Overview of the Energy Challenge, *and the* ***WindFuels*** *Solution*

Economically Producing Fuels and Chemicals from Point-source CO_2 and Off-peak Wind

A scalable, competitive energy and climate solution.

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The need for truly viable 'green' energy

"***Climate Change***"
is an
understatement.

"***Dust Bowlification***"

is upon us.

The Planet Is Heating Up — and Coral Reefs are Dying

Late-summer Arctic sea ice will be mostly gone in 15 years !

Coral reefs are dying from CO_2–induced acidification, glaciers are melting, fisheries are collapsing, wildfires are increasing, sea levels are rising, and wildlife is scrambling to keep pace.

Atmospheric carbon dioxide, the primary greenhouse gas, is now higher than at any point in the past 12,000,000 years !

Doty Energy: Beyond Biofuels – Carbon-neutral WindFuels.

Biofuels – not scalable

- Their *net* contribution in 2012 – about 0.6% of oil.
- Corn & grain prices increased by 50% in 2012.
- Newly tilled soil creates a "carbon debt" for 30 to 250 years.
- LAND USE – needed for food – for a starving billion.
- Ocean Dead Zones are expanding due to fertilizer run-off.

Under 29% of the carbon in the feedstocks going into cellulosic ethanol refineries ends up in the ethanol. Most of the rest is emitted as CO_2.

Cellulosic ethanol will not compete

- Cellulosic feedstocks (dry, delivered) were **$25/ton** in 2001.
- Wood pellets
  Now $260/ton in the U.S.
  Have sold for over
  $400/ton in Europe

Wood Pellet Heaters

- 16 million acres of wildfires in the U.S. in the last two years – "The new normal."
- Expect pellets to be $400/ton in the US by 2016
- Cellulosic ethanol from feedstocks at $400/ton costs over **$5.50/gal**, or $8.20/gge.

The Micro-algae Mirage

The cheapest, commercially available algae today (food industry) costs $5000/ton.

Several methods proposed for high-oil micro-algae:

(1) large plastic tanks, (2) racetrack ponds…

- Solazyme is selling non-photosynthetic algal oil to the Navy for $25-60/gal.
  - They abandoned photosynthetic algae.
  - Their CEO says it is 1000 times more expensive.
- Fuels from green algae won't be under $70/gal by 2020.

Thermonuclear-Fusion, an Impractical Dream

The latest official projections are like those of 40 years ago: "We'll see commercial, profitable, limitless electricity from fusion in about 40 years."

The *cost of the potential ITER electrical energy output would be over 10,000 times that of wind energy*.

- **The first fusion power plant, DEMO**, is projected to begin producing 500 MW net electrical output in 2035 at 50% duty cycle. (Lifetime unknown – maybe a few years.)

- **Probable initial cost (in 2012 $) of over $70/$W_{PE}$.**

- ***If DEMO works*** as expected, its ***energy cost would be over 200 times that of wind energy***.

The Hydrogen Economy…

- **Storage and distribution** costs are 30 times greater than for liquid fuels.
- Automotive fuel cells **20 years from now** will still be **10 times more expensive** than advanced internal-combustion engines.
- **Market Verdict:** Stocks of most hydrogen fuel-cell companies are trading at under 1% of their previous highs.

Hydrogen has a place –
but not for cars or home heating.

