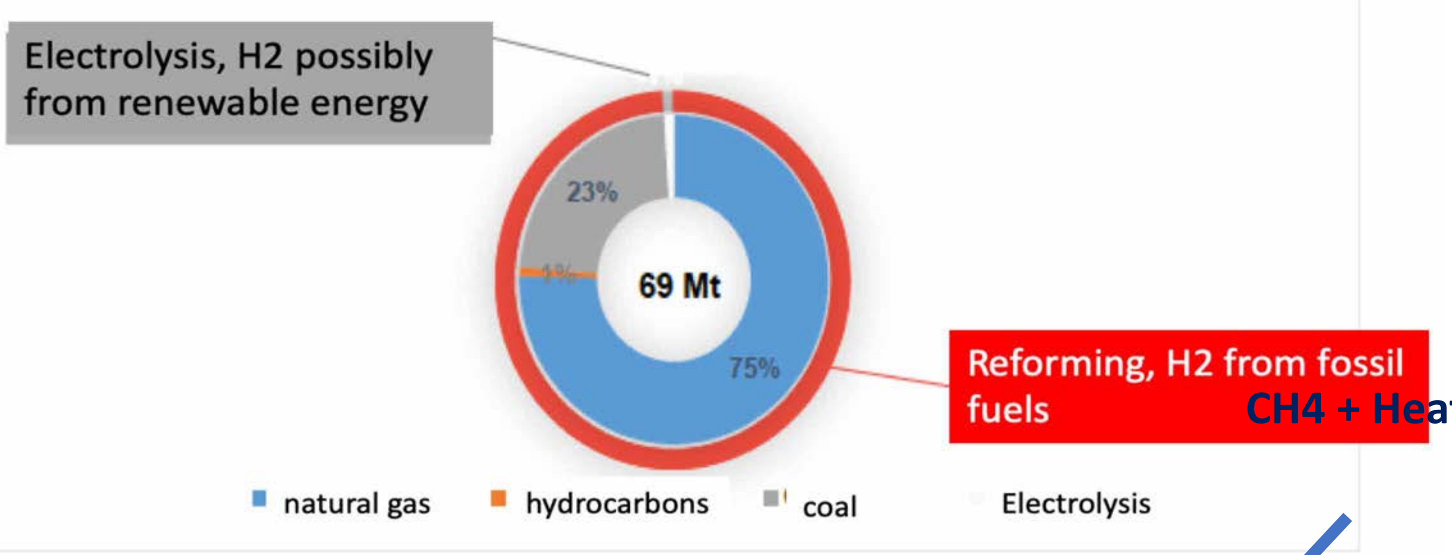
1874: « one day H2 and O2 will be a source of light and heat »

H2: an energetic vector



H2: an energetic vector

Primary energy source for H2 production worldwide



Source : EY d'après AIE 2019, Hydrogen Council

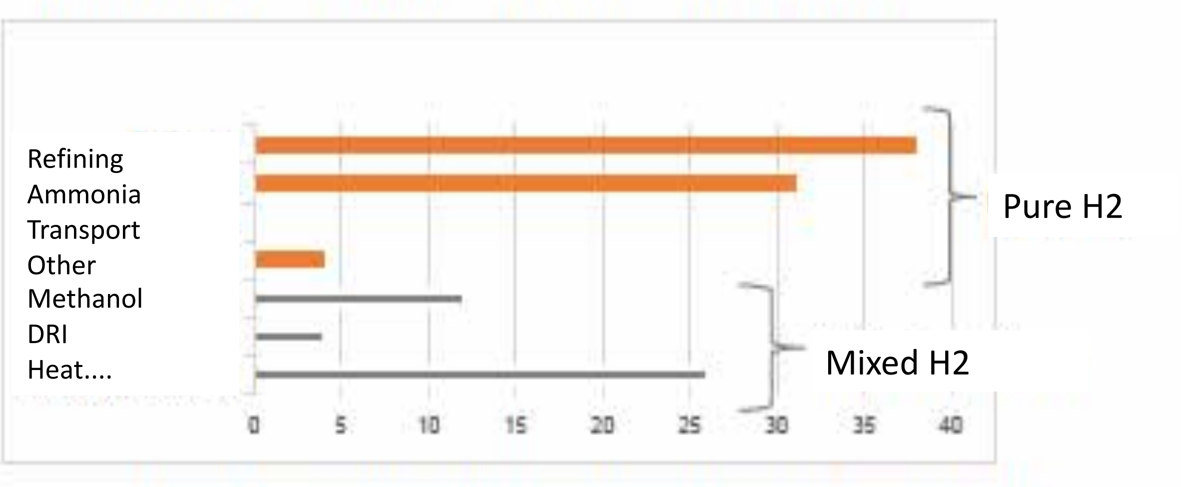
CH_4 + Heat (++++) => H_2 + CO_2

Currently the most economical way to produce H2 (from 1.5 to 2.5 €/kg H2)

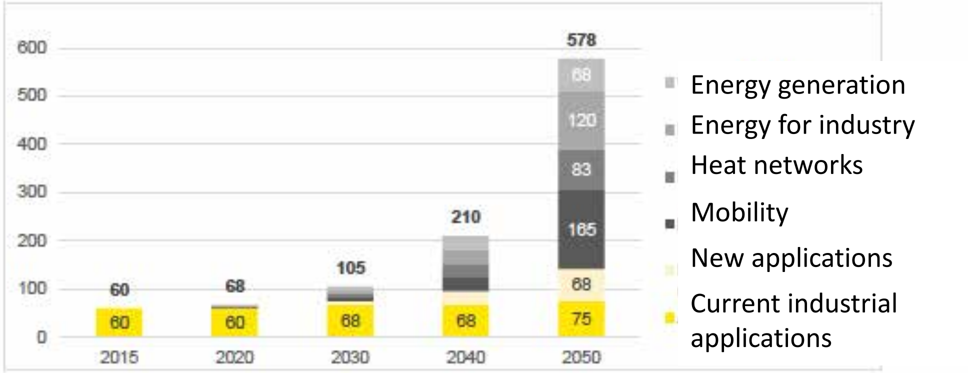
However, this process generates 10kg of CO_2 per kg of H_2 and 1 to 2% of total French emissions is due to this H2 production

H2: an energetic vector

Global H2 consumption by sector (Mt H2)



Request of pure H2, by application (Hydrogen Council)



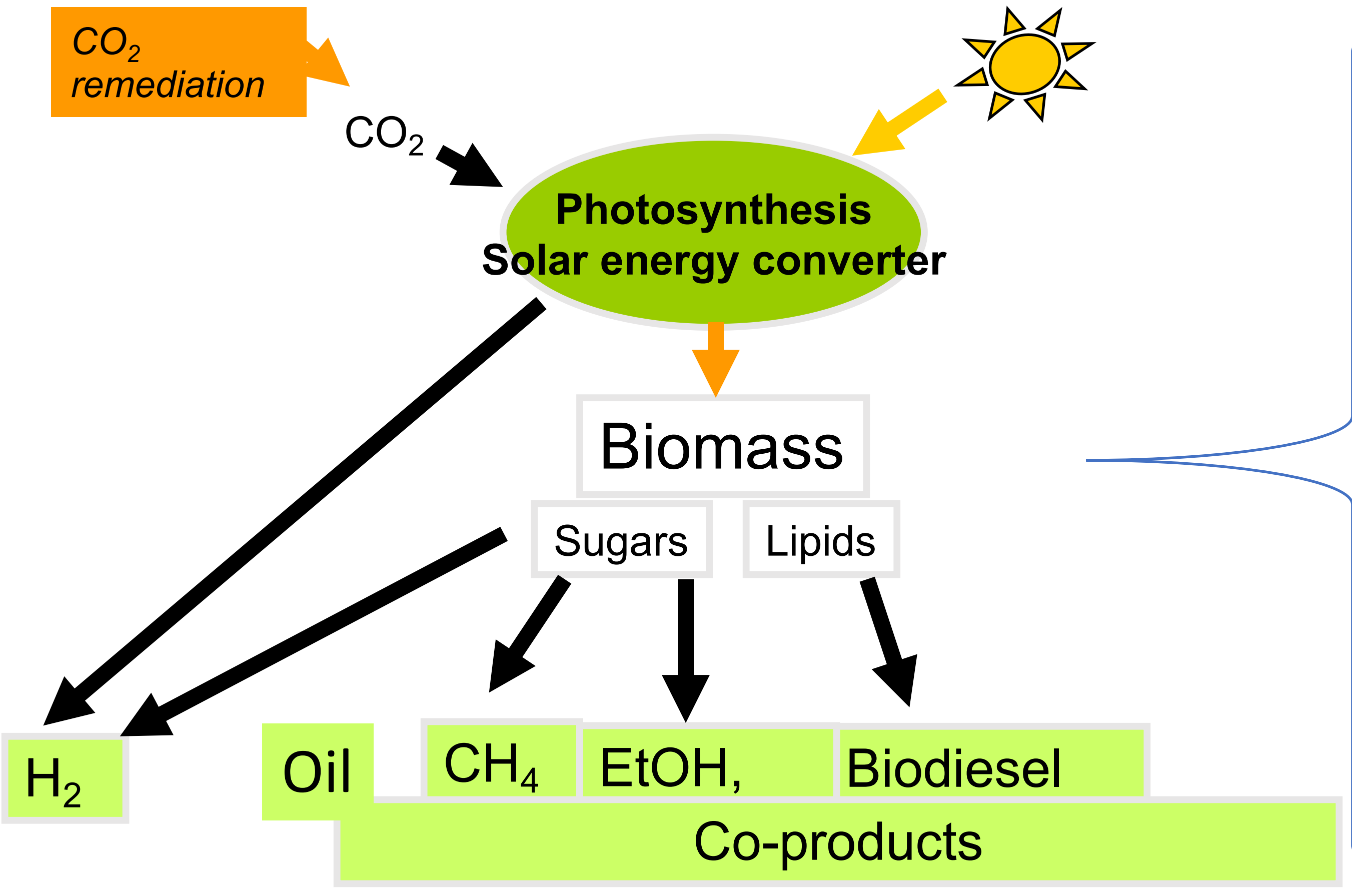
H2: an energetic vector

	Context and budget	Ambition for mobility
China	Recent but massive involvement	2020: 6200 FCEV 2025: 50 000 FCEV 2030: 1 million FCEV
US	California, a pioneer region	2020: 9000 FCEV 2030: 1M FCEV
Japan	2019 budget: 510M€ Industry mobilised	2020: 3800 FCEV 2025 :200000 FCEV 2030: 800000 FCEV
South Korea	2020 Budget: 386 M€; Several H2 cities	2020: 9000 2030: 850000
Germany	Historical H2 country in Europe Budget 2016-2026: 1400 M€ + H2 Plan 9Md€	2020: 630+ 2 Trains 2025: 90 Trains
France	National plan 7.2 Md€	2020: 400 FCEV 2028 : > 20000 FCEV

In 2020, following the Covid crisis, many countries have put in place national recovery plans which almost all include an H2 plan. This is the case in Europe with a focus on green H2

Biomass for energy

Produce energy from biomass, consists of recovering the energy released during the degradation of biomass into CO2 and H2O, and making it available in a form that can be used by humans.



Biofuels: Energy from biomass

why biofuels?

