Pulsed Plasma for Chemical Processing

Bert van Heesch, Frank Beckers, Wilfred Hoeben,
Tom Huiskamp, Guus Pemen,

Technische Universiteit Eindhoven University of Technology
Where innovation starts

e.j.m.v.heesch@tue.nl
+31 (0)6 21268881

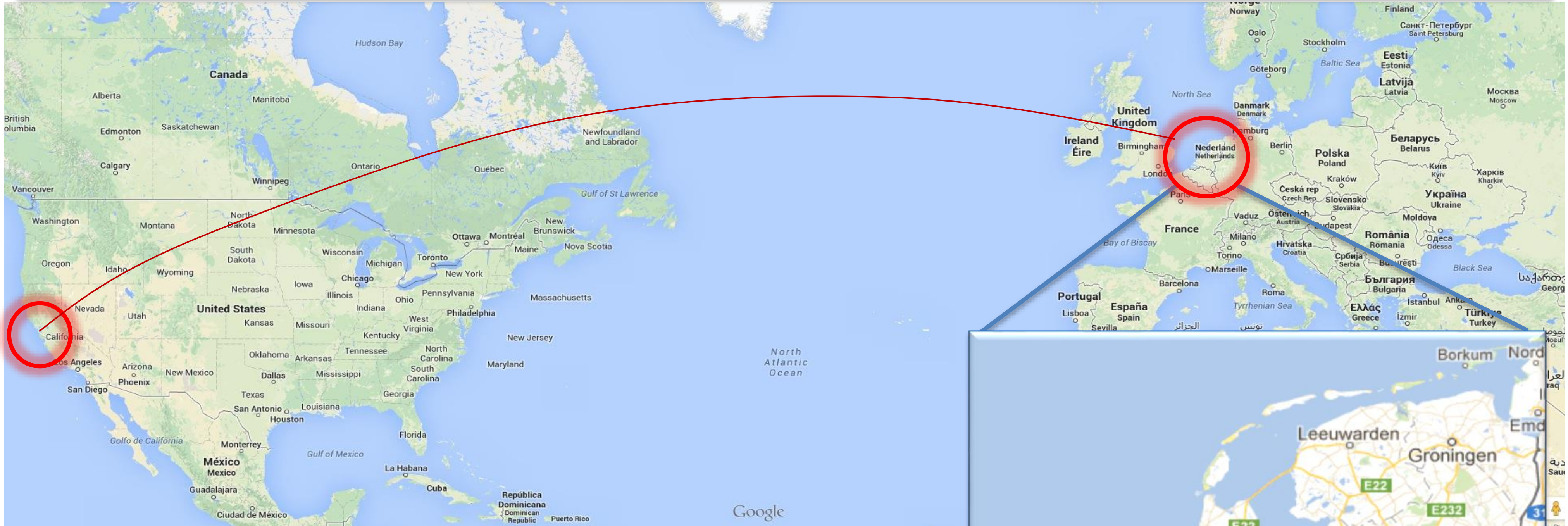
Gezinus Bonkestoter

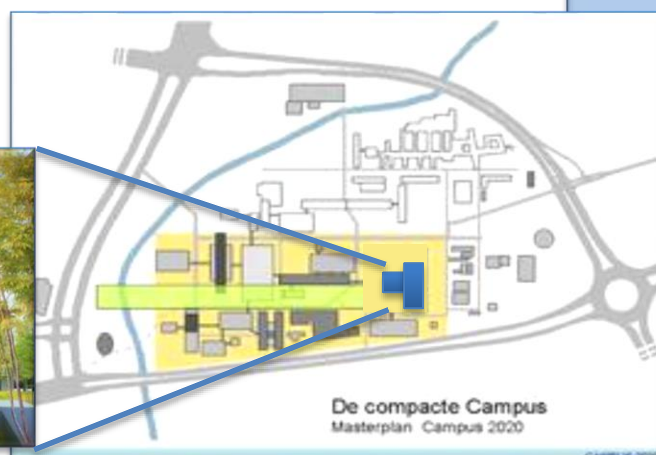
solybright
BRIGHT SOLUTIONS SMART ENGINEERING

Electrical Engineering Dept.