Renewable Energy Costs

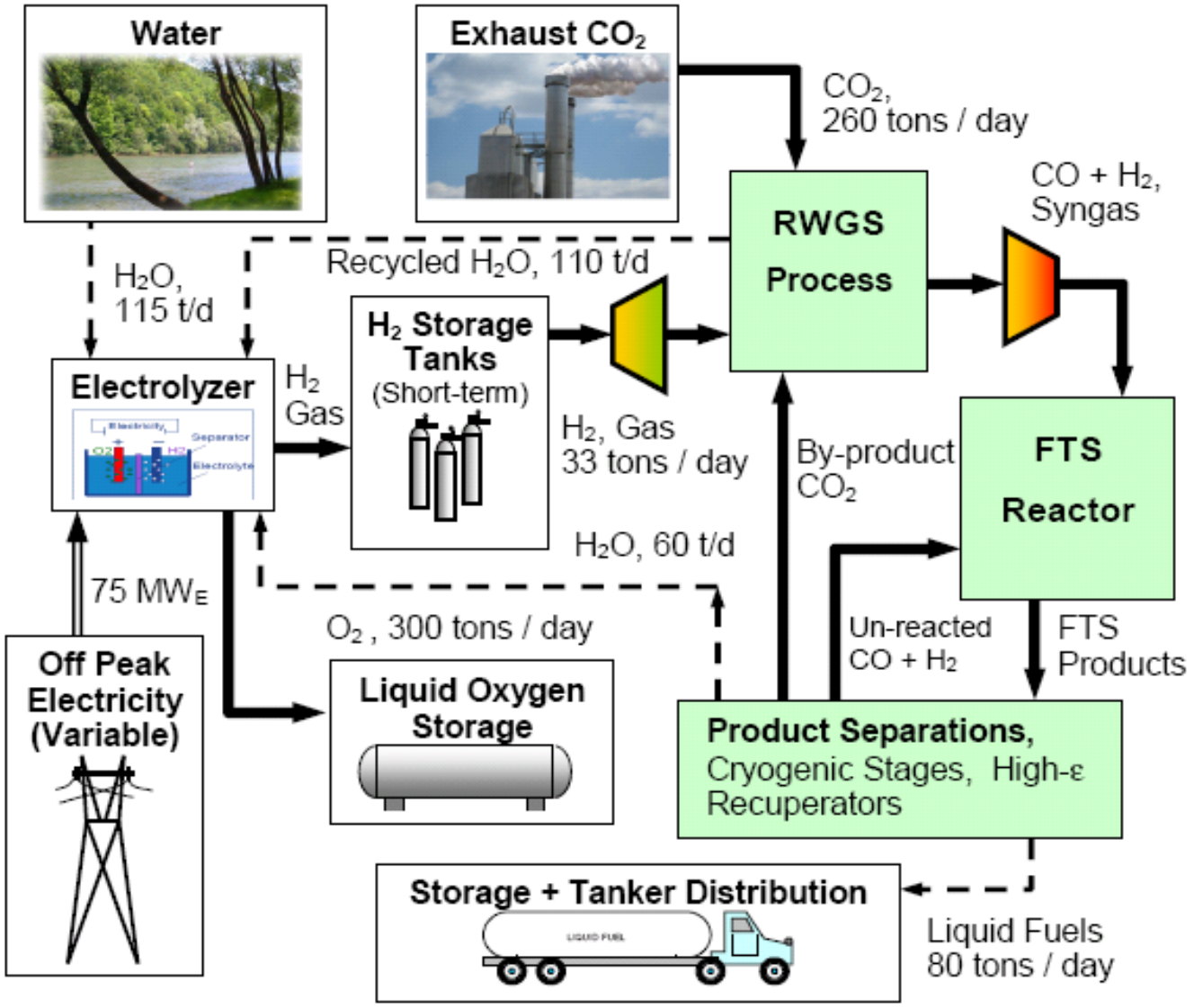
The Levelized Costs of Energy (LCOE) depend as much on discount rate and lifetimes as they do on initial *total system cost per peak watt* (C_{PE}), capacity factor (F, ratio of mean to peak power), and Operating & Maintenance (O&M) costs.

Renewable energy costs, 5/2010						
Resource	C_{PE} ($/W$_{PE}$)	Capacity Factor F	Fuel+ O&M $/MWhr	Lifetime years	LCOE 5% $/MWhr	LCOE 10% $/MWhr
Wind (prime)	1.5	0.35	1	40	29	51
Hydro (prime)	5.5	0.5	1	50	69	127
New Nuclear	8.3	0.85	26	40	90	139
Clean Coal +CCS	5	0.8	45	35	92	123
CSP, 80 MW	3.9	0.23	45	30	170	250
large PV, AZ	6.7	0.19	10	30	309	500
EGS	35	0.85	60	30	409	630
Fusion	70	0.5	50	2	8600	9300

A Better Idea

Synthesizing **standard liquid fuels**
(diesel, gasoline, jet fuel…)
from CO_2 and water
using off-peak wind energy

WindFuels – Concept Overview



Build on Proven Chemistry

and improve the processes.

