Techical-economical assessment of sodium borohydride as energy carrier

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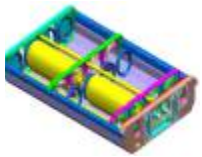
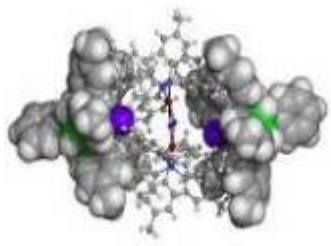
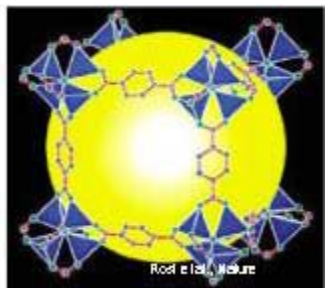
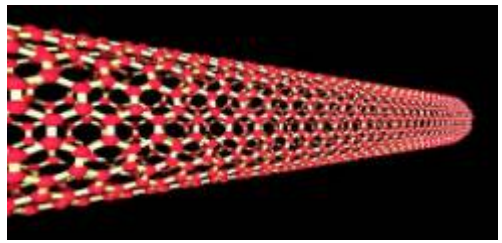
R&D Air Liquide approach

- Overview of all H_2 storages





- Focus on most promising technologies
  - For $NaBH_4$: assess the supply chain & technology

Outline of the presentation

- Technical assessments : storage performances
- Economical assessment : remote sites
- Conclusion & next steps

How to store hydrogen with sodium borohydride ?

- Commercial products



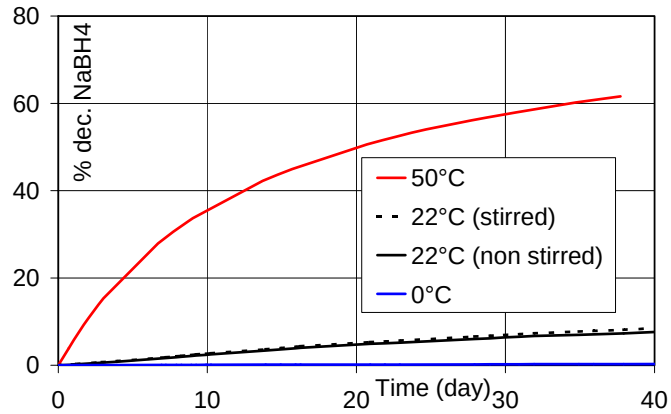
- Hydrogen Energy solutions : low concentrated solutions
  - 20-3 : %wt $NaBH_4$-NaOH-H_2O *
  - 35-3 : %wt $NaBH_4$-NaOH-H_2O *
  - Question : are these solutions stable ?

Millenium Cell standard proposals

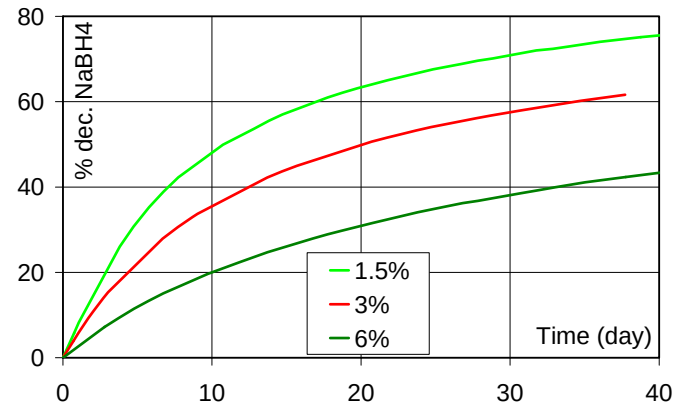
Stability assessments : experimental & results