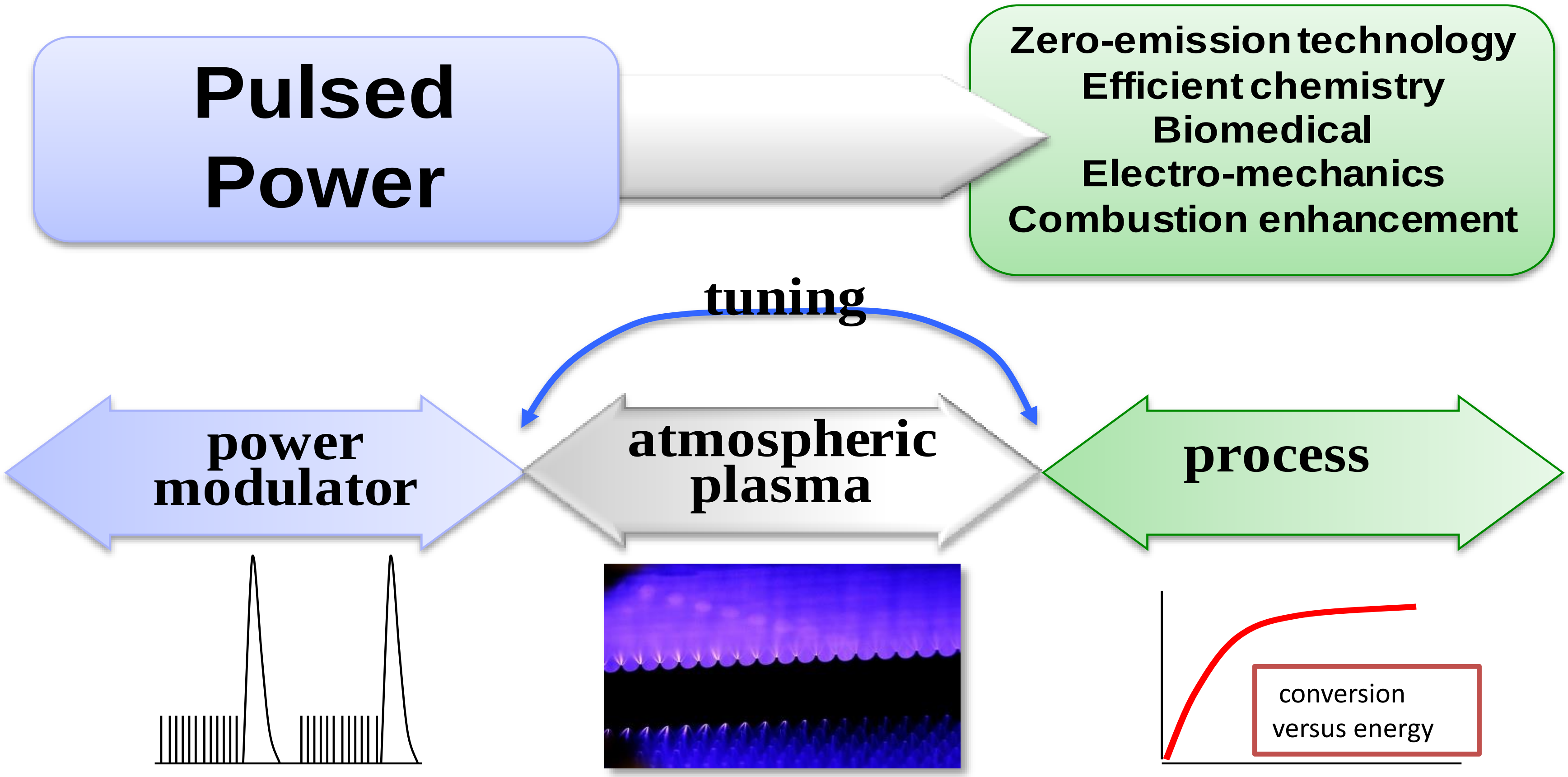
Pulsed Power Lab

My Location: Eindhoven University of Technology, Netherlands



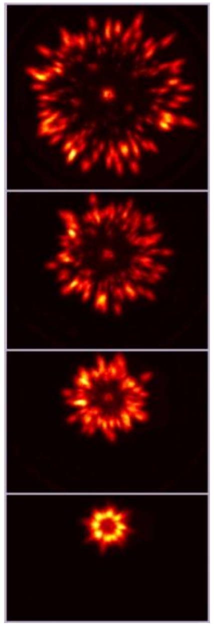


Pulsed Power for Chemical Processing



