Nuclear reactor technologies for hybrid applications

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Outline

- Context reminders
- Grids with intermittent renewable electricity production and nuclear
- Making liquid fuels: need for carbon and hydrogen
- Clean coal to liquid as an example
- Making affordable hydrogen through flexibility
- Some of the challenges for hybrids
- Conclusions on a nuclear course to meet long term challenges

A few reminders

- Presently, civil nuclear power is essentially used for electricity production
- It can be made to load follow with a reasonably good flexibility, but:
  - You only save some uranium when you turn down a nuclear plant, a very minor part of the cost
  - Lot of load following leads to wear and increase usage factor
    - » ➔ conclusion: you do not save with load following
    - » ➔ does not make sense economically with nuclear
- Meanwhile, we have a context of high oil prices, 100 to 120 $/bl, likely to stay on an increasing course

An emerging challenge

- Most countries using nuclear power limit its use to base load
- Several countries put wind or solar energy online. These will (already !) stress the stability of the grid
- Need to set a cap on liquid fuel prices while decreasing net CO2 release
- At times nuclear plant are participating in the grid control ➔ does not make economic sense

  ➔Incentive to convert the total CO2 free energy « in excess » into an easily and cheaply storable system. Liquid fuels meet this requirement. In addition, they will be required for quite some time still, as aviation fuel for instance.

Purpose of nuclear plants

- Plants can have 2 purposes:
  - Core physics goals such as:
    - Fast flux for breeding
    - Fast flux for « burning » actinides and or wastes
    - Optimized flux for conversion
    - Etc…(medical isotope generation….)
  - Heat production
    - Final product is electricity only
    - Heat only
    - Combination of heat and electricity
      - » Of course they can combine both purposes
  - If nuclear is successful, we will need to optimize both core physics purposes and heat production

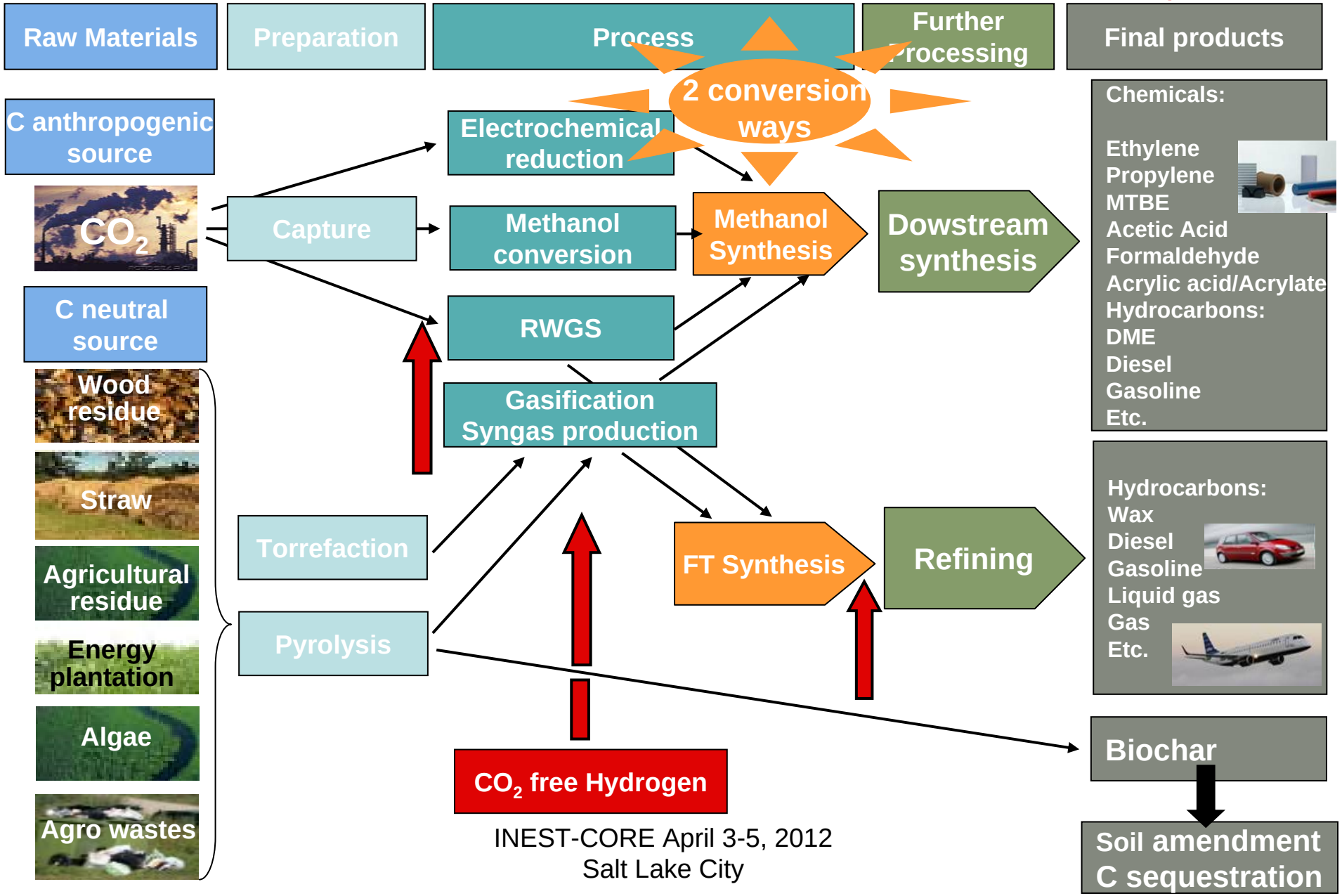
Core and Heat temperature Characteristics of Reactor Types