- ✓ Historical drivers
  - ➢ Promote employment in rural areas
  - ➢ Develop energy independence
  - ➢ Contribute to the reduction of greenhouse gas emissions in transportation

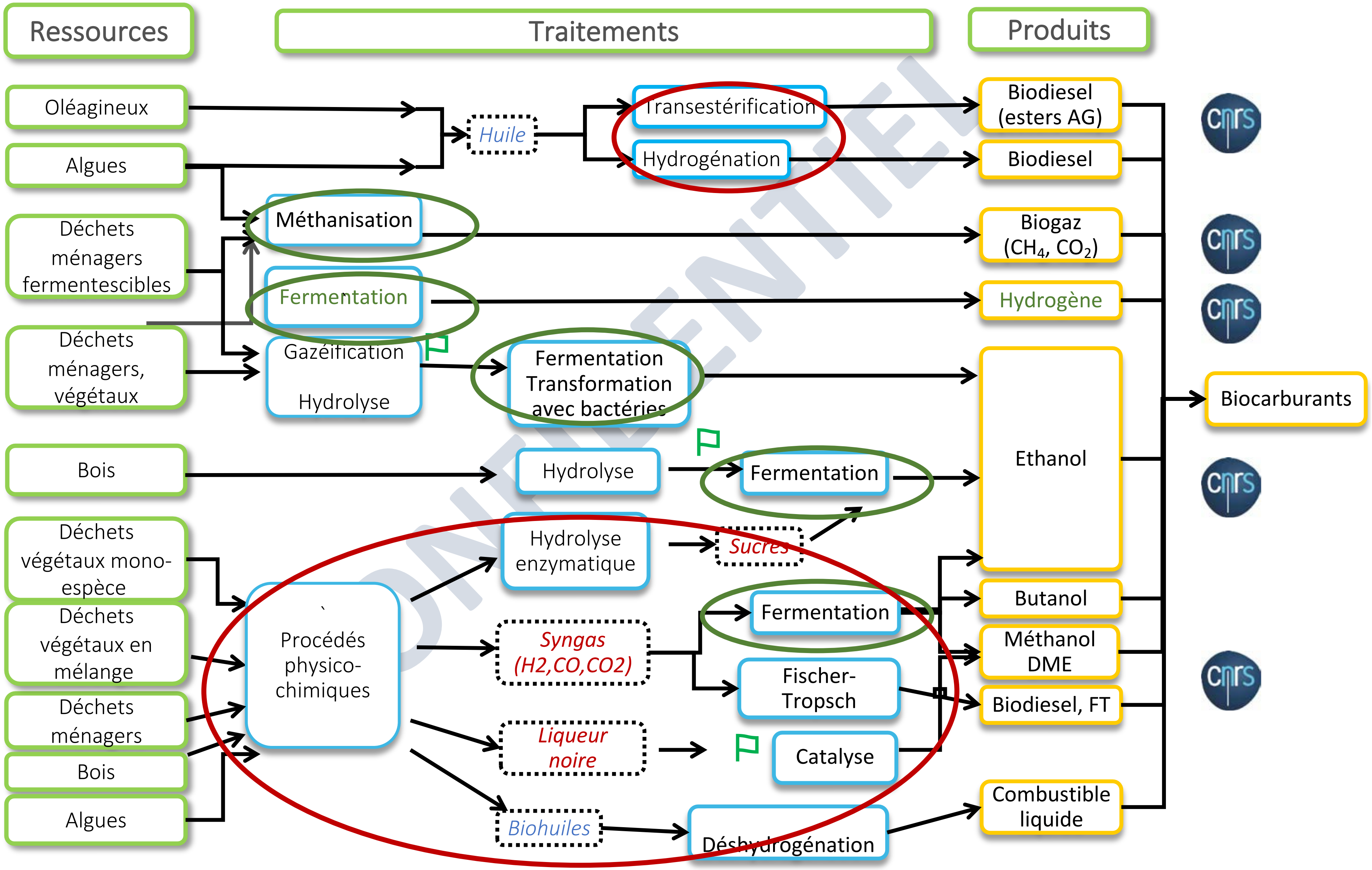
- ✓ Main current drivers
  - ➢ Contribute to the reduction of CO_2 emissions in transport
  - ➢ Geopolitics

Biofuels: Energy from biomass

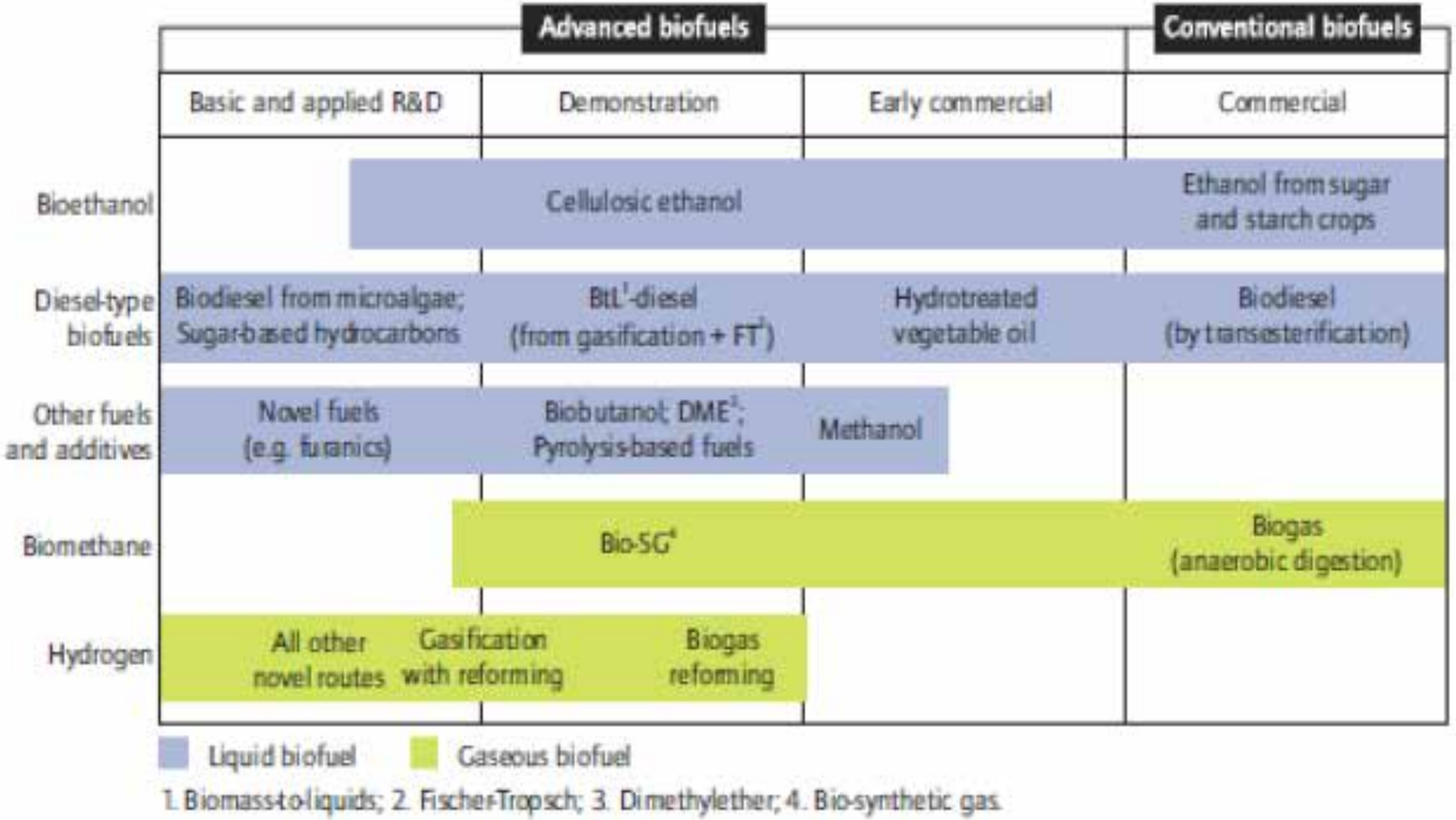
- 1st generation: Oil, ethanol from the transformation of biomass (wheat, beet, etc.). Represents from 7% to 12% of fuels.
  - In competition with water, food: Environmental and societal problem.

- Advanced biofuels: 2G and 3G: no competition with water and food, derived from biomass and therefore from CO_2 fixation.
  - 2G: Ethanol, biomethane: production by anaerobic fermentation (without oxygen) from dedicated crops, waste... (2020-2050)
  - 3G Hydrogen and biodiesel: production from biomass. (2050....)

Biofuels: the world of possibilities



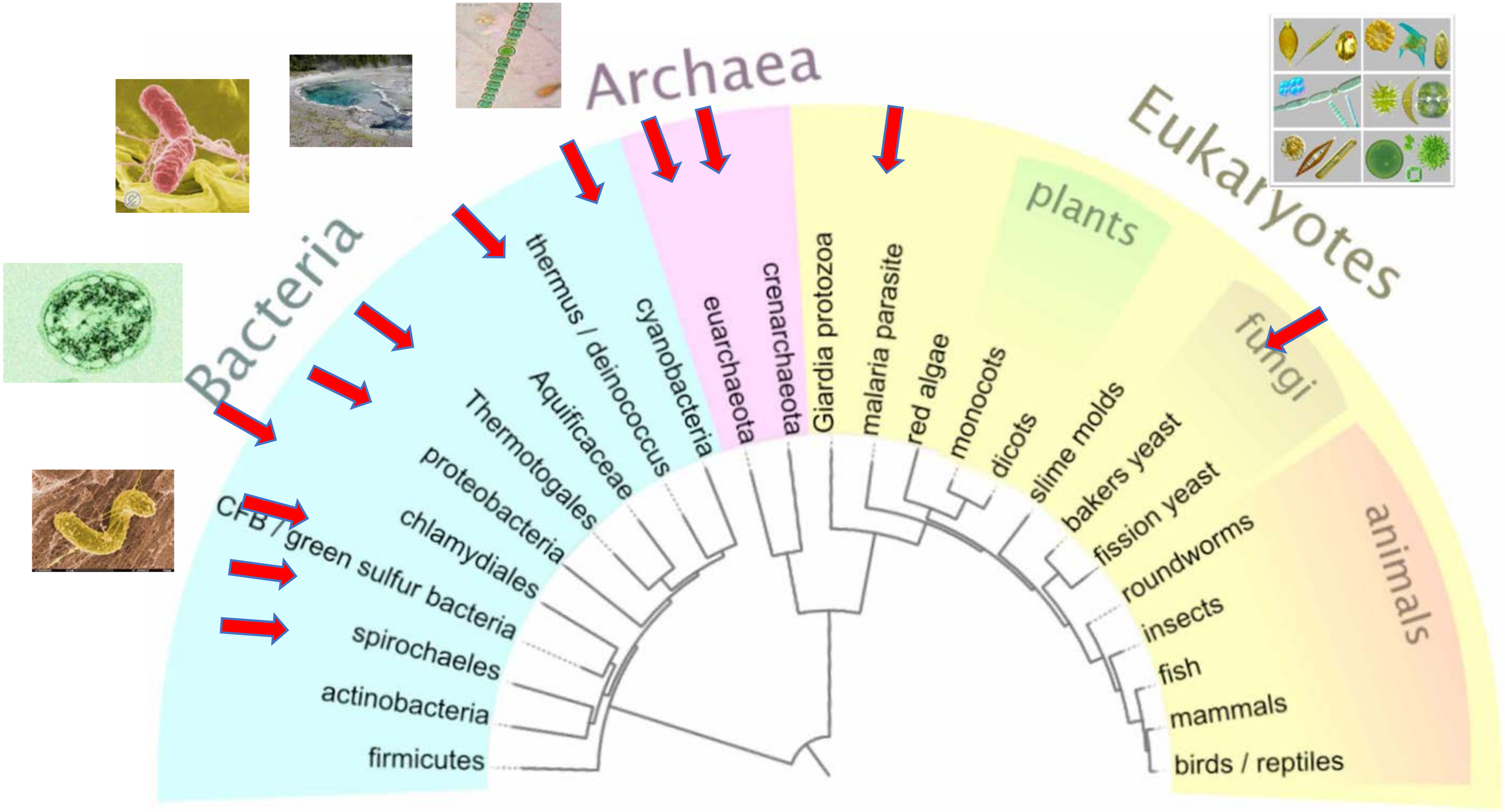
Maturity of the main biofuel production technologies