Pulsed Plasma for Chemical Processing

Pulsed Streamer Plasma

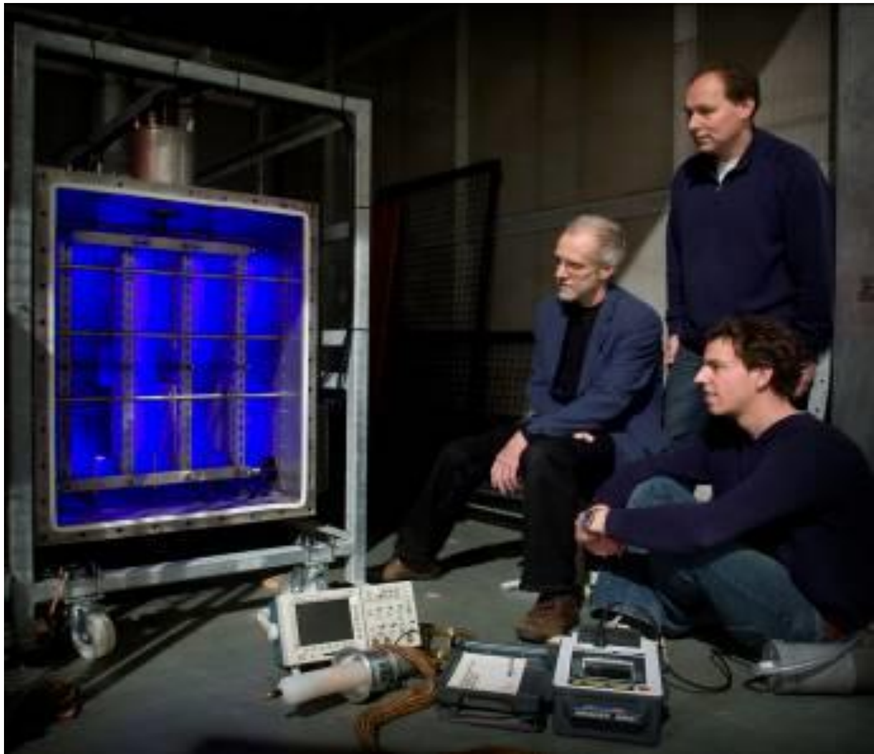


Electrical sparks in air
driven by high overvoltage,
without a complete discharge path

known as 'streamer plasma'