Start with renewable H_2 and CO from CO_2 instead of from coal.

A truly sustainable solution to the energy storage, transportation fuels, and climate challenges.

- ***There is sufficient potential excess wind energy and point-source CO_2 just in the U.S. wind corridor to make twice as much gasoline, diesel, and jet fuel as the U.S. consumes.***

Fossil-based Fischer Tropsch Synthesis

Fischer-Tropsch Synthesis (FTS), like methanol synthesis,

converts a syngas ($CO+H_2$ + some CO_2) into synfuels (diesel or gasoline) and waste heat in a catalytic reactor.

FTS reactions are not narrowly selected – i.e., they produce a wide range of products and thus require fairly complex separations.

Coal-Based Synfuels are Not Acceptable

FTS of diesel from 1 kg coal yields 2 kg of CO_2 and 0.3 kg of fuel.

The Major Technical Advances

- Nearly a **factor of two increase in the efficiency of production of syngas** from water and CO_2.
- An **order of magnitude reduction in the losses seen in recycling** of the unreacted Fischer-Tropsch (**FT**) reactants (H_2, CO_2, CO).
- Enormous **advances in cost-effectiveness of gas-to-gas recuperators** with high thermal effectiveness (up to 97%).
- Advances **in the catalysts**.
- **Optimized plant integration.**
- A **50% improvement in efficiency of conversion of waste heat** from the FT reactor and electrolyzer to electricity.

WindFuels Economics – The Basics

WindFuels can compete when oil is as low as $60/bbl.

- At $15/MWhr, the wind energy cost in jet fuel or gasoline will be $1.00/gal – and for ethanol, about $0.68/gal.
- The CO_2 ($40/ton) might initially cost ~$0.40 per gallon of product, but eventually it will be nearly free.
- The co-produced (nearly free) liquid oxygen (LOX) may be worth up to $1 per gallon of liquid fuels produced.
- Pay-back on the RFTS plants will usually be under 3 years.
- Mid-term assumptions: mean wind energy cost of $4.2/GJ ($15/MWhr); electrolysis HHV efficiency of 75%; RFTS plant efficiency of 75% HHV; 55% net system HHV efficiency.

Fischer-Tropsch Chemistry

In most GTL plants, the syngas comes from natural gas, mostly via the following endothermic steam reforming reaction:

$$CH_4 + H_2O \rightleftarrows CO + 3H_2 \quad , \quad \Delta H = 218 \text{ kJ/mol} \qquad [1]$$

and the so-called water gas shift (WGS),

$$CO + H_2O \rightleftarrows CO_2 + H_2 \quad , \quad \Delta H = -38.9 \text{ kJ/mol.} \qquad [2]$$

The CO and H_2 are converted to fuels and water, such as octane, on the surface of catalysts at suitable conditions,

$$8CO + 17H_2 \rightarrow C_8H_{18} + 8H_2O \quad , \quad \Delta H = -1282 \text{ kJ/mol.} \qquad [3]$$

The yield for mid-alcohols in most FTS has been extremely low, but ethanol selectivity above 25% has been achieved with several recent catalysts, including K_2CO_3-promoted β-Mo_2C and K/Zr/Zn/Mn. For ethanol, the net reaction is

$$2CO + 4H_2 \rightarrow C_2H_5OH + H_2O \quad , \quad \Delta H = -272 \text{ kJ/mol} \qquad [4]$$

The theoretical efficiency limit for ethanol production from H_2 and CO_2 can be shown to be ~90%. 58% is a reasonable goal.

Practical, Renewable CO Required

The Reverse Water Gas Shift (RWGS)

The water-gas-shift (**WGS**) reaction is widely used in commercial processes for production of H_2.