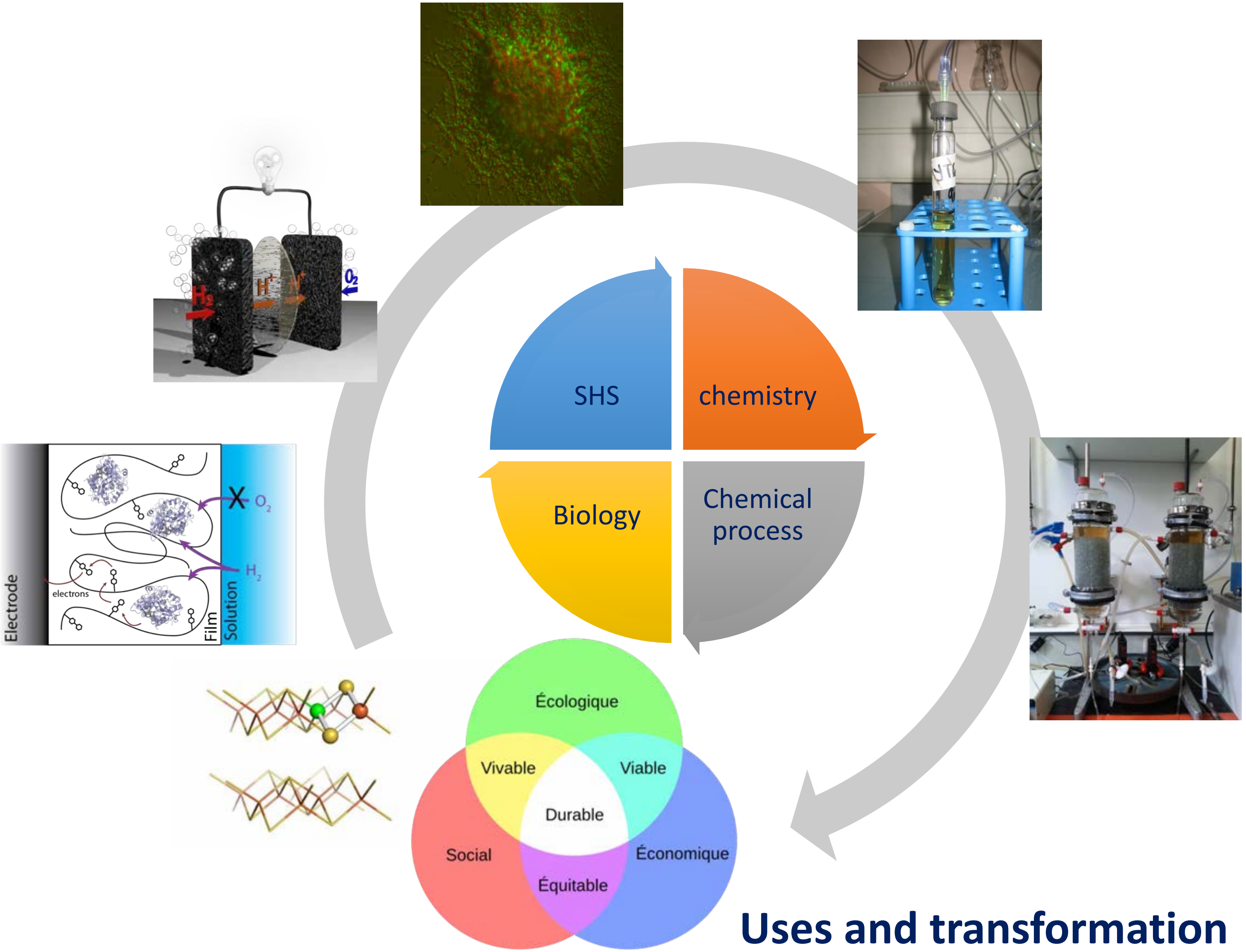
fuel eq/l	Decrease CO2
0,66	59%
0,91	47%
0,5	50%
1kg= 1,6 fuel= 1,3 gazoil	f(resource)
1kg= 4l fuel	F(resource)

Most of the advanced technologies are at the R&D or demonstration stage

H2: the energy carrier of life

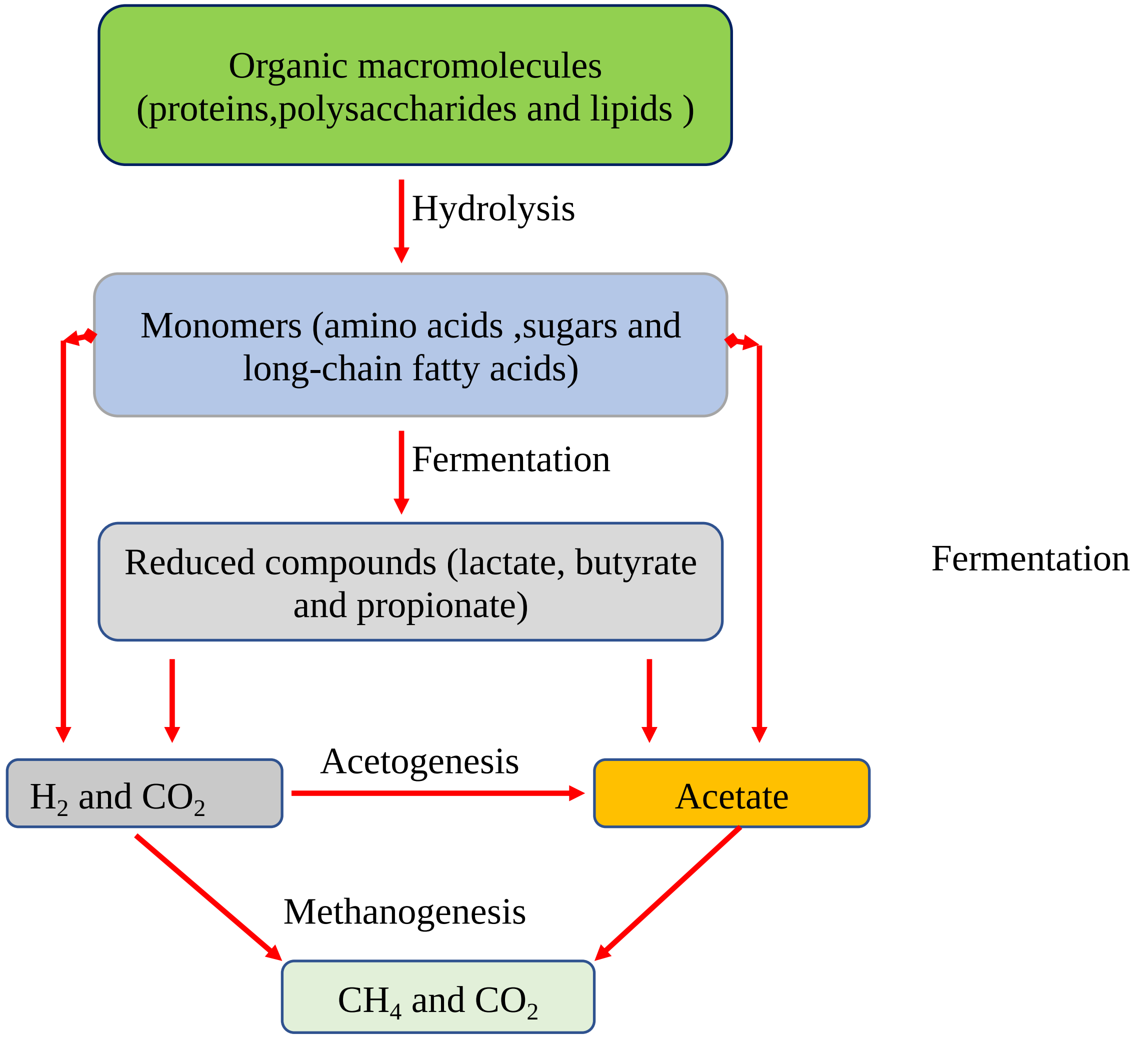


A multi-scale and interdisciplinary approach for BIO-H2

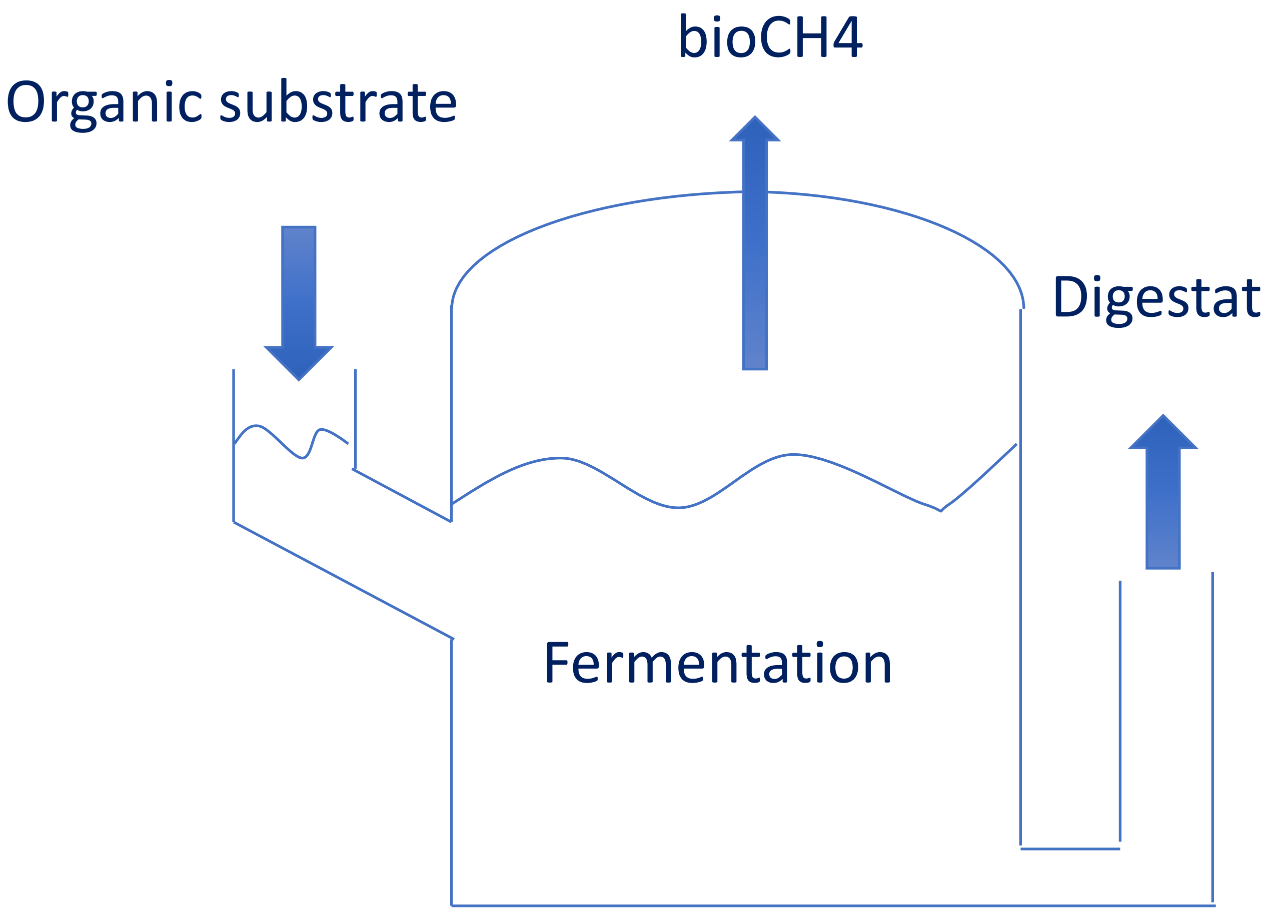


H2: the energy carrier of life

Syntrophic Biomass degradation



BioH2 from mature technologies to innovation

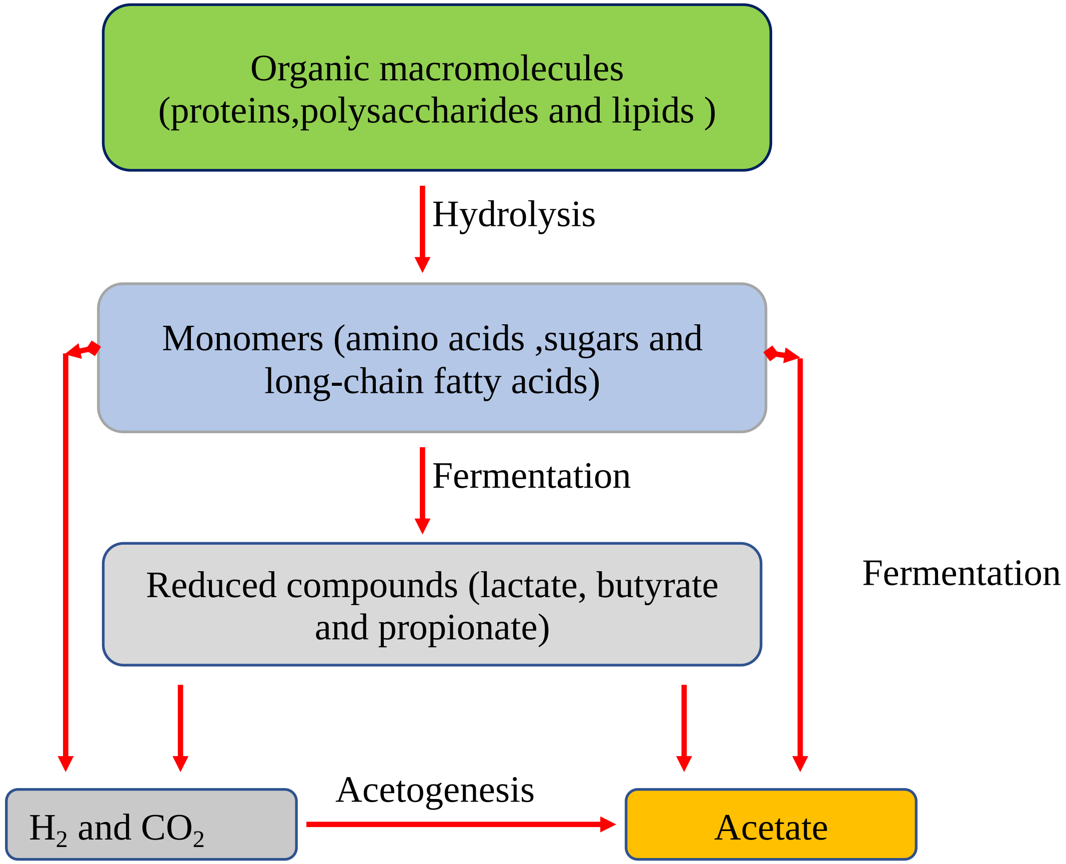


BioCH4 production:

- Mature technology
- Biological process not controled
- In France in 2020, 214 installations injected biomethane into the natural gas networks. Their capacity amounts to 3.9 TWh/year, an increase of 73% compared to the end of 2019

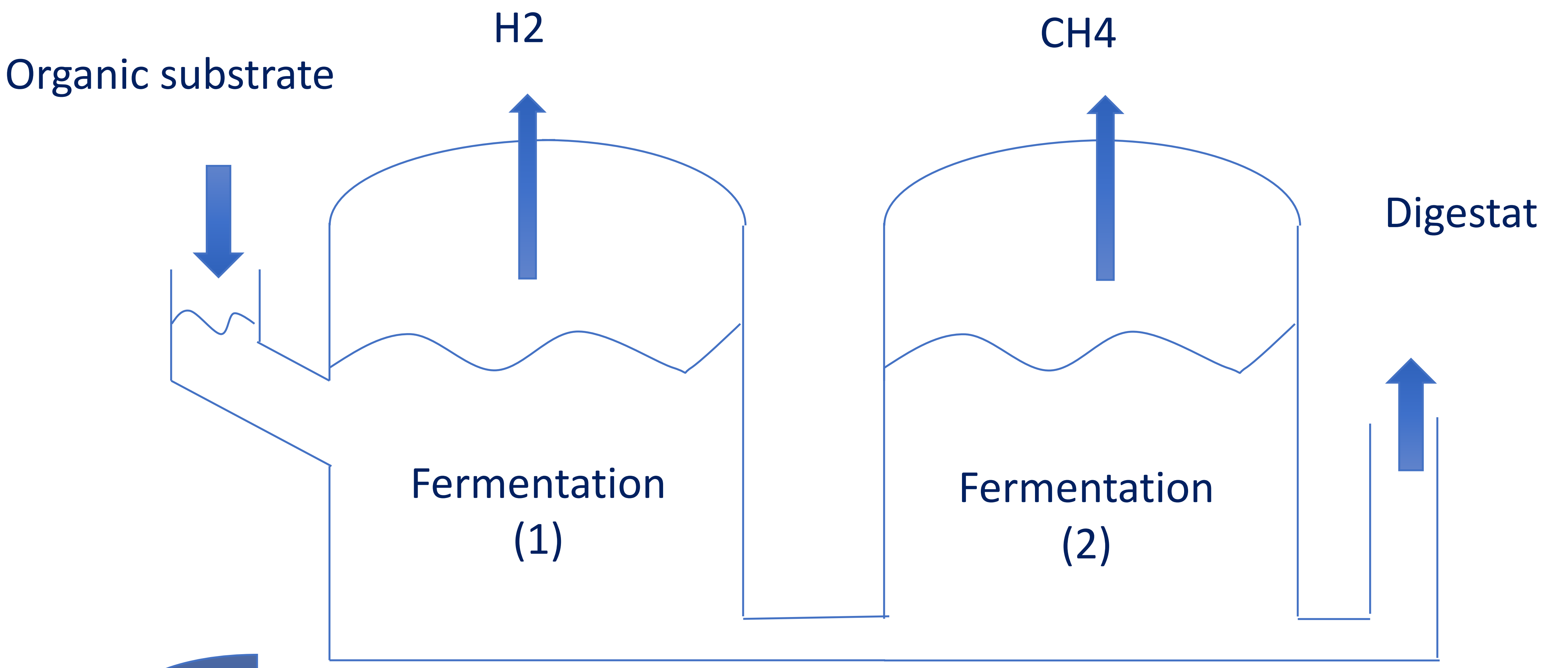
H2: a green energy

Syntrophic Biomass degradation and H_2 metabolism



- Requires reverse electron transfer, physical proximity and metabolic synchronization of the partners *via* biofilm formation.

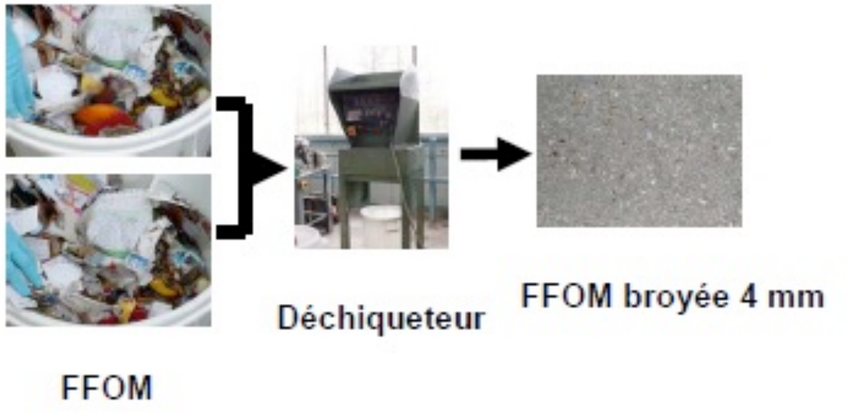
Advanced biofuels based new biological concepts



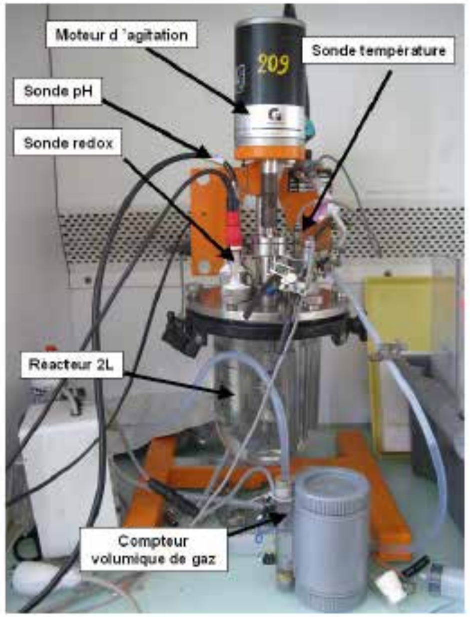
Better energetic biomass valorisation

bioH2 based new biological concepts

BIOH2 production from organic wastes

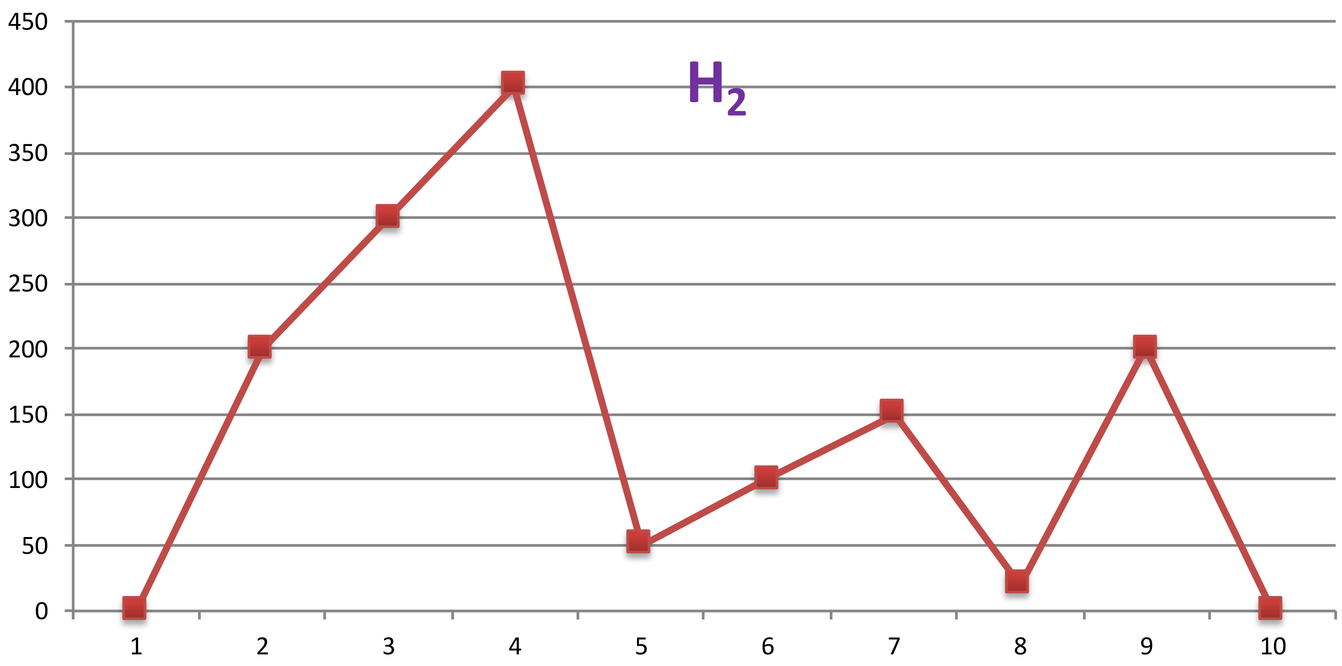


Wastes

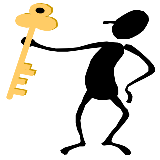


Cultivation, determination of hydrogen, methane, microbial and enzymatic potential
no need to inoculate the waste with a specific exogenous inoculum
Yield of 1.5 to 7 l H_2/kg FFOM (~ 20 kWh/kg FFOM)