Plant type	Max temp (for heat use)	conversion	maturity
LWR	< 240°C	poor	Very good
HWR	< 240°C	medium	good
HTGR	< 700 to 850°C	medium	Low
FBR	< 500°C	good	Low
MSR	< 750°C	good	none
HCR High Conversion Water Reactors	< 240°C	medium	None but Based on LWR

Needs of Hybrid processes

- Sometimes heat (but not always)
- Nearly always need for Hydrogen
  - Reforming not a solution because it uses fossil fuel and it is very polluting (gas reforming yields ~ 10 kg CO2/kg H2)
  - Looks like large scale water electrolysis from renewable or nuclear electricity is the only solution for massive production
- Always need for carbon
  - Can be obtained from biomass
  - From CO2 recovery from:
    - Industry (cement, steel, but extensive purification)
    - From atmosphere (clean but very diluted)
    - …..

From carbon carrying materials to chemical products and synfuels



INEST-CORE April 3-5, 2012
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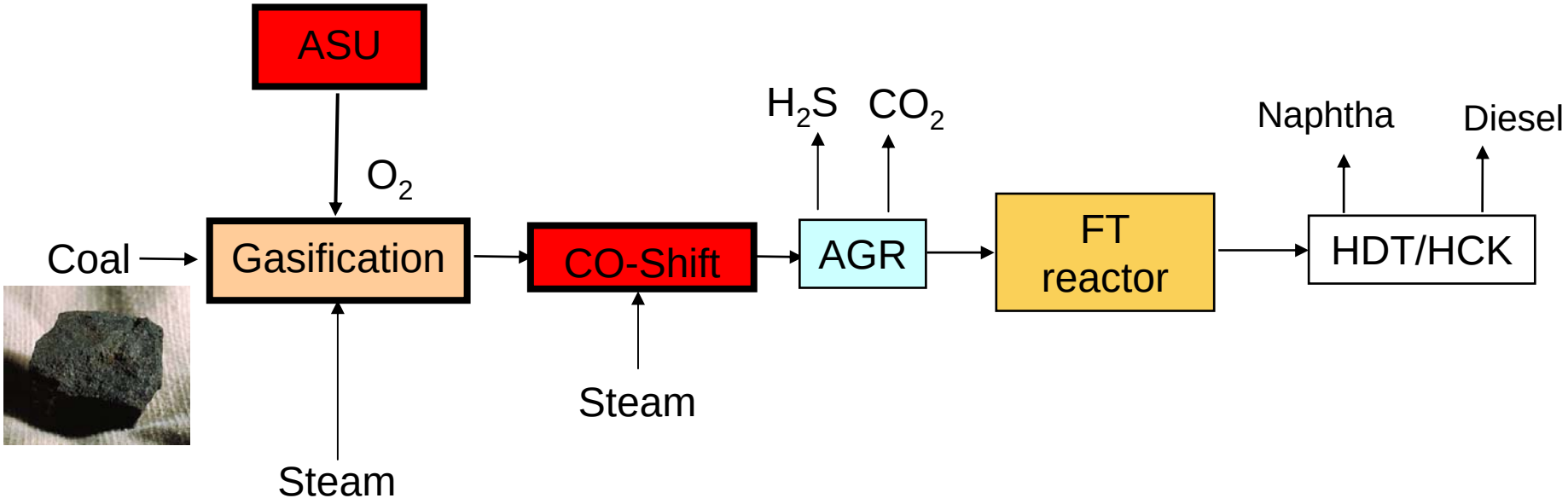
From a classical CtL Plant to a nuclear integrated one



ASU: Air Separation Unit
AGR: Acid Gas Removal
HDT: Hydrotreatment
HCK: Hydrocracking

