Ammonia, Carbon Capture and Gas Turbine ensure U.S. Energy Independence

Edgar Vercruysse
Luc Vercruysse

The 9th Annual NH_3 Fuel Conference,
San Antonio, TX,
October 01-03, 2012

http://www.probatex.info

Probatex and Ammonia

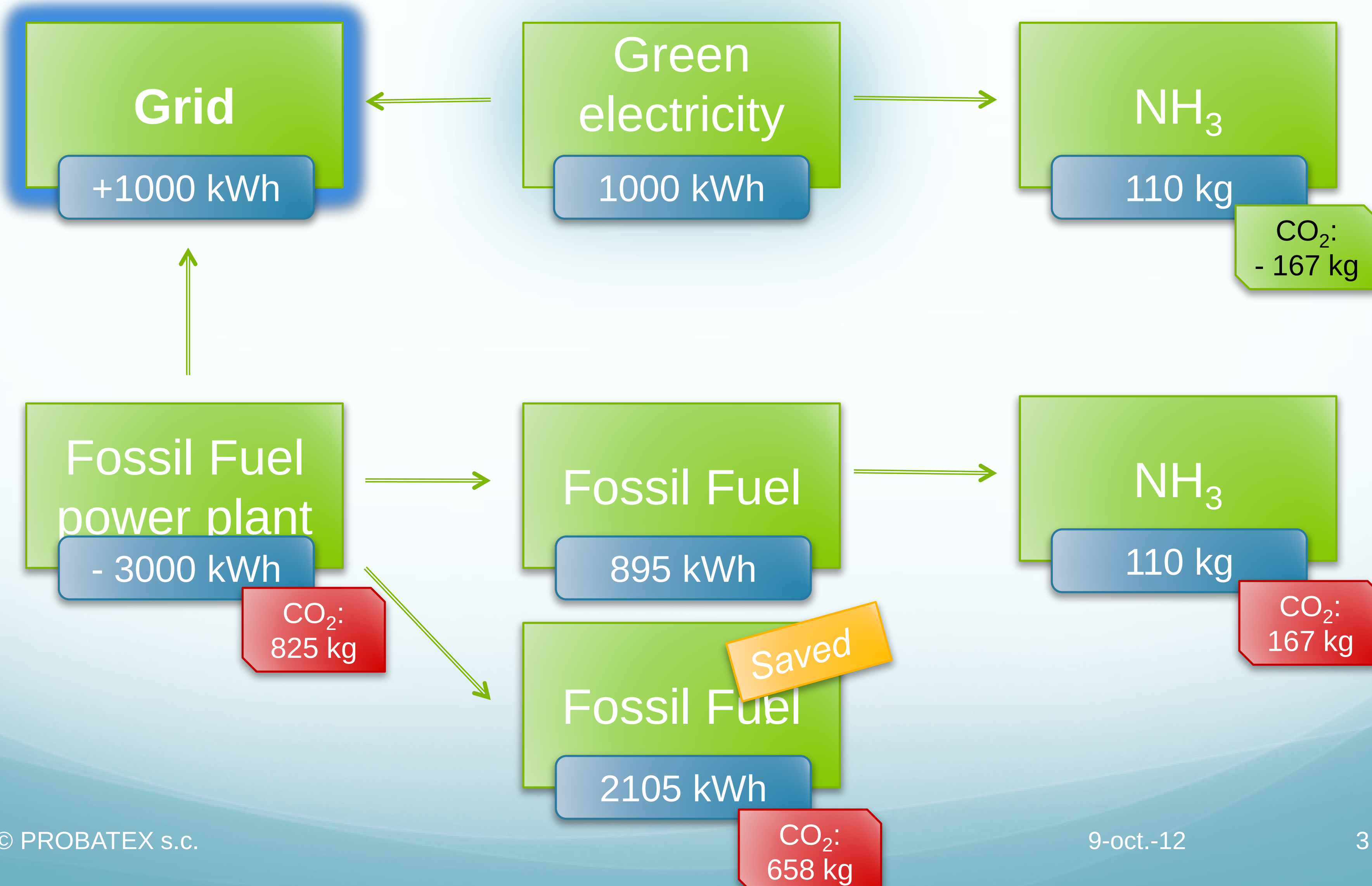
- Because we share the major concern : **climate change**
- Because **renewable energies** must take there part but need to be **complemented** by fast responding stored energies.
- Because we believe that **ammonia** has great **fuel** properties.
- Because ammonia production technology is already well developed.