Experiments carried out on $NaBH_4$ decomposition		
T, K	NaOH, w%	$NaBH_4$, w%
323	**1.5**	19.4
323	**3**	19.4
323	**6**	19.6
273	3	19.8
295	3	19.8
323	3	19.4
295	3	**19.8**
295	3	**28.2**
323	3	**6.93**
323	3	**19.8**
323	3	**31.2**
323	0.2	42.02

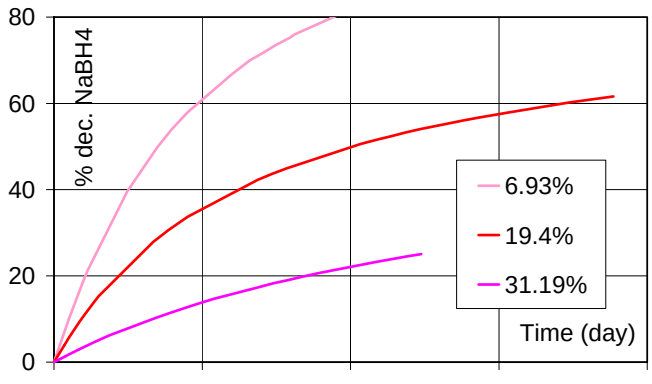
T effect



[NaOH] effect

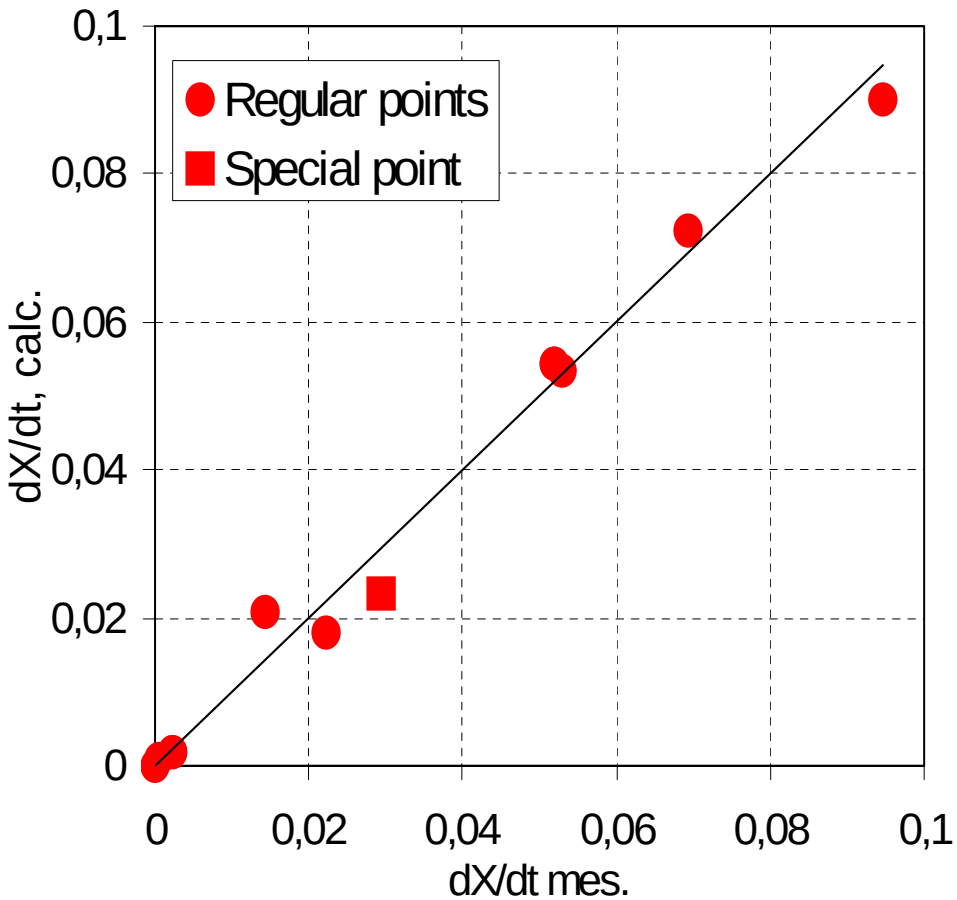


[NaBH4] effect



Stability assessments : initial decomposition modeling

$$\frac{d\left[BH_4^-\right]}{dt} = \left(51.0 - \left[BH_4^-\right]_0 - 4.18 \times \left[NaOH\right]_0\right) \times 12.52 \times 10^{12} \times \exp\left(\frac{-11634}{T}\right)$$