It is a shower of thousands of little sparks

Electric Shower

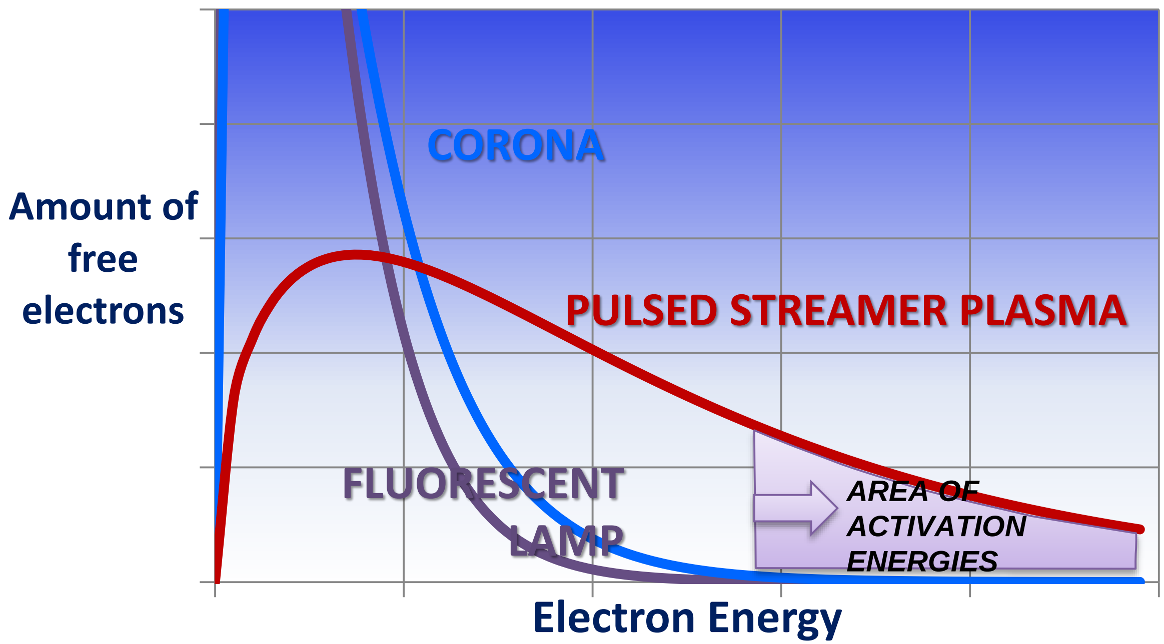


The Advantages

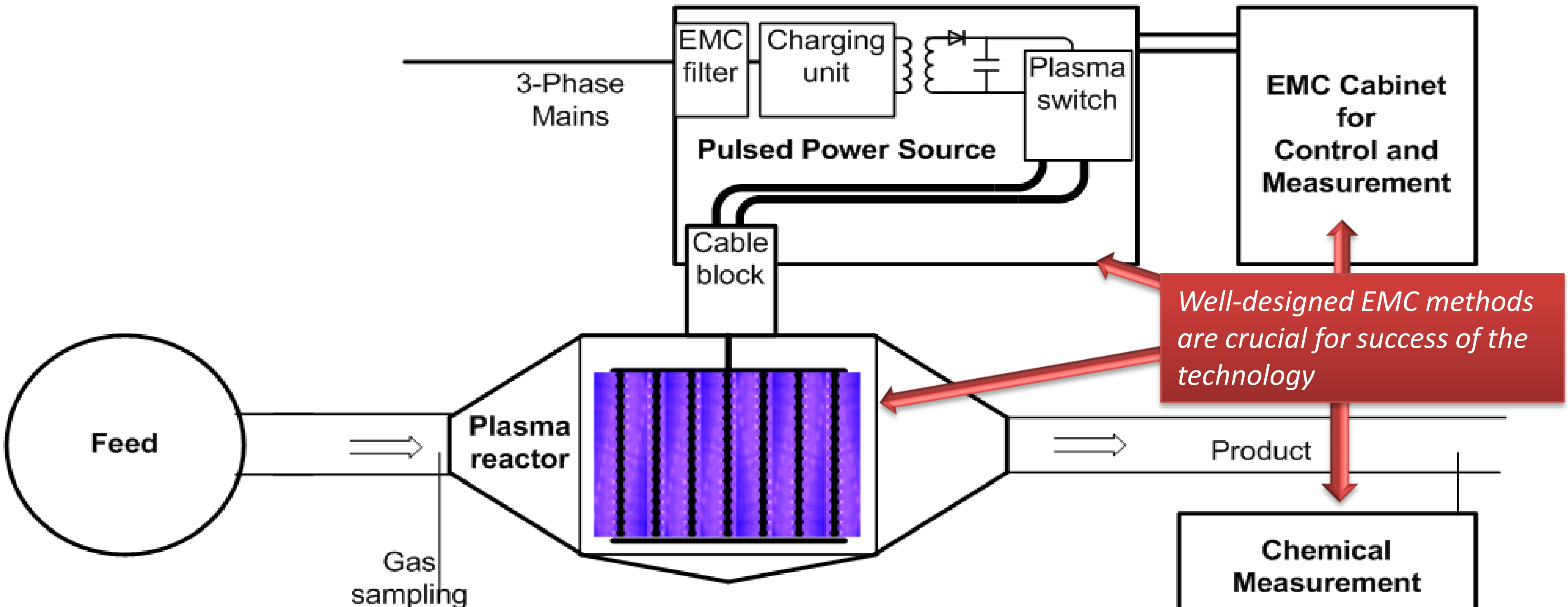
- very powerful plasma chemistry (see activation area)
- can treat a wide variety of contaminants
- efficiënt in energy consumption