➔ Probatex is engaged in the ammonia fuel promotion and development.

- ➔ First study (last year) : Where to produce ammonia from renewable sources ?
- ➔ Second study (current): Ammonia from coal and usage in Remote Gas Turbines (CCGT).

Last year summary

1. NH_3 versus the Grid



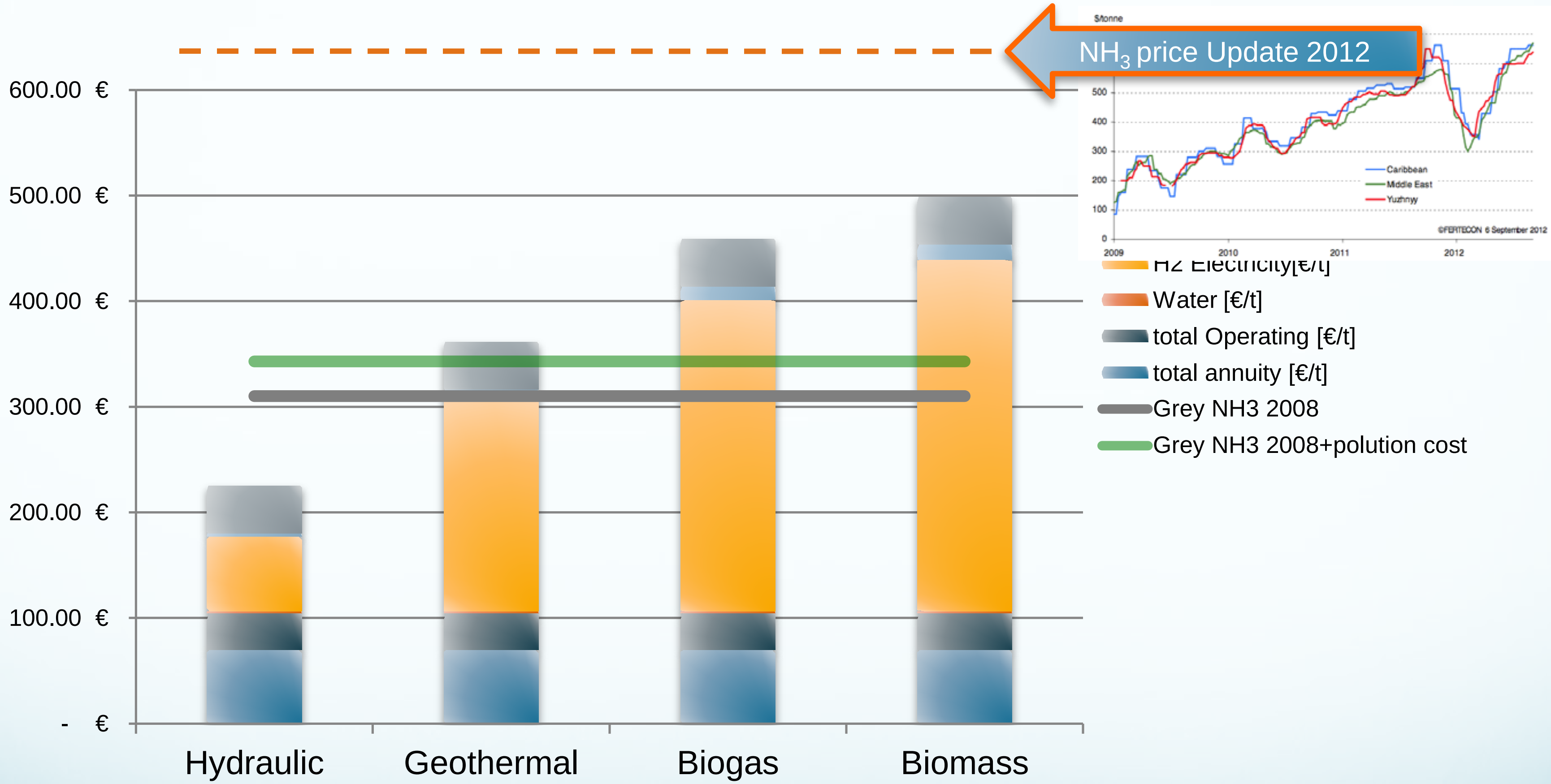
Last year summary

2. Green NH_3 production constraints

- To get competitive NH_3, the source of electricity shall be continuous.
- A large scale production plant is required.