bioH2 based new biological concepts

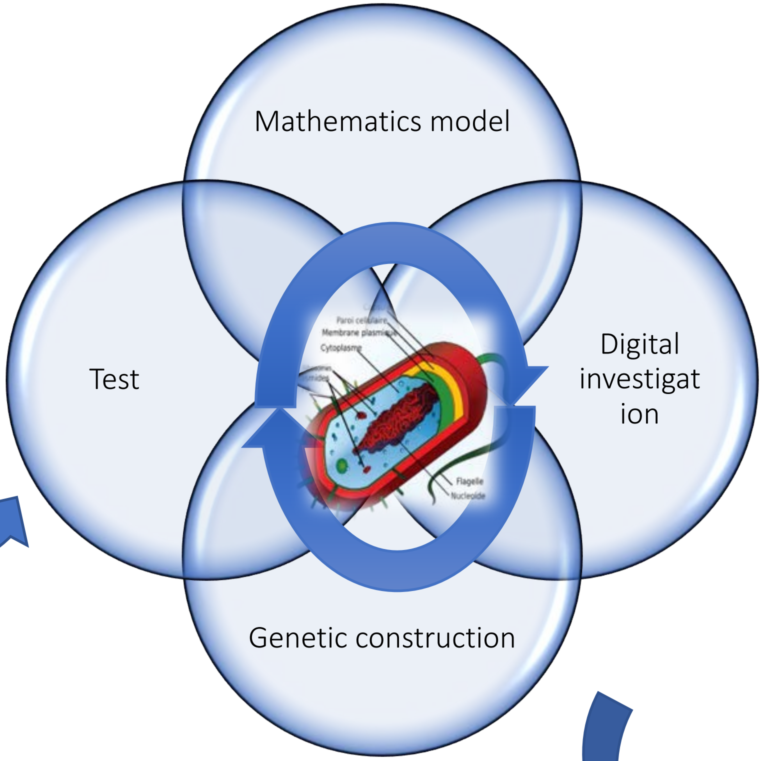


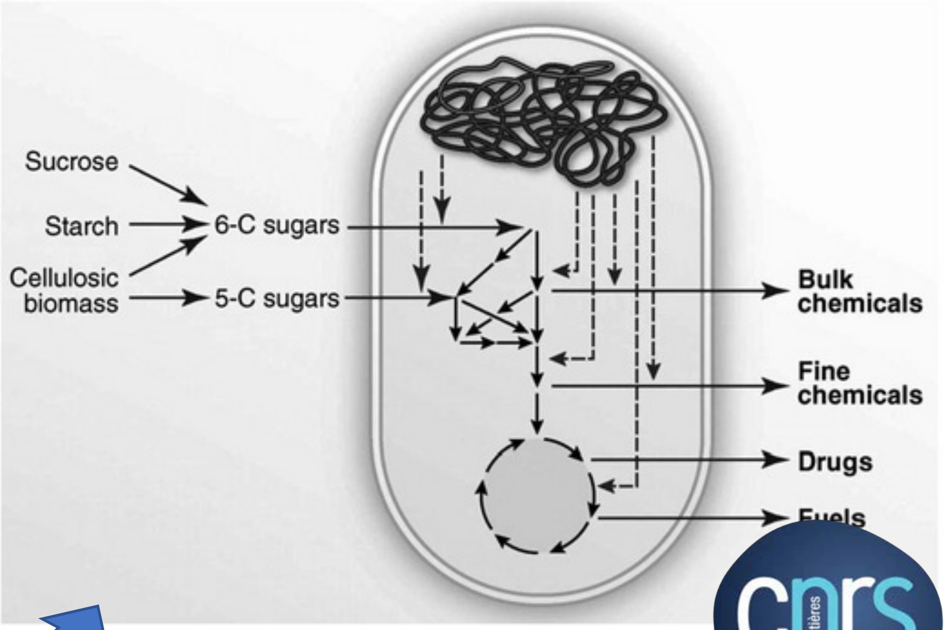
Abiotic conditions (pH, ° C, TSH)



Biotic conditions intra/inter species interactions

BioH2 based on metabolic engineering and synthetic biology





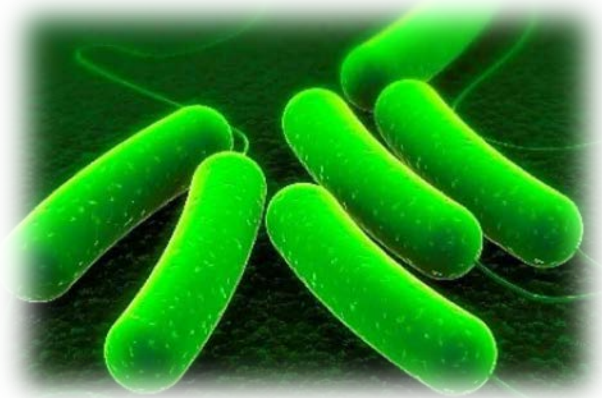
Advanced biofuels based on metabolic engineering and synthetic biology

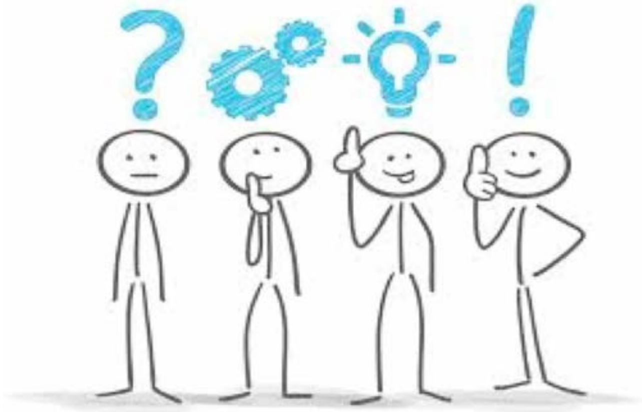
Program funded by U.S. Department of Energy's

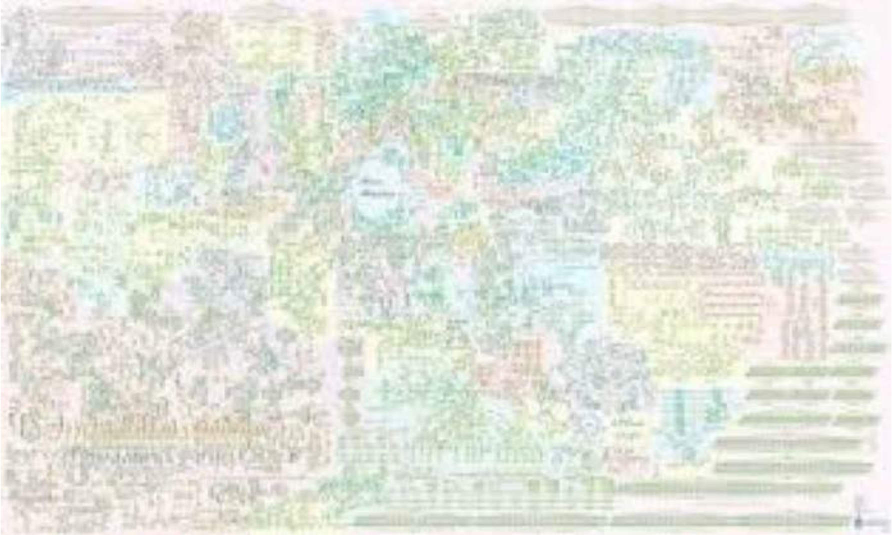
Developing emerging model microorganisms and/or microbial communities with unique or enhanced capabilities to produce H2 and advanced biofuels and/or bioproducts.

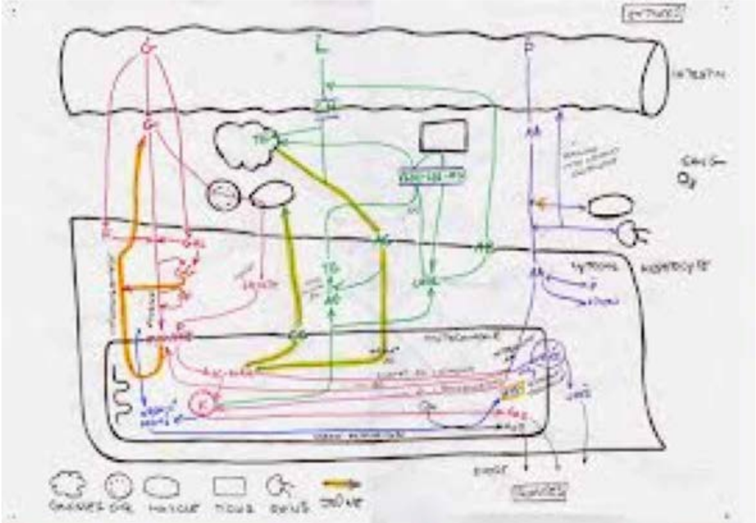
Understanding novel microbial functional capabilities and biosynthetic pathways relevant to the production of H2 and advanced biofuels and bioproducts.

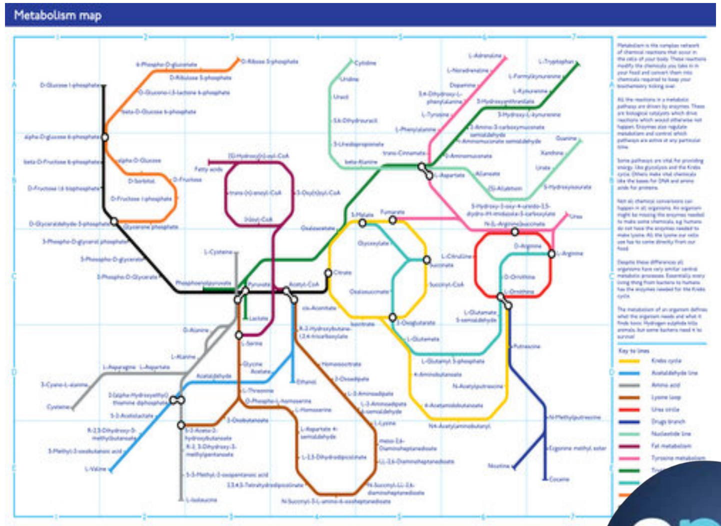
Advanced biofuels based on metabolic engineering and synthetic biology





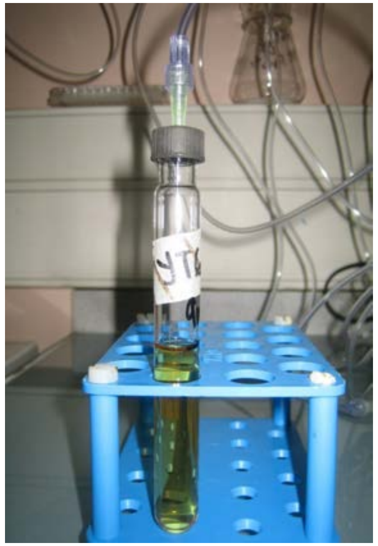


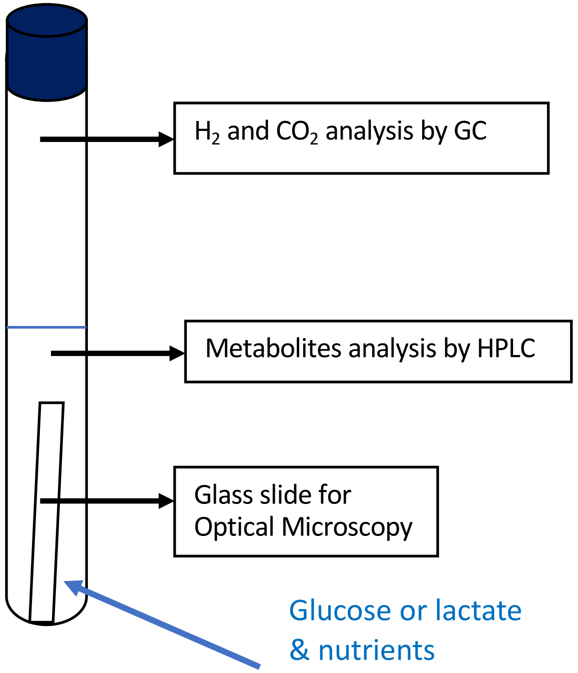


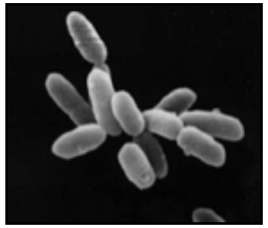


bioH2 based new biological concepts

Microbial consortium = simplified ecosystem







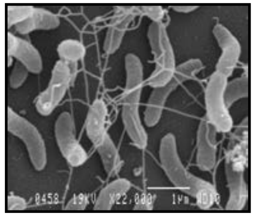
Fermentative bacterium

Large range of carbon source

H_2 prod.

C. acetobutylicum (wt)

Gram +



Sulfate reducing bacterium

Lactate

H_2 prod/cons.