However, the **RWGS** reaction, shown below, has not yet been practical for reduction of CO_2 to CO.

$CO_2 + H_2 \rightleftarrows CO + H_2O$, $\Delta H = 38.9$ kJ/mol

The equilibrium constant K_P is defined by

$$K_P = \frac{p_{H2O}\ p_{CO}}{p_{CO2}\ p_{H2}}$$

where the *p*'s are the partial pressures.

More on Scale-up – the Big Picture

1st : Wind-Turbine Manufacturing

• At least ten multi-billion-dollar companies around the world build and install multi-megawatt wind turbines.

2nd : The Water Electrolyzer

• This may represent up to 35% of the capital for expected near-term electrolyzer prices.

3rd : The RFTS Plant

• Much of the equipment is produced for GTL plants.

4th : CO_2 separation processes at existing plants

The high cost of electrolyzers for the next 5-8 years represents the only real challenge for Windfuels.

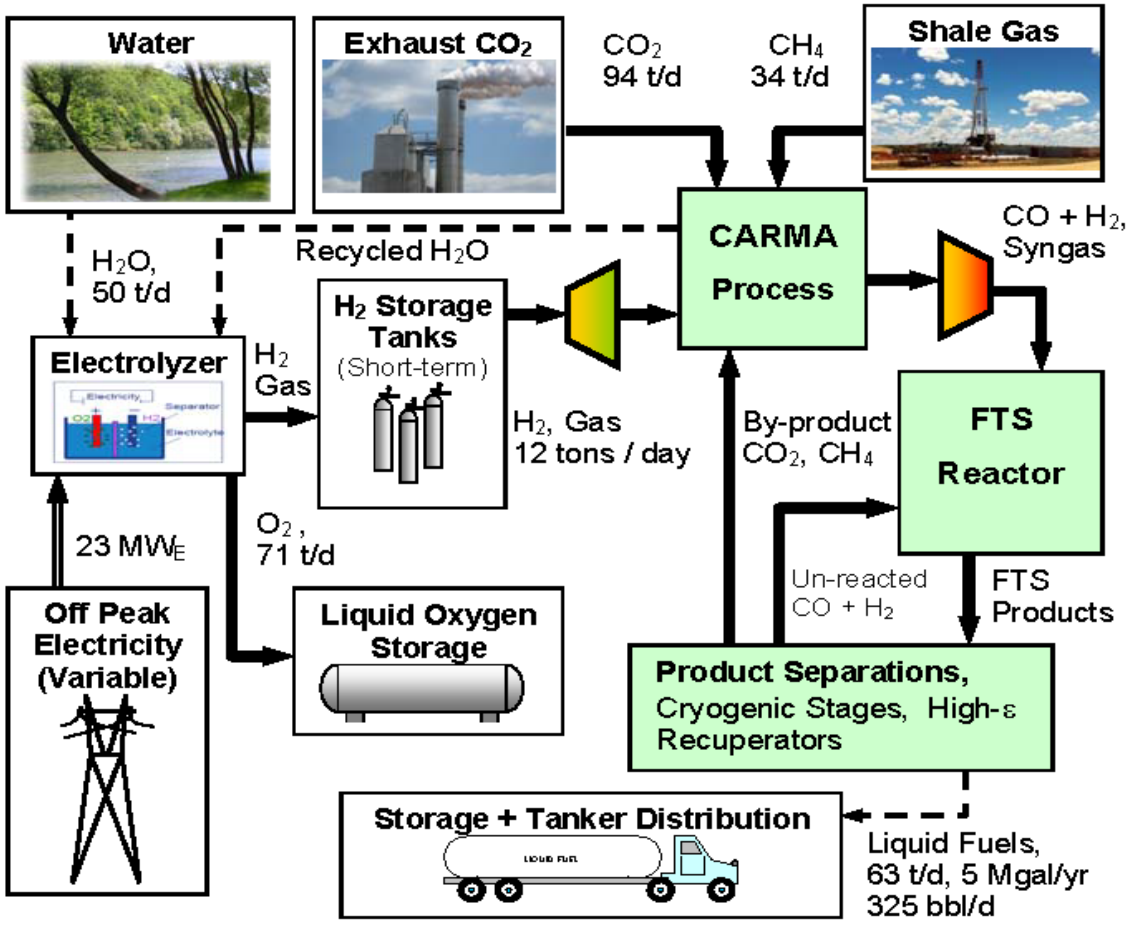
CARMA – A Lower-Cost Bridging Solution

(**C**O_2 **A**dvanced **R**eforming of **M**ethane **A**diabatically)

Synergistically combine biogas or shale gas with off-peak wind.