Selection of 4 sources:
- hydropower,
- geothermal power,
- biogas,
- biomass

3. Evaluation of the production cost



-118	19	116	156	Subsidy req. €/t_{NH3}
-172	27	170	228	Subsidy req. $/$t_{NH3}$

8^{th} NH_3 conference: a trigger for new developments

- Mr. R. James Woolsey, Jr. (former CIA chairman) point out major reasons to get rid of Oil economy:
  - Climate change;
  - Ecological disasters
  - Geopolitical reason
  - Commercial balance (money escape)
- It is easy and efficient to power CCGT with NH_3

➔ The question is : How to assemble these requests and statements ?

Global context

<u>The Shale Gas & Natural Gas trend</u>

- Shale Gas boom in US currently puts Natural Gas prices under pressure.

But:

- Japan has decided to quit nuclear power
- In Europe, the global trend is to reduce or eliminate nuclear power plants.
  - Germany will close its last nuclear plant in 2022.
  - Belgium will close its last nuclear plant in 2025.
  - → Nuclear capacities will be replaced by Natural Gas CCGT in order to open the grid to wind and solar energies.
- Russia spend money for pipelines to secure its deliveries

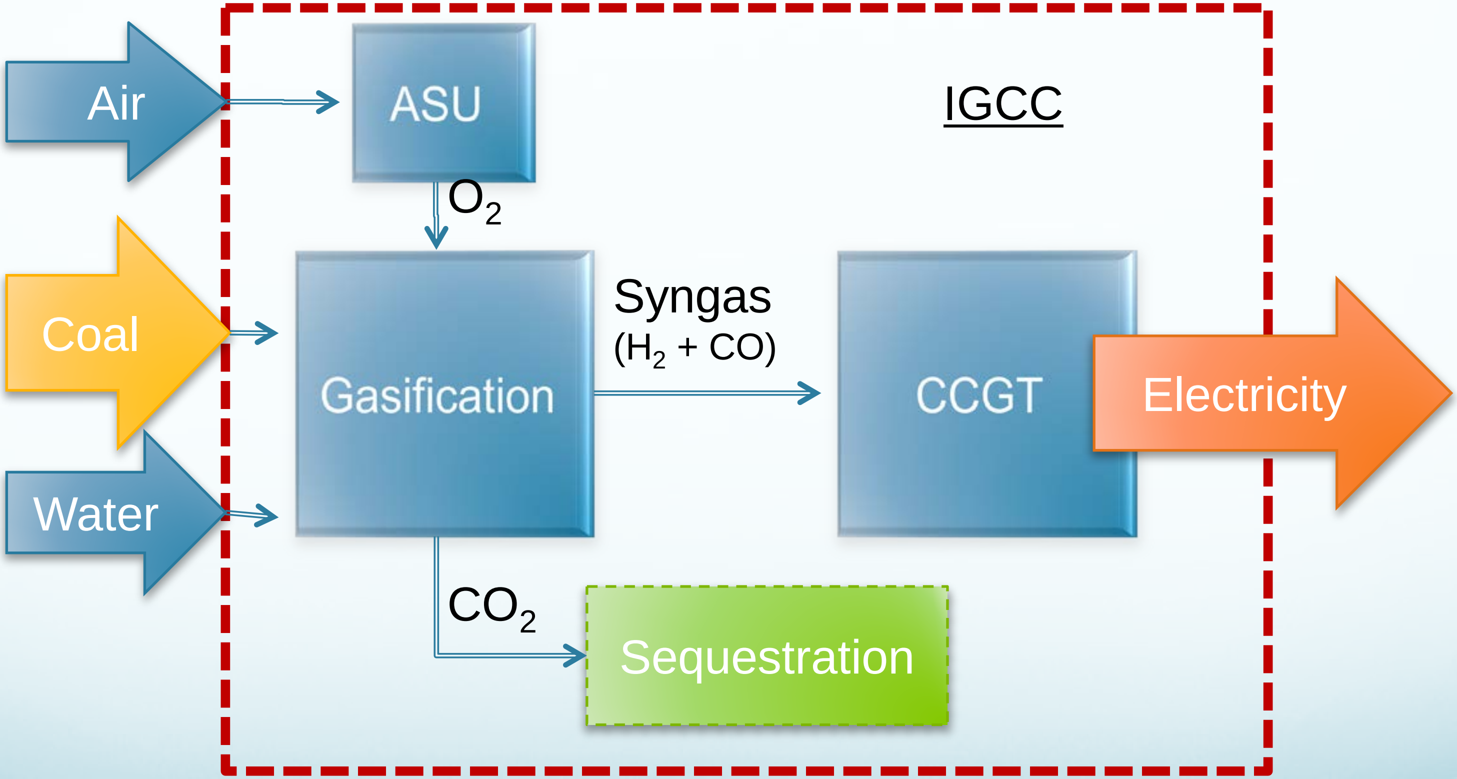
→ Natural gas prices are expected to raise again in a mid term.