D. vulgaris (wt)

Gram -

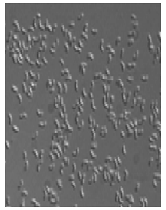
Both involved in complex biomass degradation

BioH2 production by synthetic consortium

Hydrogen production: batch results

Pure culture

D. vulgaris



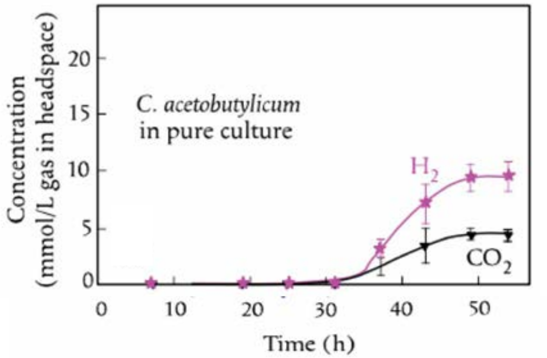
Lactate/sulfate medium

→ No H_2

C. acetobutylicum

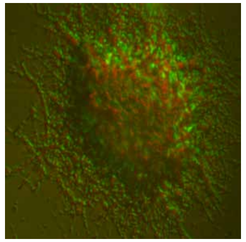
Glucose medium

→



No pH buffer
[glucose] = 14 mmol/L

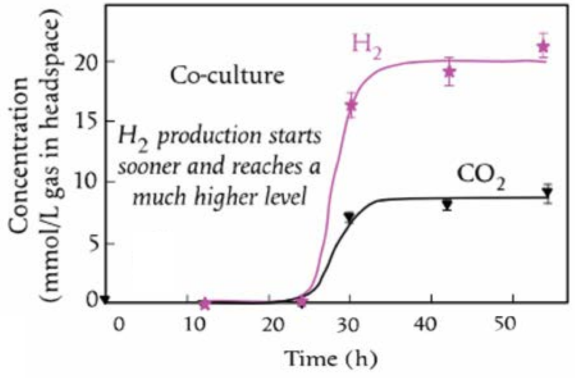
Co culture: consortium



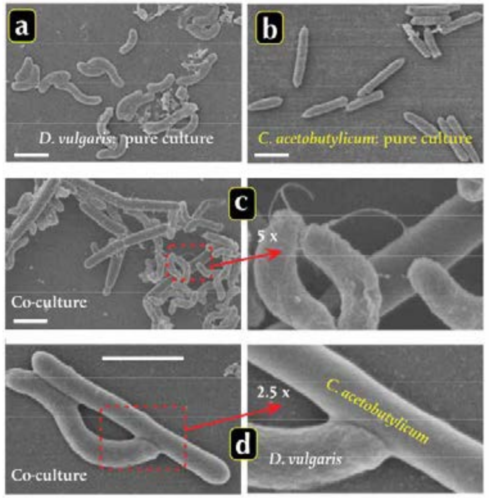
Glucose medium

Biofilm formation

→

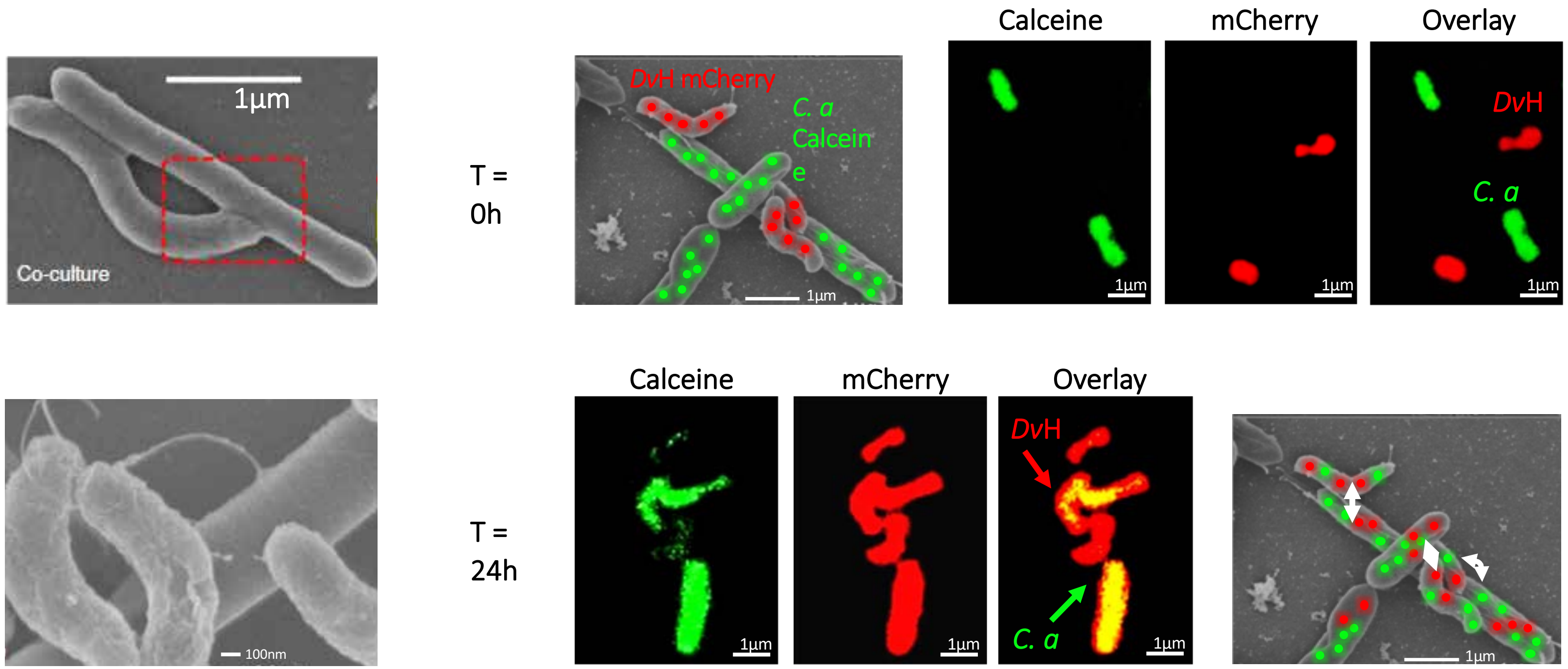


Increase of hydrogen evolution



Benomar, Ranava *et al*, Nature Commun. 2015
Ranava mBIO 2021

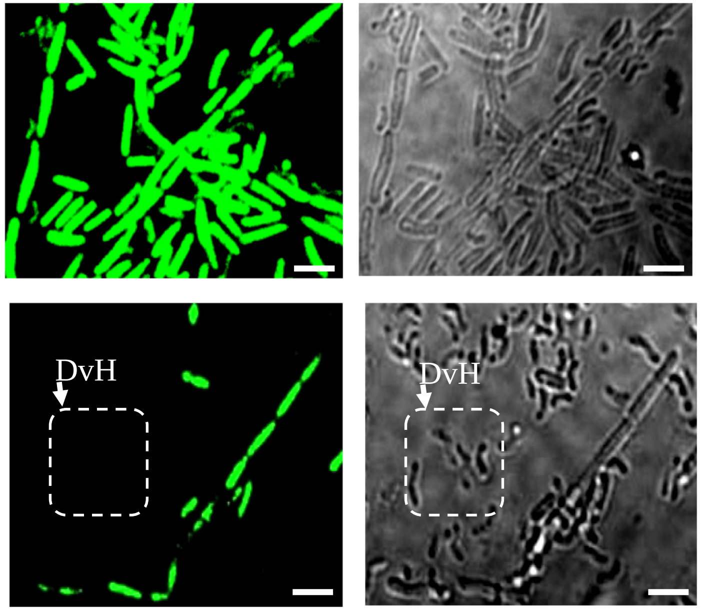
BioH2 production by synthetic consortium: role of physical interactions



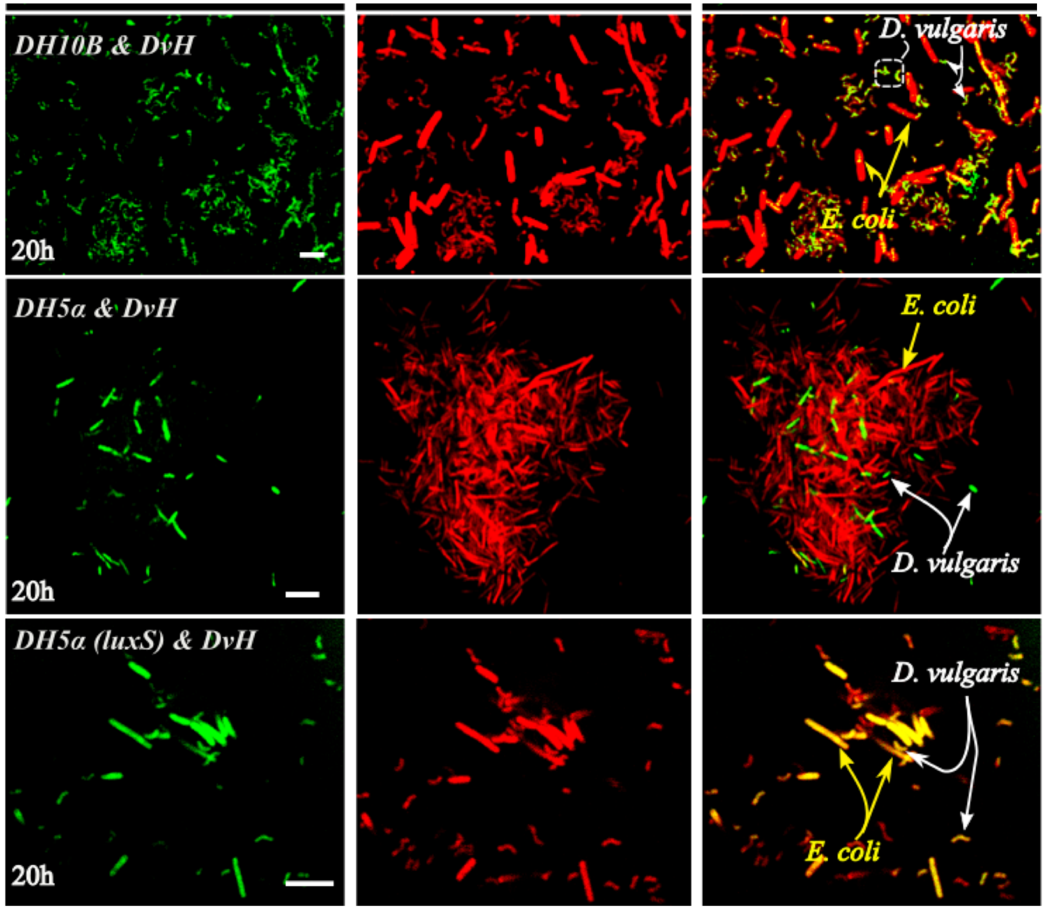
- ➢ Bidirectional exchange of cytoplasmic material between C. acetobutylicum and D. vulgaris associated with higher H_2 production (better yield)

Benomar*, Ranava* *et al*. Nat. Commun.; Ranava et al mBIO

BioH2 production by synthetic consortium: role of physical interactions



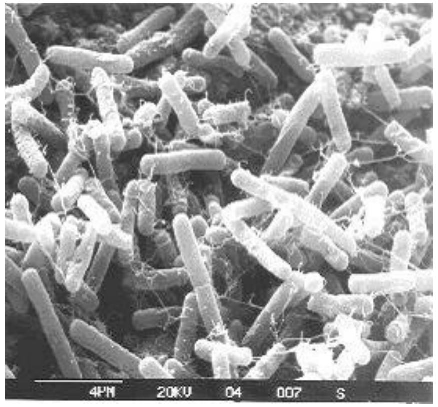
Link between nutritional stress and bacterial communication



QS and nutitional stress are necessary

Stress + QS = Increase in H2 production

Metabolic and cellular coupling model

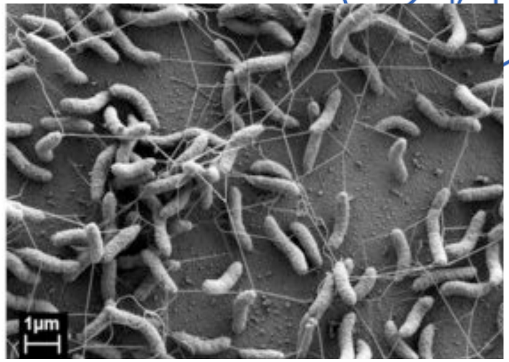


Clostridium acetobutylicum (Cab)