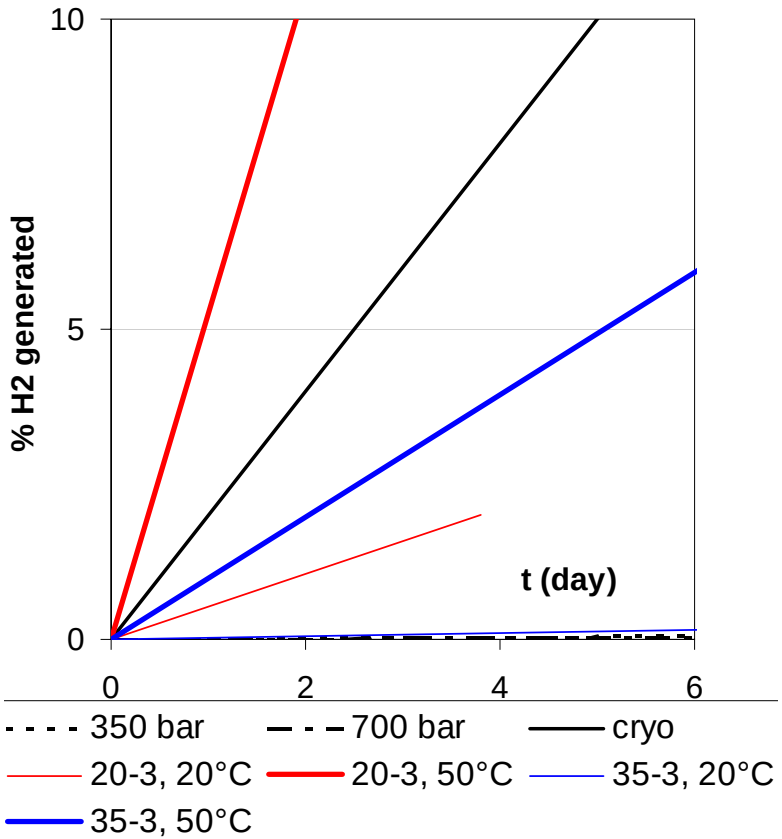
- $NaBH_4$ solution * decomposition increases with
  - Temperature
  - Low condentrated NaOH solution
  - Low condentrated NaBH4 solution
- Slurry studies :
  - some improvements
  - Handling ?