<u>Coal trend</u>

- US has the bigest coal reserves in the world.
- Coal is disliked due to its high carbon content
- But CO2 capture and sequestration technology and capacities are available.
- Gasification technologies improve the efficiency of both gas cleaning and CO_2 capture. Refer to IGCC (Integrated Gasification Combined Cycle)

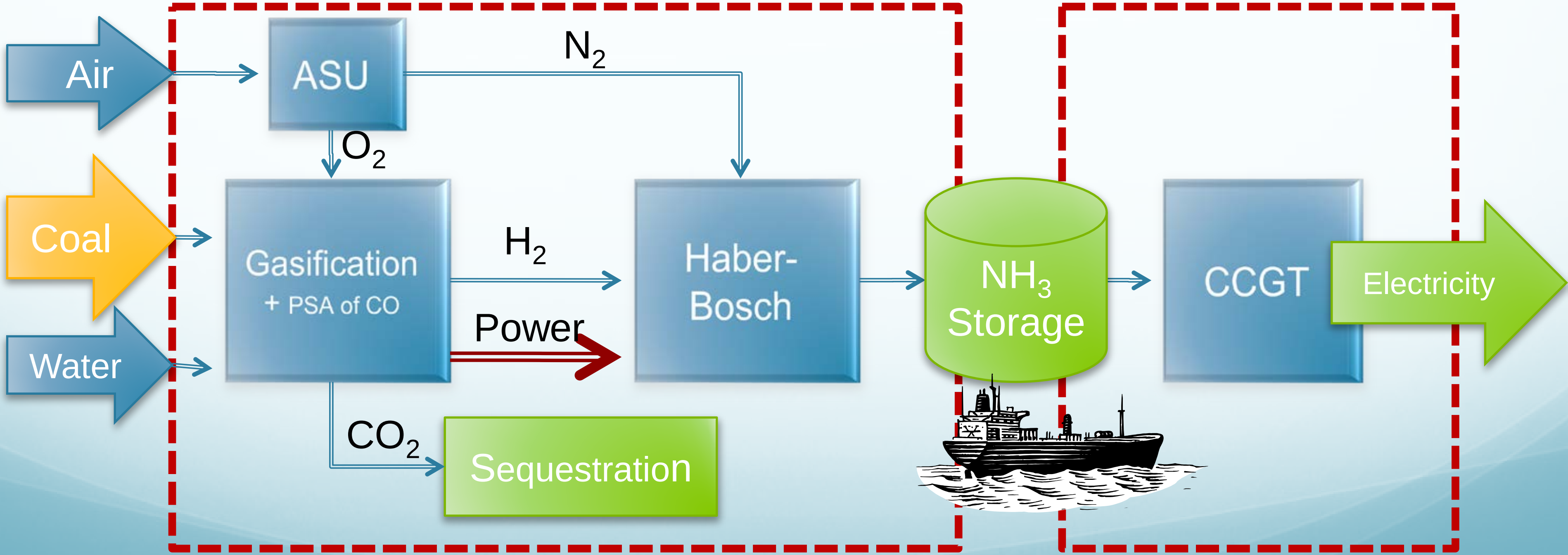
Concept (1/2):IGCC

- The proposed process is inspired by the IGCC technology



Concept (2/2)

- Compared to the IGCC, the syngas from the gasification is used to produce ammonia instead of being burned directly in the Gas Turbine.
- NH_3 can be stored and transported.
- NH_3 can be burned on demand in a CCGT power plant