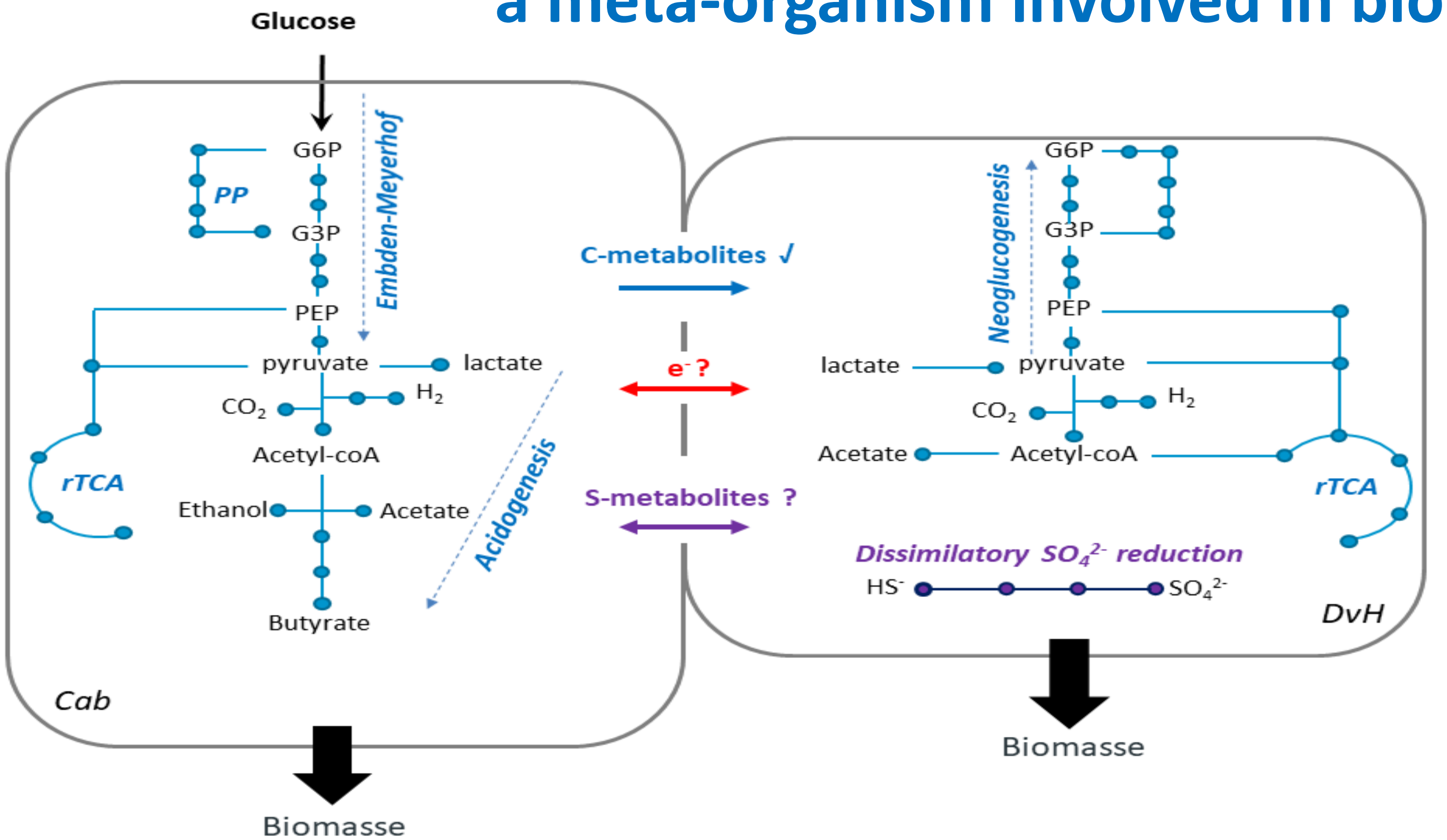
Glucose fermentation
Acidogenesis ->
H_2-producing

Desulfovibrio vulgaris Hildenborough (DvH)

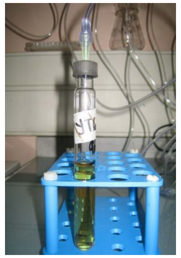
Lactate/Pyruvate respiration (SO_4^{2-})?
Lactate/Pyruvate/Formiate
Fermentation ?
H_2-producing/consuming



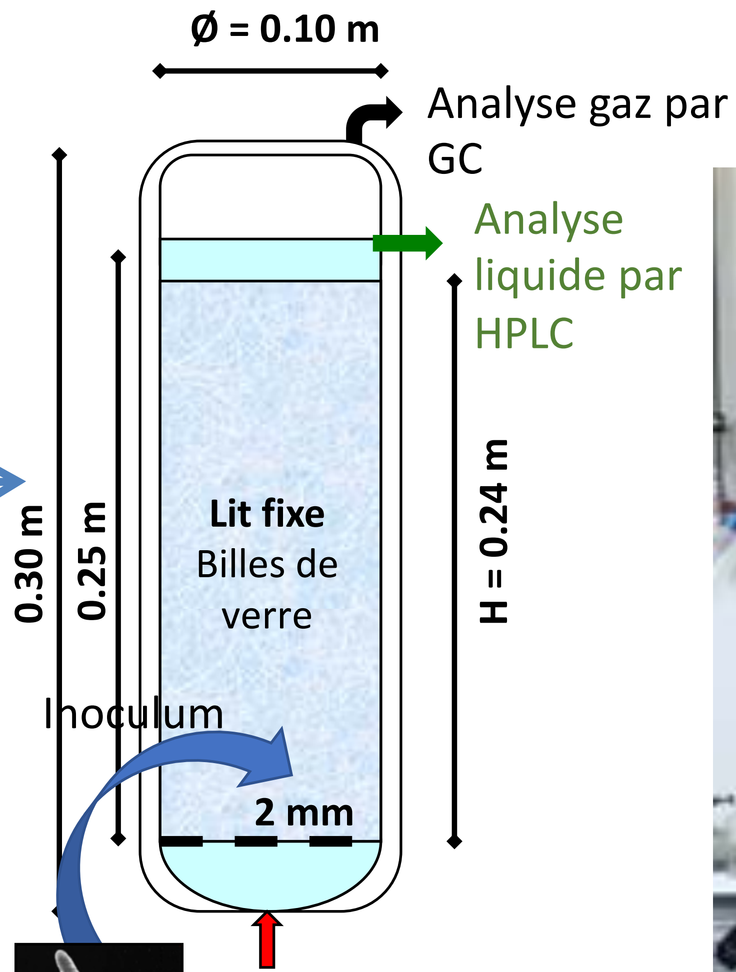
a meta-organism involved in bioH2 production



Scale up: Design



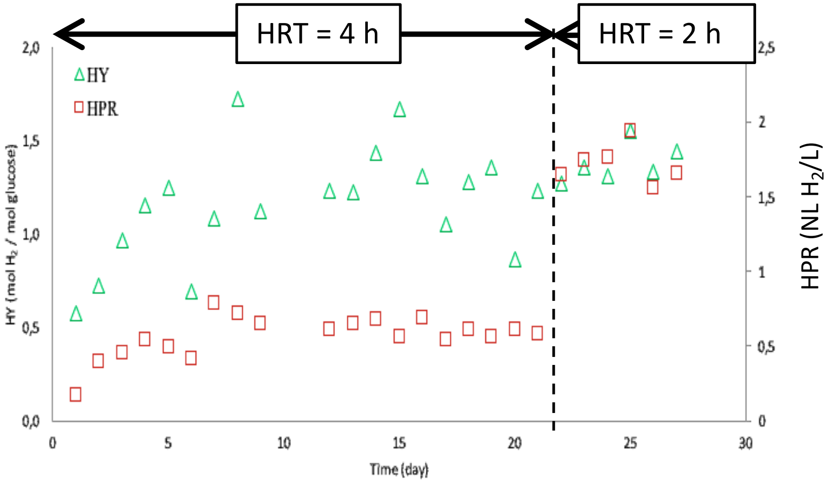
10.10^{-3} L
batch



Système stérile,
Anaérobie strict
T régulée

2 L
continu

Système non stérile, dé-oxygéné,
eaux « sales » synthétiques



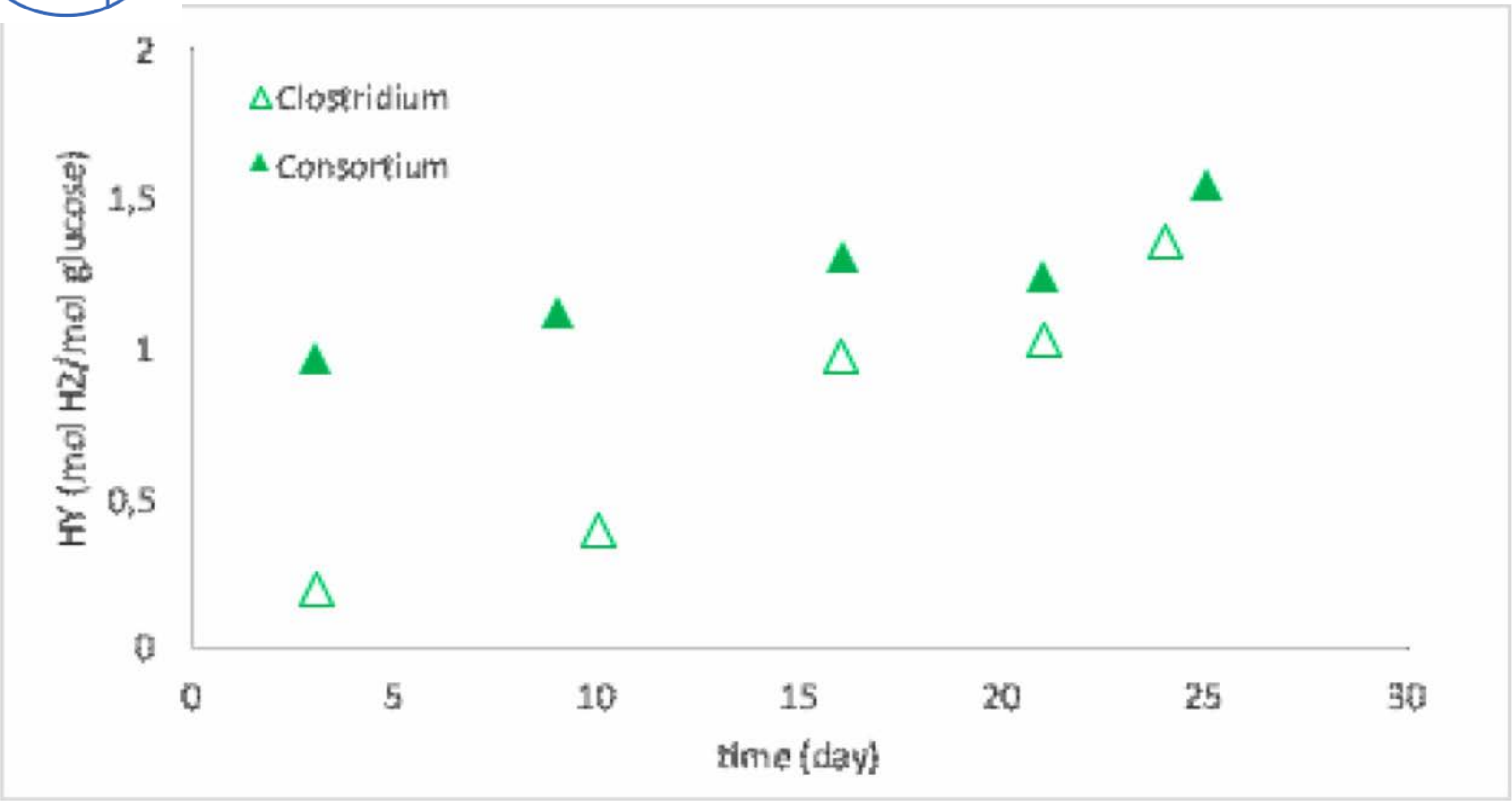
0.01 < **0.1** < 7.4 NL H_2/h/L(réacteur)

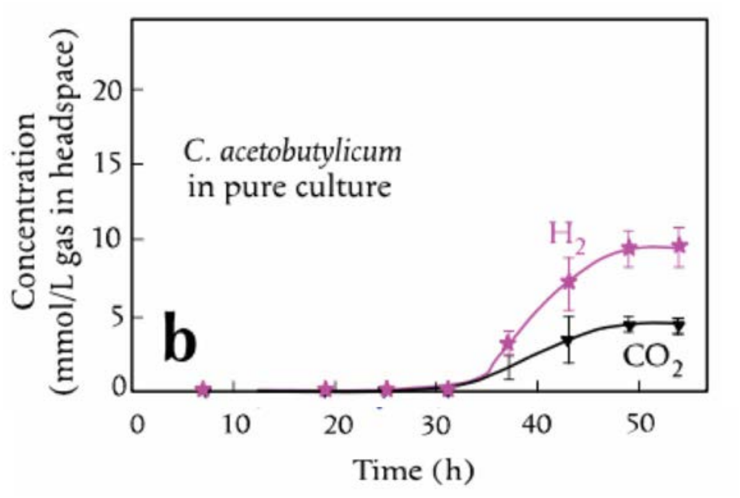
Production stable et continue d'hydrogène