Reduce electrolyzer and wind-energy needs by a factor of 3 to 10.

Begin driving the electrolyzer industry to the scale needed for Windfuels.



Fuel costs from $0.85/gal to $2.50/gal.

Stabilizing the Grid to 50% Wind

- The electrolyzer can respond in milliseconds – so the WindFuels plant will draw electrical power to produce (and store) hydrogen only during off-peak hours.
- The chemical processes will run more steadily, but they can be ramped up and down in a few hours.
- WindFuels solves both short-term energy storage (in hydrogen) and long-term energy storage (in liquid fuels.)
- WindFuels will allow wind energy to grow from the current 2.5% to over 50% of the grid.

There is enough potential, recoverable wind energy to make more than twice as much fuel as we currently use in transportation.

Efficiency is actually not the biggest issue…

It's the price of off-peak grid energy and the price of oil that matter the most.

- **The price of off-peak grid energy today is *half* what it was four years ago in many areas of high wind penetration.**
- **We're still only at ~10% wind energy in the best states.**
- ***Will we see 5 hours of free, clean, grid power most nights in the wind corridor 8 years from now?***
- **Probably – unless we begin investing heavily (and soon) in CARMA and WindFuels.**

A Realistic Energy/Climate Plan

The Sustainable-Grid Energy Mix in the U.S. in 2040

- Natural Gas (currently 22%), increases to 23%, mostly peaking.
- Nuclear (currently 20%), drops to 18%, mostly base-load.
- Coal (currently 45%), drops to 14%, mostly for peaking.
- Hydro (currently 6%), grows to 8%, used mostly for peak.
- Biomass (currently 1.4%), grows to 2%, mostly for peak.
- Diesel (currently 2%), grows to 3%, all for peaking.
- Geothermal (currently 0.4%), grows to 1%, mostly peaking.
- Solar (currently 0.1%), grows to 1%, all for peaking.
- Wind (currently 2.5%), grows to 30% of the grid (mostly off-peak) and 40% of our transportation fuels.

The market generated by WindFuels for off-peak grid power allows wind to maintain its rapid growth and reduce our dependence on foreign oil.

The Primary Challenges

- The Agrofuels industry and lobby
- Disinformation on promises of current “alternatives”
- Turf protection by established researchers
- Closed-mindedness amongst many energy experts
- Very little process design is currently supported
- The needed developments are not “sexy” sounding
- Short-term focus by investors and DOE
- Lack of appreciation for the looming oil crisis
- NIH (Not Invented Here) attitude