Process efficiency

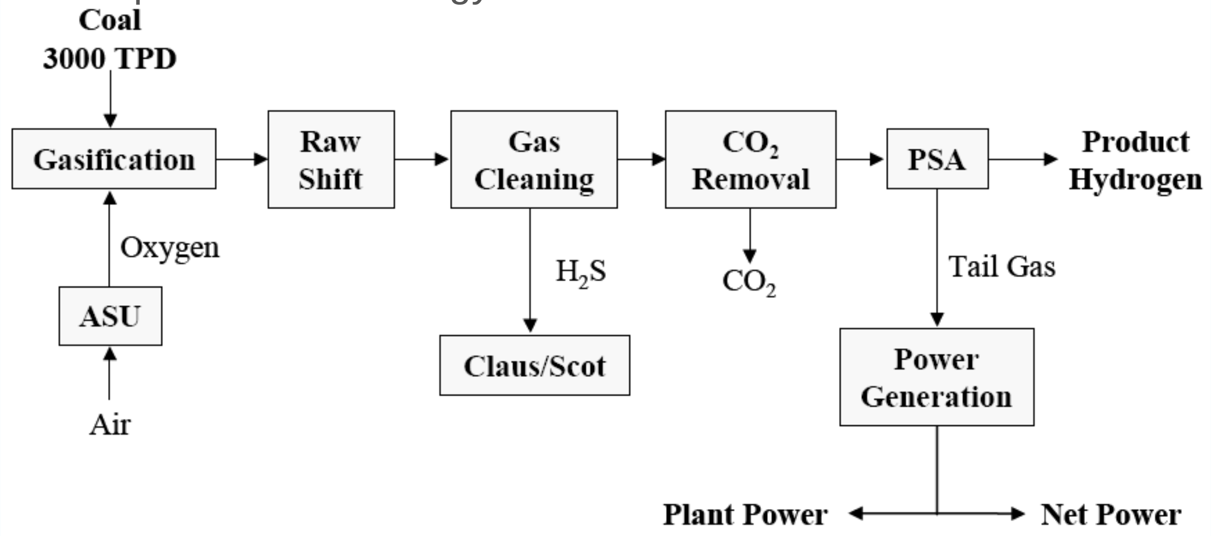
Efficiency: Coal to electricity	
Coal to hydrogen (incl. CCS), % HHV	59
Hydrogen to ammonia, % LHV	81.8
Ammonia to electricity, % LHV	60
Total energy efficiency, %	**28,98**

Coal-fired power plant	Efficiency, % LHV
Pulverised coal PCC without CCS [1, USA]	39
IGCC without CCS	39
IGCC with CCS	32-35

Cost computation

1. Assumptions

- Gasification process: GE Energy



Gray D., Tomlinson G., *Hydrogen from coal*, Mitretek Technical Paper, MTR 2002-31, July 2002

- Computation made for a reference coal and for 5 coal types produced in the US.

Coal origin	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
Year/reference	1998 [36]	2012 [48]	2012 [48]	2012 [48]	2012 [48]	2012 [48]
Price [$/t]	27.30	61.84	70.99	51.26	9.37	39.13
HHV [Btu/lb]	10,665	12,500	13,000	11,800	8,800	11,700

Cost computation

2. Cost of Hydrogen produced from Coal gasification

- Production cost

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
Coal consumption [t/d]	3,000	2,560	2,461	2,711	3,636	2,735
Coal cost [$/d]	81,900.00	158,284.81	174,714.48	138,981.61	34,066.12	107,011.11
Annuity [$/d]	152,355.99	152,355.99	152,355.99	152,355.99	152,355.99	152,355.99
Water cost [$/d]	9,000.00	9,000.00	9,000.00	9,000.00	9,000.00	9,000.00
CO2 Storage [$/d]	47,526.09	47,526.00	47,526.00	47,526.00	47,526.00	47,526.00
Total daily cost [$/d]	290,782.08	367,166.79	383,596.47	347,863.59	242,948.11	315,893.10
H_2 cost [$/t]	**1,034.44**	**1,306.18**	**1,364.63**	**1,237.51**	**864.28**	**1,123.78**