*** validity $NaBH_4$ <40%wt ; 0.2%wt < NaOH <10%wt**

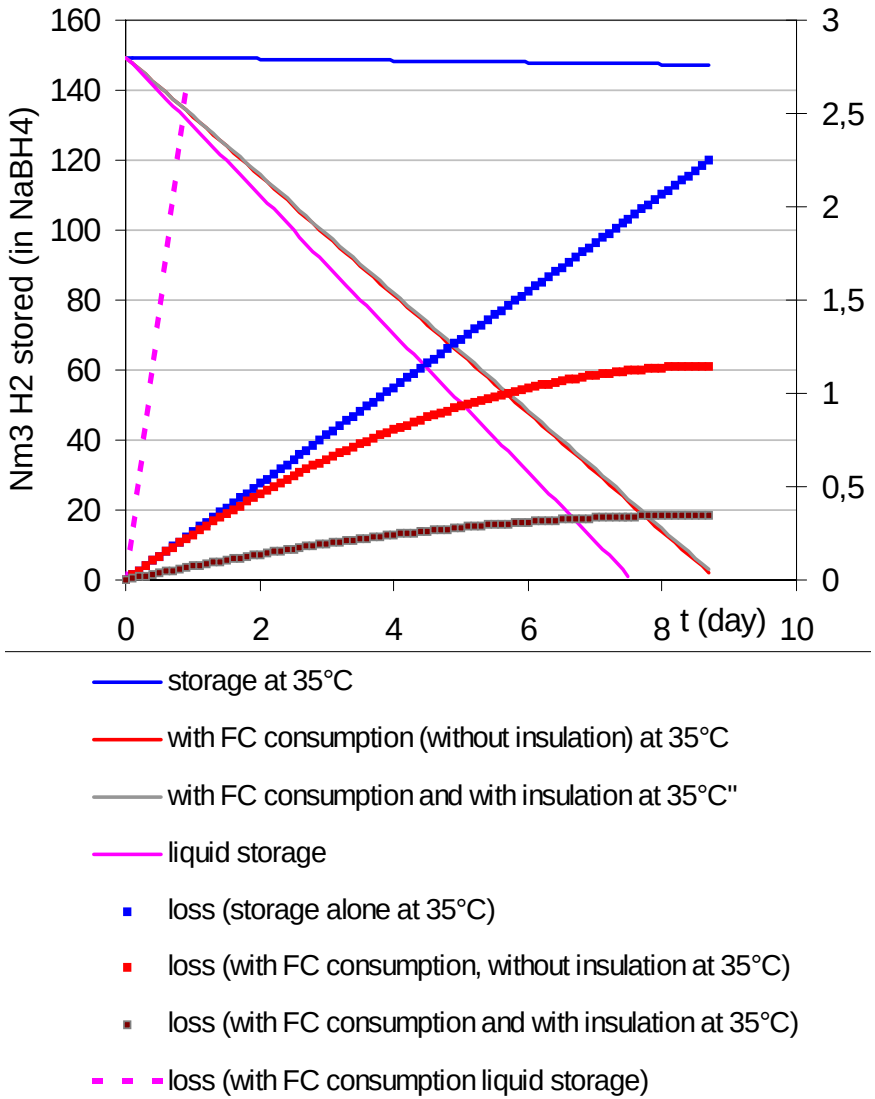
$NaBH_4$ storage assessment : comparison