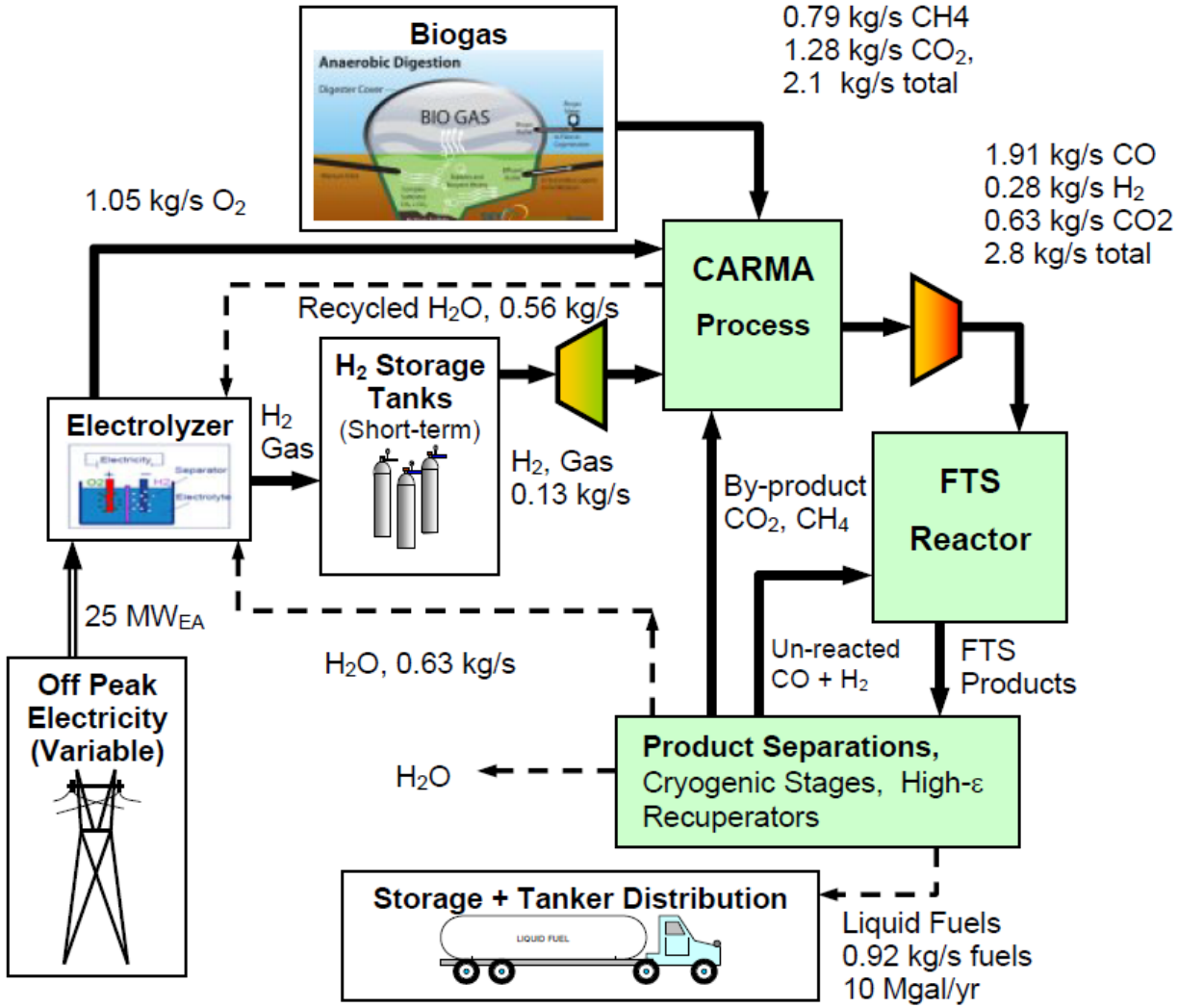
*None of the **technical** challenges compares to the above non-technical challenges.*

Down to Basics

- Wind power output is usually greater at night when grid demand is minimum, so off-peak power costs in windy regions will drop further as wind energy expands.
- *WindFuels* will only use off-peak, cheap, low-carbon power.
- *W*ith reasonable subsidies for climate benefit, *WindFuels* will initially compete when oil is as low as **$60/bbl**.
- We are predicting oil will average over $130/bbl in 2016.

- *WindFuels* can realistically ***eliminate our imports of oil and gas*** within 35 years while reducing our CO_2 emissions by 40%.
- *WindFuels* will enhance our energy security, economic growth, international trade balance, and national security far more than any other alternative.

WindFuels / CARMA Recap



Driving the wind market – to 20% well before 2024

Doty Energy WindFuels

- The RWGS and CARMA reactions can be utilized to produce the needed syngas (CO and H_2) at efficiencies approaching theoretical limits.

- With well optimized processes, we can sustainably synthesize everything we currently get from petroleum at prices that compete with oil.

- We'll be able to do this soon enough to avoid an oil price surge that would have dire global consequences.

Thank you for your attention !