- Taking into account an avoided coast associated to the removal of CO_2
  - Value of a ton of CO_2: **24$**
  - Amount of CO_2 removed = the CO_2 emitted if the H_2 is produced from Natural Gas

→ The avoided cost per ton of H_2 is **75.90$**

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
Adjusted H_2 cost [$/t]	**958.54**	**1,230.28**	**1,288.72**	**1,161.61**	**788.37**	**1,047.87**

Cost computation

3. Cost of Ammonia

- Production cost (based on on 1560 t/d)

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
H2 cost [$/t]	958.54	1,230.28	1,288.72	1,161.61	788.37	1,047.87
H2 cost [$/d]	269,446.08	345,830.89	362,260.56	326,527.69	221,612.20	294,557.19
Annuity cost [$/d]	44,812.86	44,812.86	44,812.86	44,812.86	44,812.86	44,812.86
Operating cost [$/d]	24,799.81	24,799.81	24,799.81	24,799.81	24,799.81	24,799.81
NH3 production cost [$/d]	344,557.65	344,558.65	344,559.65	344,560.65	344,561.65	344,562.65
NH3 production cost [$/t]	217.20	266.13	276.66	253.77	186.56	233.29

- Including transportation over 1000 miles and storage during 45 days for FOB delivery and use in the US.

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
FOB cost of NH3 [$/t]	288.80	337.73	348.26	325.37	258.16	304.89

- Including insurance and freight for CIF delivery in Europe. Estimated according to the freight and insurance coast observed for Ammonia US imports: 70$/$t_{NH3}$

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
FOB cost of NH3 [$/t]	358.80	407.73	418.26	395.37	328.16	374.89

Cost computation

4. Cost of electricity in US

- Production cost from ammonia produced from US coal

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
Electricity cost [$/MWh]	116.67	134.20	137.98	129.77	105.68	122.43

- Comparison with other conventional electricity sources

Electricity production	Cost [$/MWh]
Natural Gas CCGT	79
Natural Gas CCGT with CCS	96
NH3 CCGT	106(+10%) to 138(+43%)

Cost computation

5. Cost of electricity in EU

- Production cost from ammonia produced from US coal

	Reference Coal	US Central Appalachian	US Northern Appalachian	Illinois Basin	Powder River Basin	Uinta Basin
Electricity cost [$/MWh]	132.62	148.40	151.80	144.41	122.73	137.81

- Comparison with other conventional electricity sources

Production way	Production cost $/kWh in 2008	Production cost $/kWh in 2011	Country
Hydroelectric	74	75	Sweden
Solid biomass	129	131	Netherlands
Biogas	79	80	France
On-shore wind	90	91	France
Off-shore wind	138	139	Germany
Photovoltaic	287	≈150	France
Natural Gas CCGT (incl. carbon Cost)	90	91	Belgium

CO_2 market engineering

CO_2 Market

Green certificates

CO_2 Quota

Emmission trading

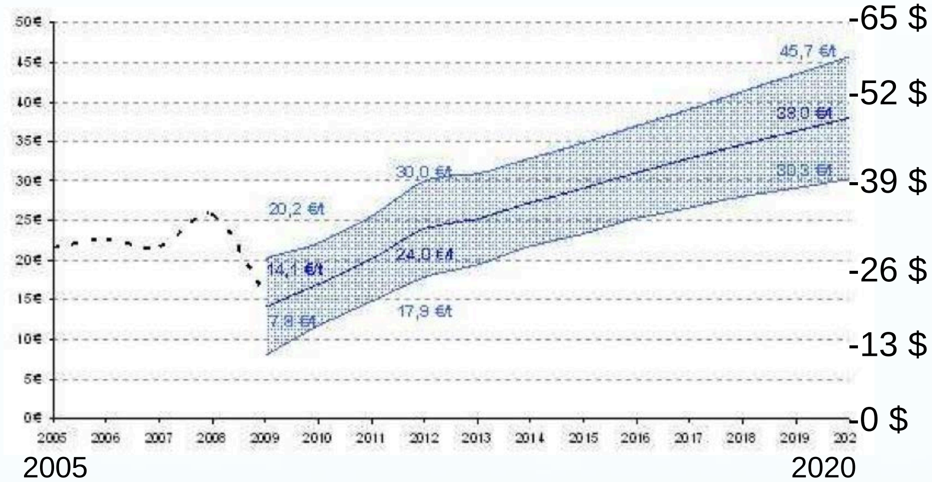
Carbon tax

- Ammonia is a carbon free fuel. This is strong added quality compared to fossil fuels. This quality can be translated into a negative cost associated to the avoided CO_2 emissions. It is estimated at **24 $/t$_{CO2}$**. This is the value of the Carbon tax that applies in Australia.
- But the exact figures differs from one market to another depending whether a carbon tax is due or if the consuming industry is subject to emission quota.
- In all cases this avoided cost is expected to raise and will have a positive impact on the final price of electricity produced from ammonia.