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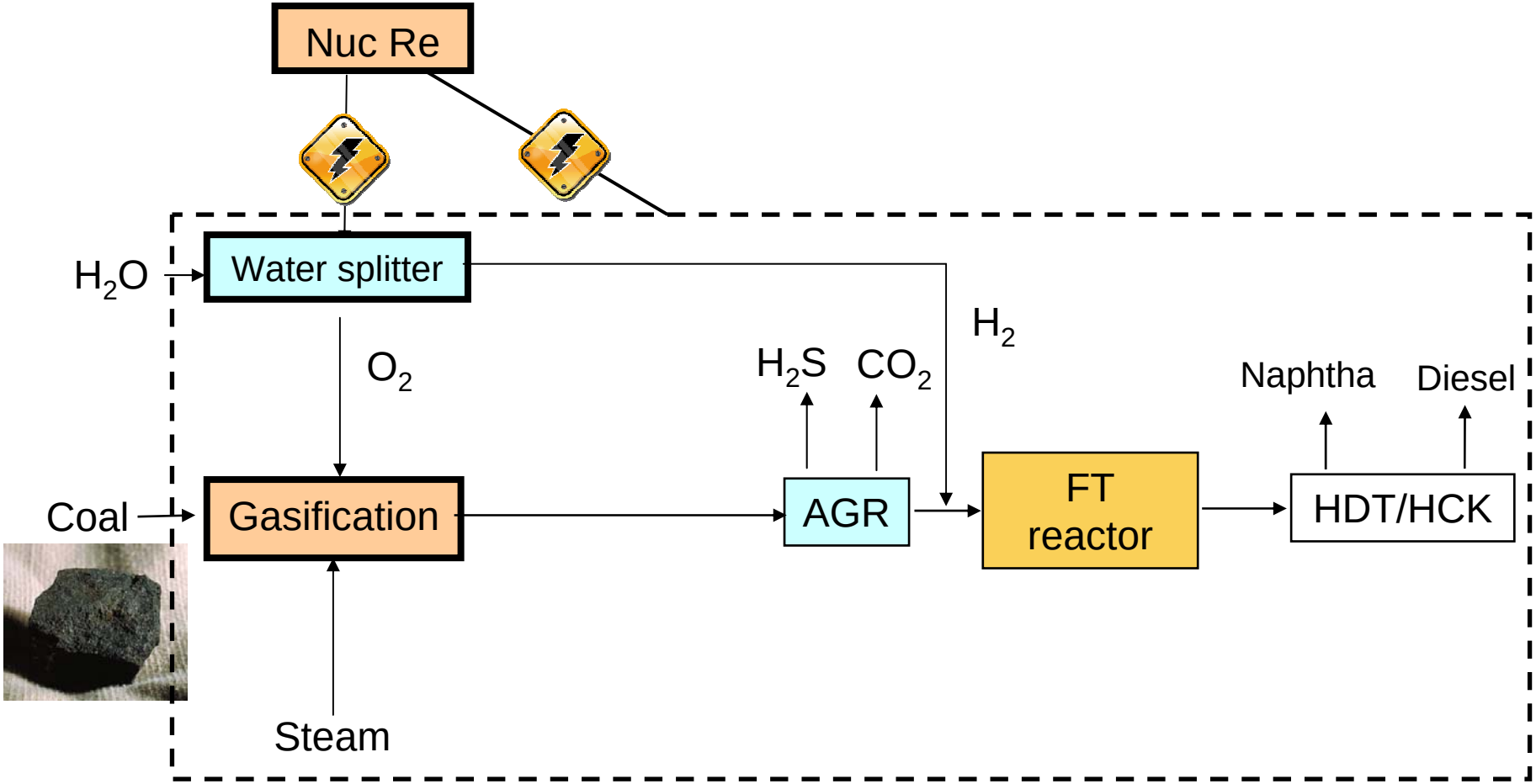