Storage

Solution stability is comparable to H2 liquid tank boil-off

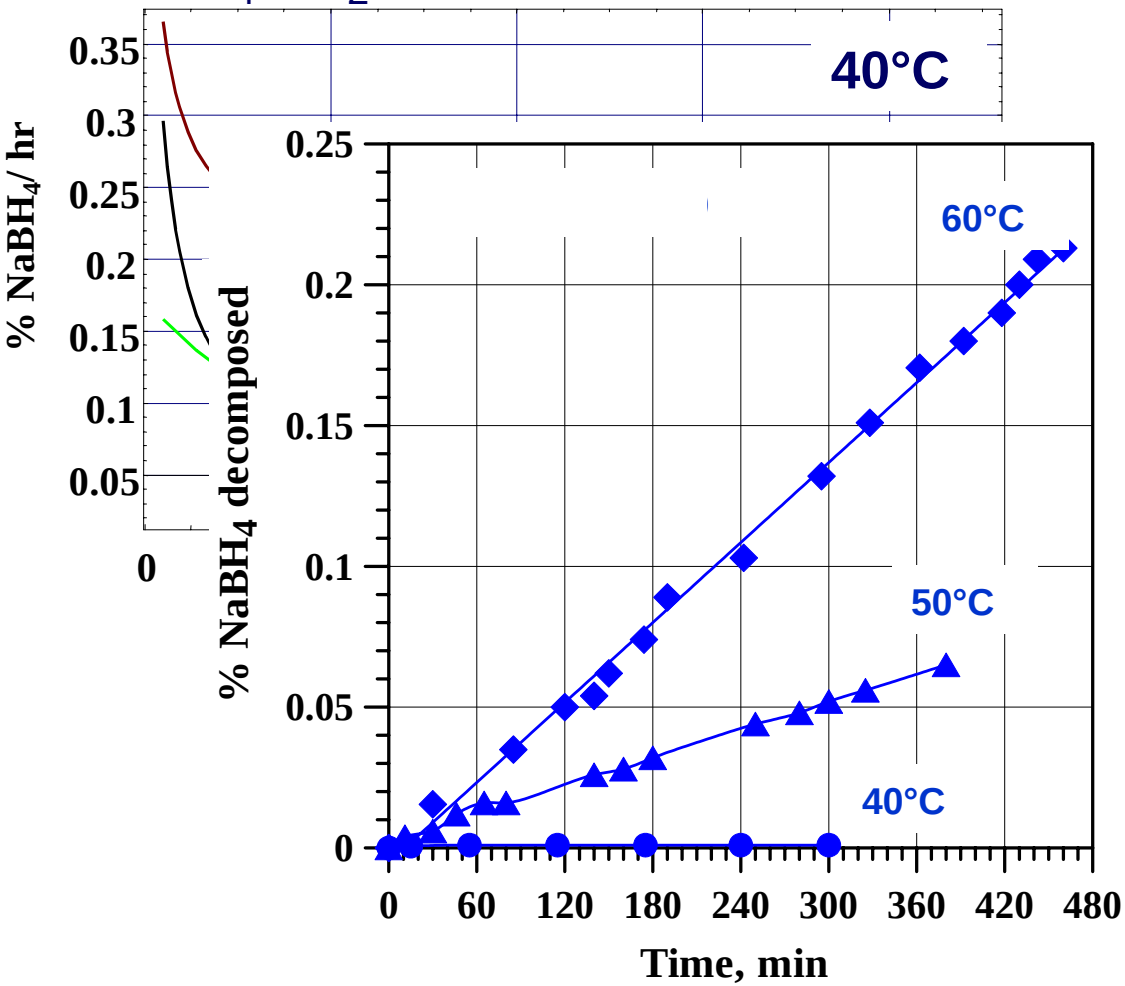


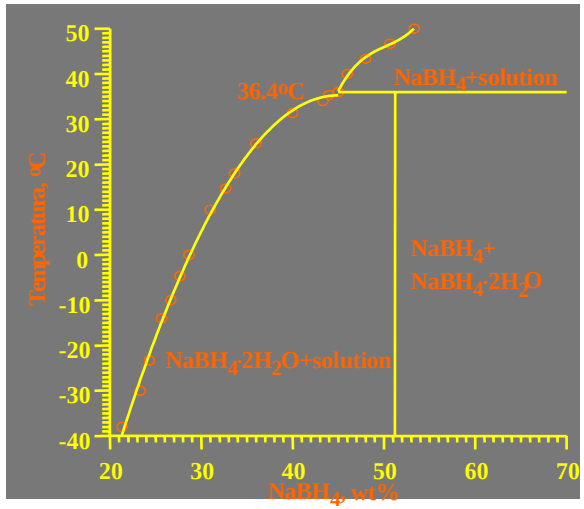
Fuel Cell consumption



Stability assessments : concentrated form

- $NaBH_4.2H_2O$-NaOH





- But, it is impossible to completely avoid the H_2 generation

$NaBH_4$ storage : conclusion

- Depending on use, some compromises have to be done :
  - Weight performance : [$NaBH_4$]
  - Safety :
    - [NaOH]
    - Allowed H_2 loss
  - Temperature of use
    - Freezing
    - High temperature (ambient)
  - Storage lifetime : allowed H_2 loss
  - Fuel handling : liquid / solid
  - Fuel price…
- Reactor performances & design…