Energy profile (indicative) of plasma electrons is most efficient for chemistry

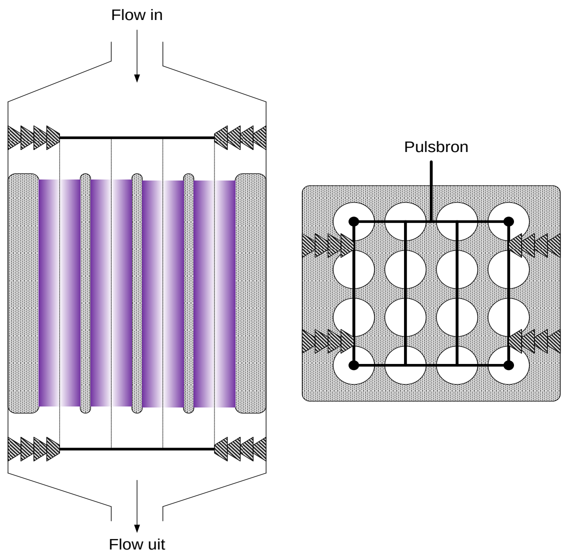
- very little air resistance (airflow)
- fast reactions
- relatively small installation
- large flows



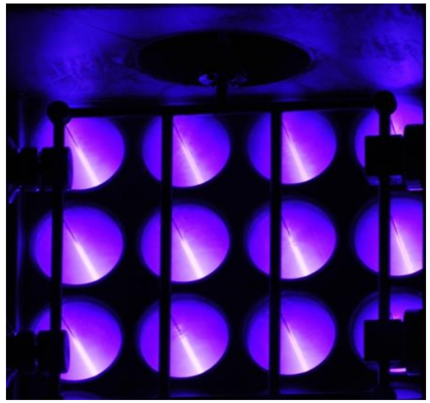
A typical system



Technical Data of our System



Schematic overview reactor



Top view reactor in operation

Reactor & power supply

- **10 kW power supply (pulsed & dc)**
- **100 ns 60 kV pulses, 30 kV DC, 1 kHz repetition rate**
- **300 L active volume**
- **Up to 5000 m^3/h flow handling**
- **Incorporated in a freight container**
- **Remote control & monitoring**

Technische Universiteit Eindhoven University of Technology

Application areas

Market	Emissions*	% of total emissions	Business opportunity
Consumers	Wide range	9 %	Low emissions No business opportunity
Agriculture	80 % = NH3	22 %	Conservative. Needs regulation to create business opportunity.
Transport	77 % = NOx	35 %	Scattered source. Little business opportunity.
Trade, Services, Construction	Wide range	8 %	Low emissions. Little business opportunity.
Industry **	Wide range, VOC, 42% NOx	26 %	High emissions. Localized. Good business opportunity.