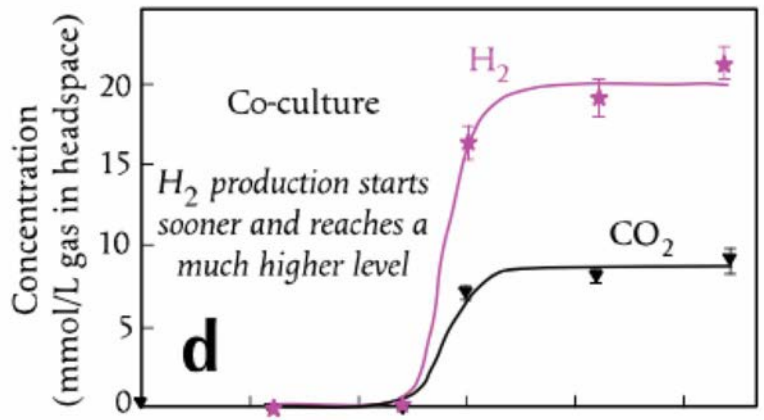
Bactéries toujours présentes

Rendement constant = voies métaboliques

H_2 Yield







Etude en continu confirme les résultats batch

Continuous

$0.5 < HY_{C.\ ab} < 1.3$ mol H_2/mol glu

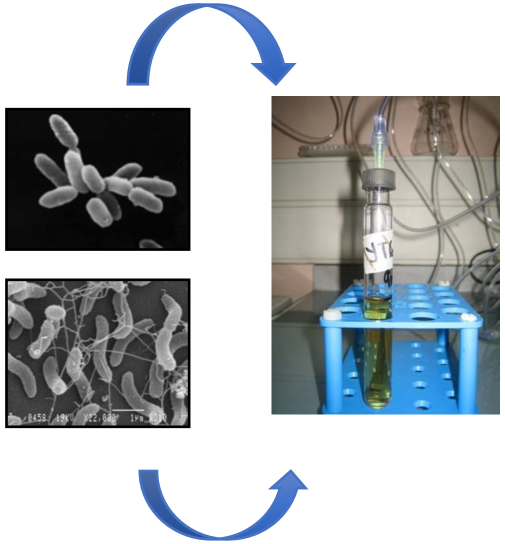
$1 < HY_{C.\ ab+D.\ vH} < 1.45$ mol H_2/mol glu

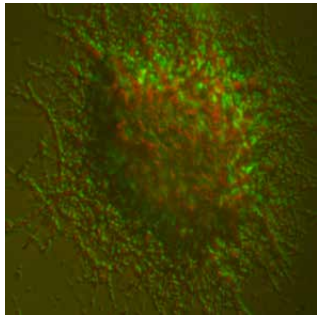
Batch

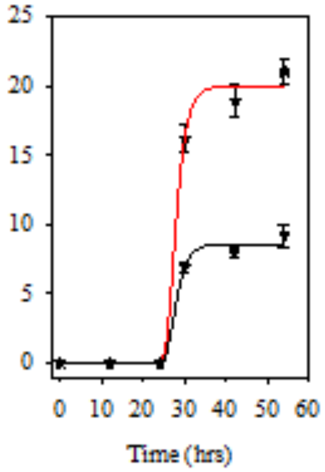
$HY_{C.\ ab} = 0.5$ mol H_2/mol glu

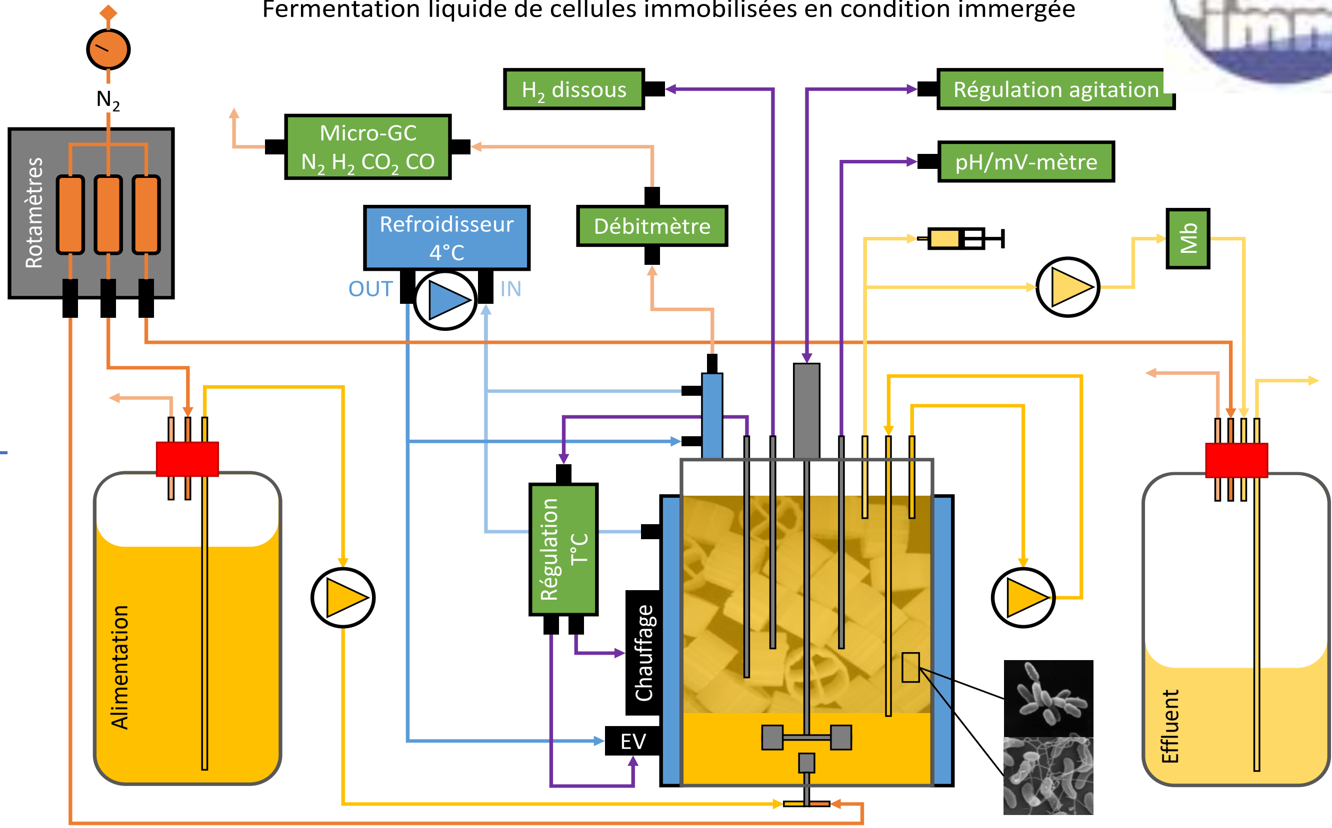
$HY_{C.\ ab+D.\ vH} = 1.43$ mol H_2/mol glu

Advanced biofuels based on new biological concepts





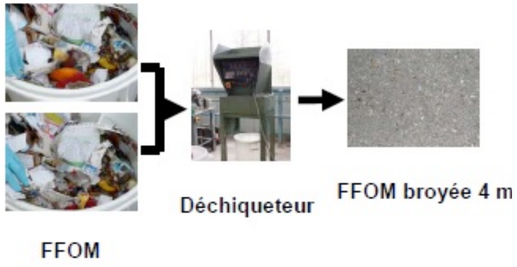


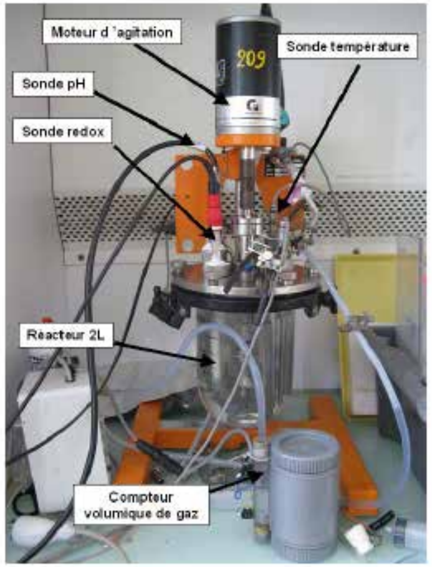


Ecological engineering: meta organism concept

Production d'Hydrogène à partir de déchets ménagers

Wastes



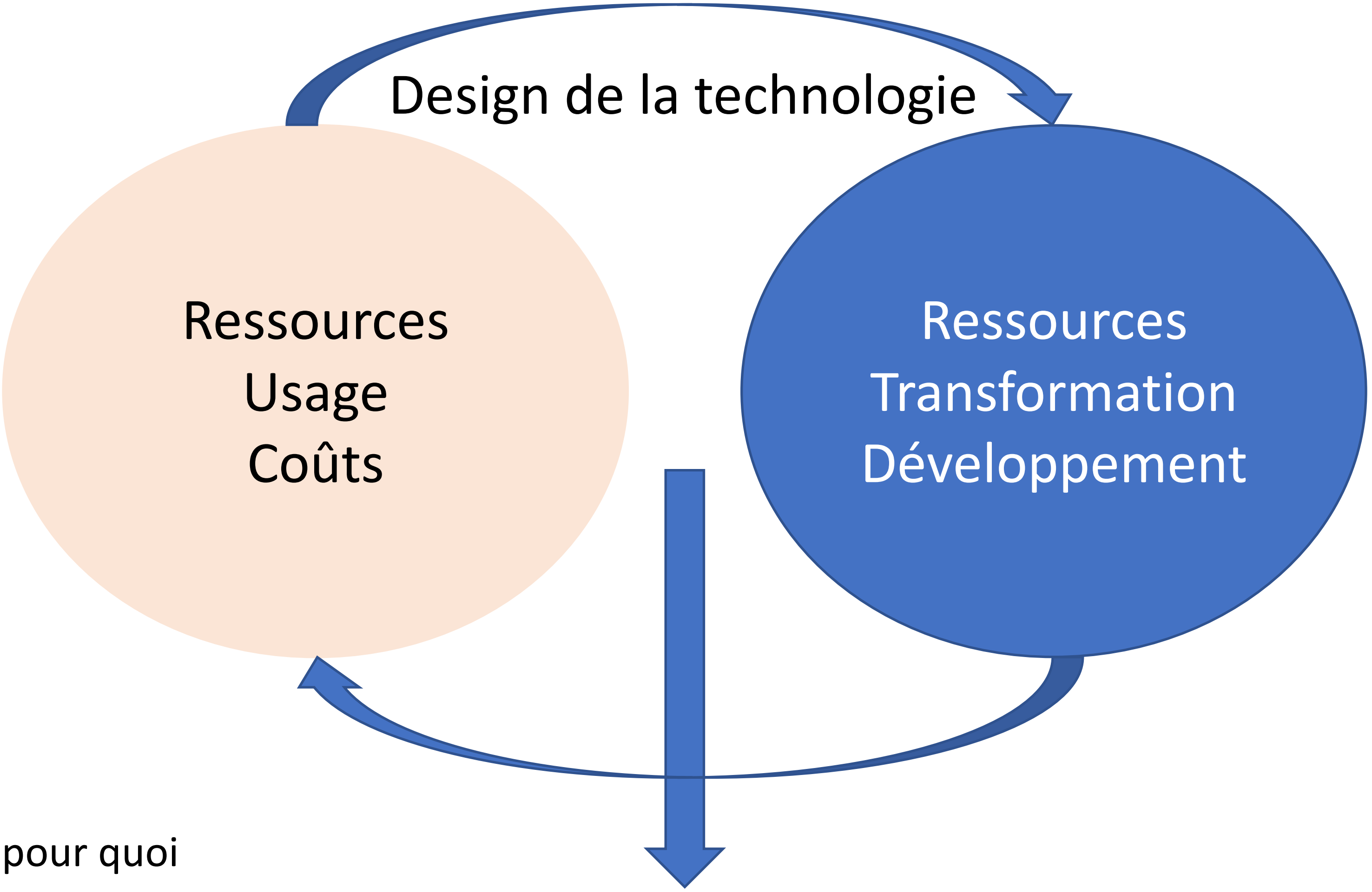


Mise en culture, détermination du potentiel hydrogène, méthane et potentiel microbien et enzymatique

pas nécessaire d'ensemencer les déchets avec un inoculum exogène spécifique

Rendement de 1.5 à 7 l H_2/kg FFOM (~ 20 kWh/kg FFOM)

To take home: Biofuels need integrated researches



Idée quel carburant pour quoi

Vecteur énergétique
(Biodiesel, H2, Bio-CH4…)