Economical assessments : remoted sites

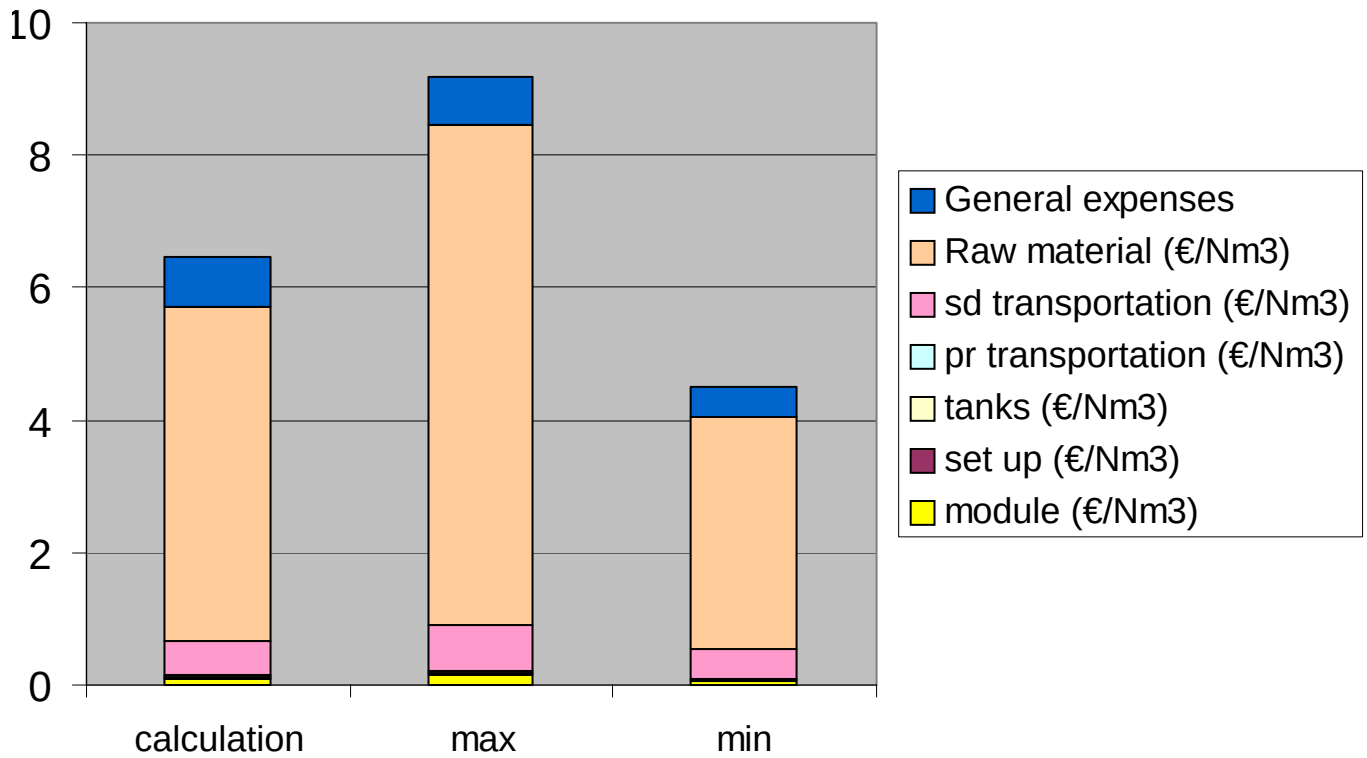
- Objectives : roughly calculation to set bottlenecks

- Hypothesis of the calculation :
  - System made of : storage tanks + generator module
    - Depreciation 7 years (module) ; 20 years (metallic tanks)
  - Logistics : primary and secondary transportation (France)
  - $NaBH_4$: 35-3-62
  - $NaBH_4$: 12€/kg*
  - Module : small on site H2 generators
    - 1Nm^3/h
    - 50 Nm^3/h