* VOC, odor, fine dust, acid (NO_x,H_2S,SO_2,NH_3)

** Refineries/Food&Beverage/Power Plants/Disposal sector/Base metal/ Chemicals

Competition

Key items	TU/e	PlasmaCat/Bekzon	APP	Aerox/UniQair
Catalyst	Yes	Yes	No	No
Technique	pulsed streamer plasma + cat	Catalyst + corona plasma	corona Plasma	Ozone
O-Radicals per 100 eV	10	< 1	< 1	0
Plasma/reactor ratio	1	< 0.2	< 0.2	0
Plasma Intensity	Unlimited	Max 10 J/L	Max 3 J/L	very low
Temperature range	Unlimited	Room temperature	Room Temperature	Room temperature
Wet scrubbing option	yes	no	no	no
odor	yes	yes	yes	partial
VOC	yes	low concentrations	no	no
fine dust	yes	no	no	no
NOx	yes	?	no	no
H2S, NH3	yes	yes	no	no
Tar	yes	no	no	no
micro-organisms	yes	yes	no	no
documented performance	**yes**	no	no	one document
investment cost	high-moderate	moderate	moderate	moderate

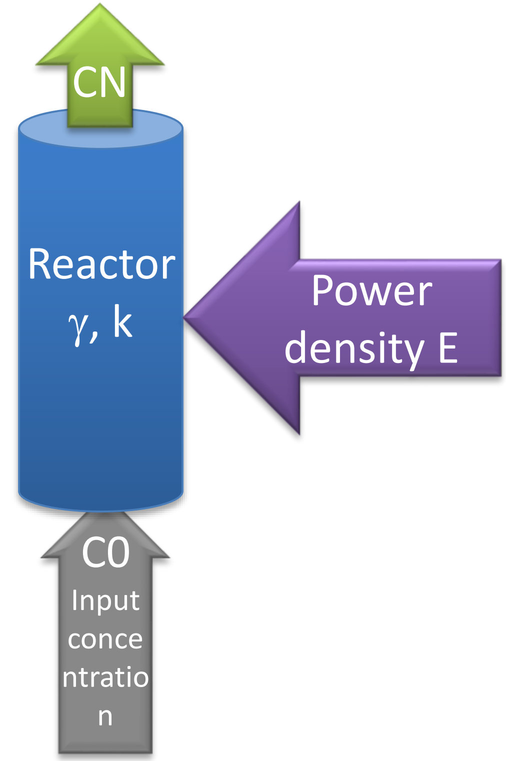
80% NO_x removal
(incinerator)

90% Limonene (VOC) removal
(waste drying)

Documented Performance	Pollutant concentration	Removal	Indicative power consumption (kW) at 1.000 m³/hour
VOC's :(toluene, TCA, Pentane, Ethylene, Furane, Terpens, Aromatic CH, Ketone, Aldehyde, Organic sulfur)	up to 500 ppm	80 -99 %	Toluene, 50 ppm, 60% removal @ 60 J/l - 17 kW
NOx	up to 60 ppm	up to 90%	10ppm 95% removal @ 8J/l – 2.2 kW
Odor	150.000-350.000 odor units / m³ (NER L27 - NL specifications)	85-90 %	2 J/l – 0.6 kW
H2S	20 ppm	99 %	20 ppm 99% removal @ 9J/l – 2.5 kW
NH3	30 ppm	up to 90 %	10ppm 100% removal @ 5J/l – 1.4kW
fine dust	PM 1.0-2.5 up to 3 µg/m³	80-95 %	90% removal @ 5 J/l – 1.4 kW
fine dust	PM .25-1 up to 250µg/m³	50-65 %	60% removal @ 5 J/l – 1.4 kW
Tar	400 ppm	99%	> 150 J/l
traffic emissions	fine dust, HC and NOx	50-90 %	5 J/l – 1.4 kW

Applications: How to predict the process?

We want to know: the ratio $R = CN/C0$



One can derive: $(C0 - CN) + \gamma . Ln(C0/CN) = k.E$ (1)

Solution of (1) for R is →

$$R = \gamma . W_0(Y)/C0$$

where $Y = (C0/\gamma).\exp(C0/\gamma - k.E/\gamma)$

W_0 is the Lambert function, complicated function, forgotten but getting popular again