CO_2 Market forecast and expectations

- Current quotation on BlueNext (environmental trading market)
  - EUA (European Union Allowance) (sept 21): 7.40€ = 9.62$
    (1 EUA = 1 t_{CO2})

- Perspective of the price of European CO2 quota (tCO2)



Source: Conseil économique pour le développement durable, n°12, 2012

- Cost of Avoided CO_2 for IGCC with CCS (source DOE.NETL) : 35 to 46 $/t_{CO2}$

→ A mature CO_2 market should tend to align these figures.

- Noticeable market news :

  Australia an EU tend to merge their markets.

EU ETS links to Australia: Lifted up from Down Under

On August 28th 2012, the European Commission and the Australian Department for Climate Change announced that they will link their carbon markets. This link will take place in two stages: Australia will retain a fixed emission price of AU$23/tCO2 (~€17.00) until 2015. Then, from July 1st 2015 onwards, when the Australian Emission Trading Scheme (AETS) is introduced, EUAs will be eligible for Australian firms' domestic compliance, up to a usage limit of 50%. From 2018, the EU ETS facilities will become able to surrender Australian emissions allowances (AEUs) for their compliance purposes.

Source:
Tendances Carbon n°72, sept 2012

Conclusion

Going green deserves a serious debate. We have to pave the way for adequate solutions for the CO_2 emissions problem.

The first positive answer is given by the renewable and CO_2-free energies: hydraulic, geothermal, biomass, wind and solar.

They are commonly accepted around the world.

Their *intermittent* action is so far complemented by the *continuous* action of *storable* fossil energies which, unfortunately, are also responsible for CO_2 emissions.

The CO_2 emissions problem is consequently not completely solved.

This study proposes *green ammonia from coal* as a substitute fuel for the fossil energies.

The CO_2-free emissions, storability and competiveness represent its main *worldwide* benefits.

Green ammonia production *costs* ranging from 258 to 349 $/t FOB US port must be compared with the non-green ammonia market *price* assessed at 560 $/t FOB US port.

Biogas, off-shore wind and solar energy costs in Europe, respectively 80, 139, 289 $/MWh, have to be compared with green ammonia energy costs ranging from 123 $/MWh for coal from the Powder River Basin to 152 $/MWH for coal from US Northern Appalachian.

The United States, China and Russia are all potential *producers* of green ammonia from coal. All these countries would find additional benefits in green ammonia since it replaces imported fossil fuels, ensures national energy independence, extends the energy-mix target, presents competitive green ammonia versus non-green ammonia on the international market and promotes the coal economy. Huge coal reserves, geographical situation, technology, economy and ecological concerns place the United States in a leading position in this respect.

On the other hand potential *consumer-countries* will find additional benefit in the extension of the green-energy-mix target.

Last but not least, the 'CO_2 quota regulations' of some countries might be extended to other countries in order to reach an *international agreement* beneficial to all. Widely accepted in the European Community, the CO_2 quota regulations represent a serious asset for a green ammonia trade kick-off between the United States and the European Union

Conclusion

- on the ammonia market
  - production cost ranging from 258 to 349 $/t
  - Market price 600 to 700 $/t
- on the electricity market, competiveness will depend on
  - the price of coal vs the price of natural gas
  - technology
  - carbon policy (taxes, incentives, quota)
- benefits for States:
  - with coal reserves (e.g. US): valorization
  - without coal reserves (e.g. EU): extension of the green energy mix, energy security.
- benefits for industry
  - for coal mining industry
  - for electricity producers in countries with a lack of energy resources.
- **Benefits for the environment and all of us, thanks to CO_2 removal !**

Thank you for your attention!

The full report is available on http://www.probatex.info/nh3

Contact: nh3@probatex.info