* Air Liquide assessment considering the standard Schlesinger process

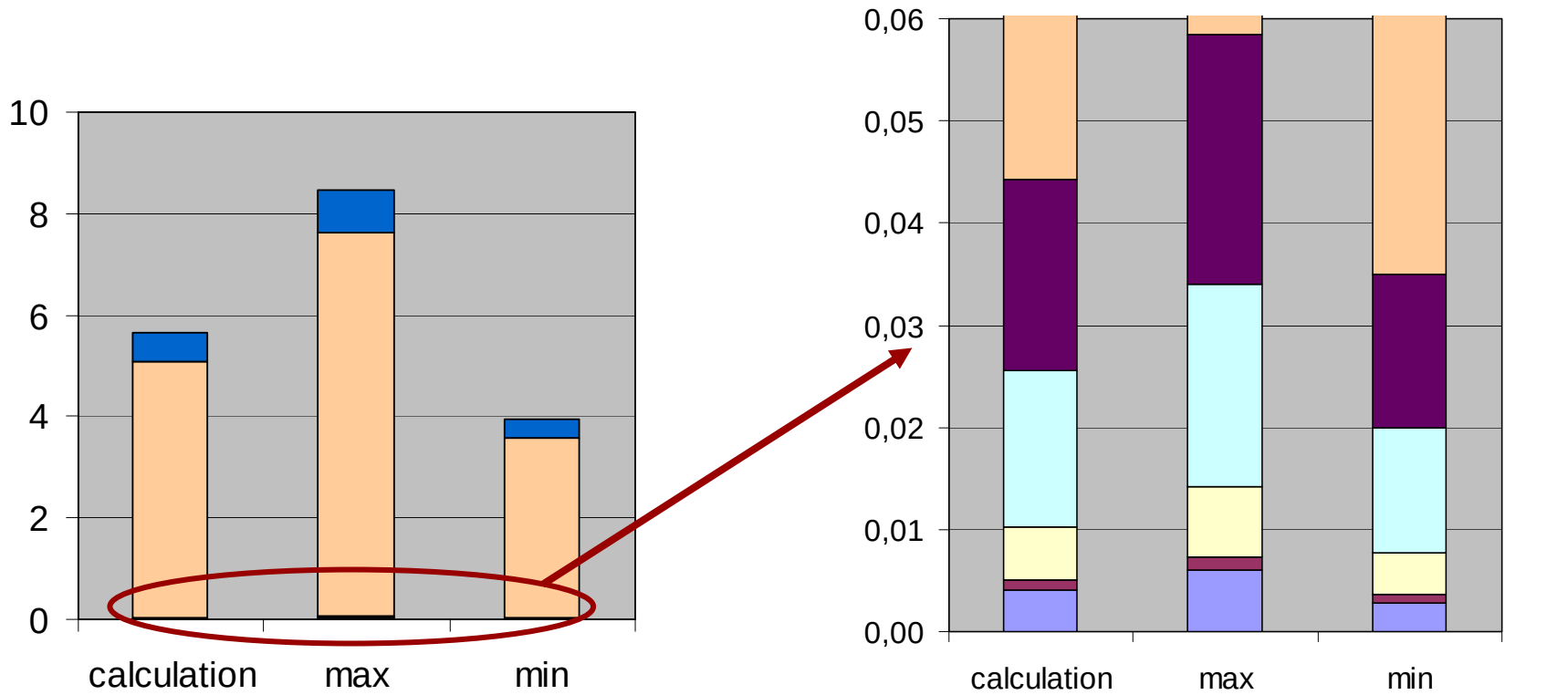
Economical : Calculation results

❑ 1 Nm^3/h system production



Economical : Calculation results

❑ 50 Nm³/h system production



Conclusion

- Raw material : bottleneck
  - 3.5 to 7.5 €/Nm^3 H_2 just considering raw material cost
  - Work is performed to decrease the $NaBH_4$ cost
    - Bottleneck in the standard synthesis has been identified
    - New synthesis schemes are tested
- System + logistics (without raw material)
  - 0.5 to 1 €/Nm^3 H_2
- As mentioned : technical issues still to be improved or to be by-passed
- Focus : technical items (production / material handling)

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Thank you for your attention