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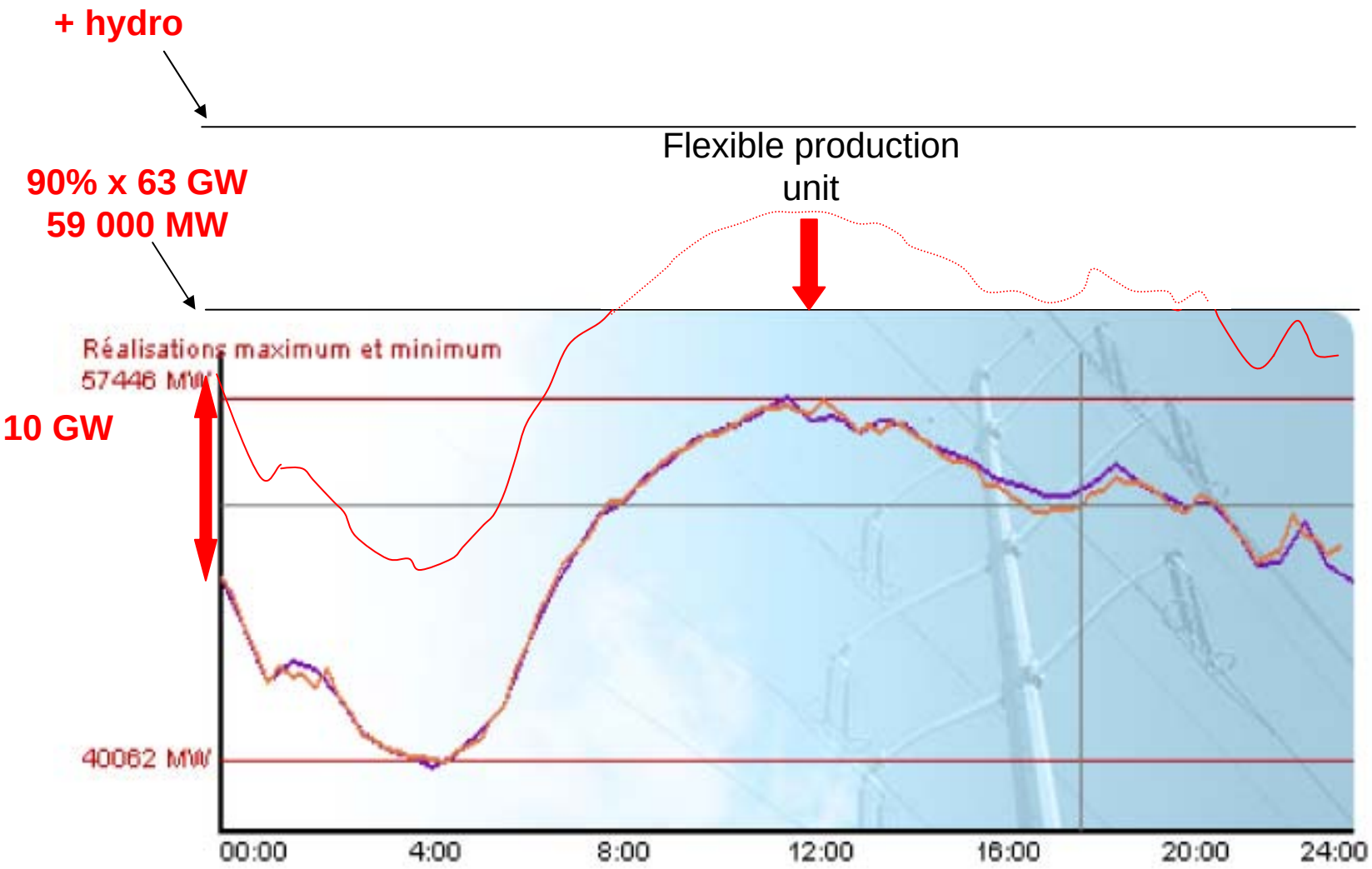
Synfuels for less than 150 $/bl !

Raw material	*H_2 (kg/bbl)*	*Electric consumption to produce H_2*	*Price of an equivalent brend barrel and comments*
Coal	**~ 40**	**1825 kWh/bbl** **1 EPR™ for a 20000 bbl/d CtL unit**	**~ 140 $/bbl** Very close to classical CtL price Drastic reduction of CO_2 emissions and up to 3-fold conversion ratio (bbl/t of coal) ASU removal
Biomass	**~ 22**	**1000 kWh/bbl** **0,6 EPR™ for a 20000 bbl/d BtL unit**	**~ 90 to 140 $/bbl (waste – biomass)** Small capacity Units, no dedicated EPR™ Up to 2-fold conversion ratio (bbl/t of biomass) has a direct impact on agricultural areas **The nuclear integration makes biofuels incorporation European objectives possible**
CO_2	**~ 55**	**2510 kWh/bl** **1,5 EPR™ for a 20000 bbl/d CO_2tL unit**	**200 - 270 $/bbl (off peak hours – baseload)** With energy and H_2, it is possible to convert CO_2 into synfuel This range of prices seems to be the absolute upper price expected for a barrel of oil

A focus…on electricity availability



Hybrids challenges

- Cost competiveness requires low cost electricity for H2 production
- Hybrid plant must be turned down during peak electricity consumption ➔ design flexible chemical processes:
  - Interesting field for innovation
  - New catalyst definition for flexible operation

Conclusions

- Massive clean electricity needed for H2 production ➔ nuclear absolutely required
- Short term : LWR meet the needs
- Medium term :if large scale deployment, fuel savings needed HCR are a good compromise
- Longer term : a mix of HCR and fast spectrum reactors ensure hundreds of years of synfuels