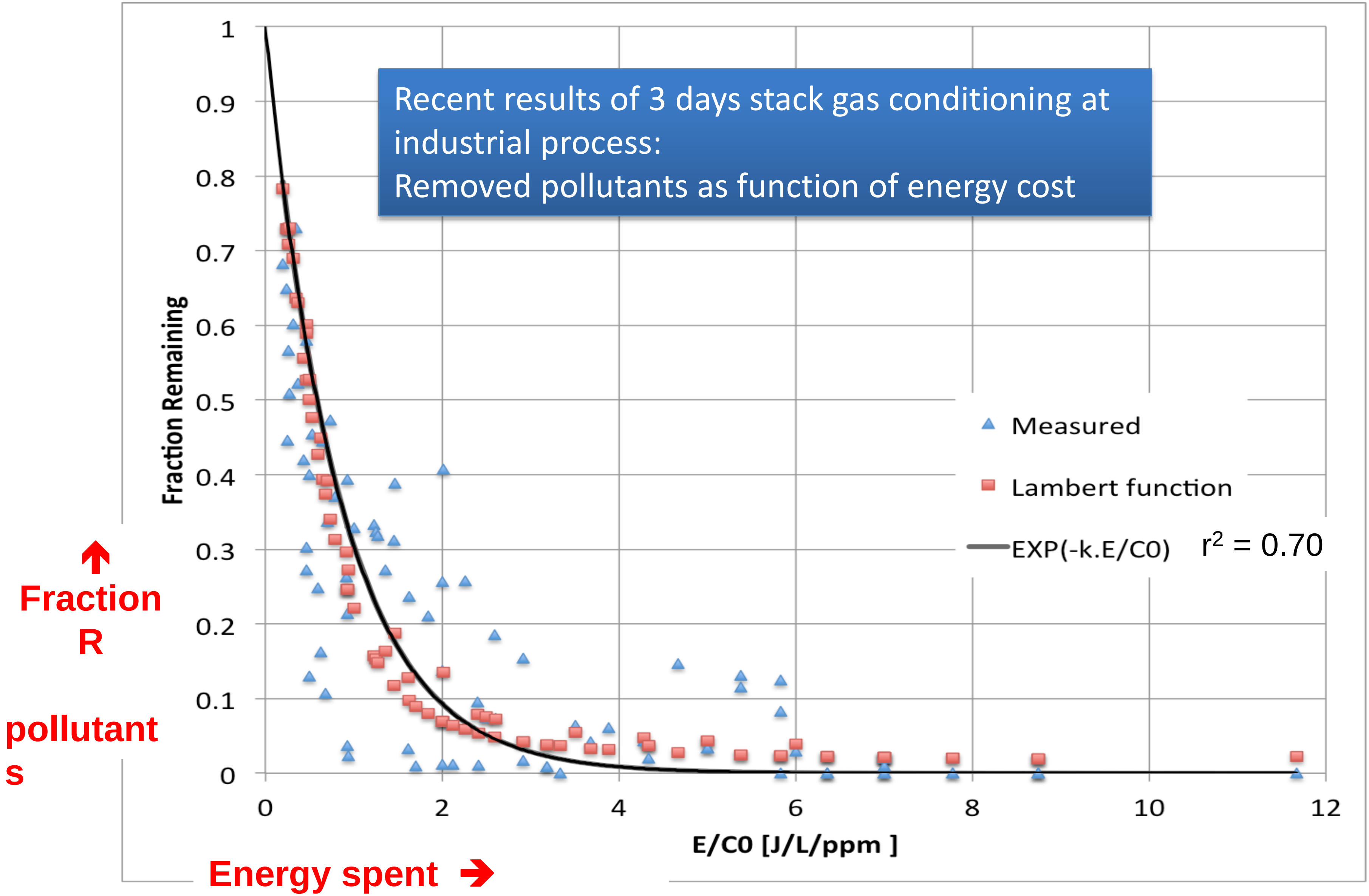
A rather good approximation in our case is:

$$R = \exp\{-k.E/C0\}$$

American Scientist, Volume 93, March-April 2005
Applied Mathematics, 2013, 4, 887-892

ABSTRACT
The Lambert W function has its origin traced back 250 years, but it's just been in the past several decades when some of the real usefulness of the function has been brought to the attention of the scientific community.

Verification of the model



The Next Step: storage of renewable power

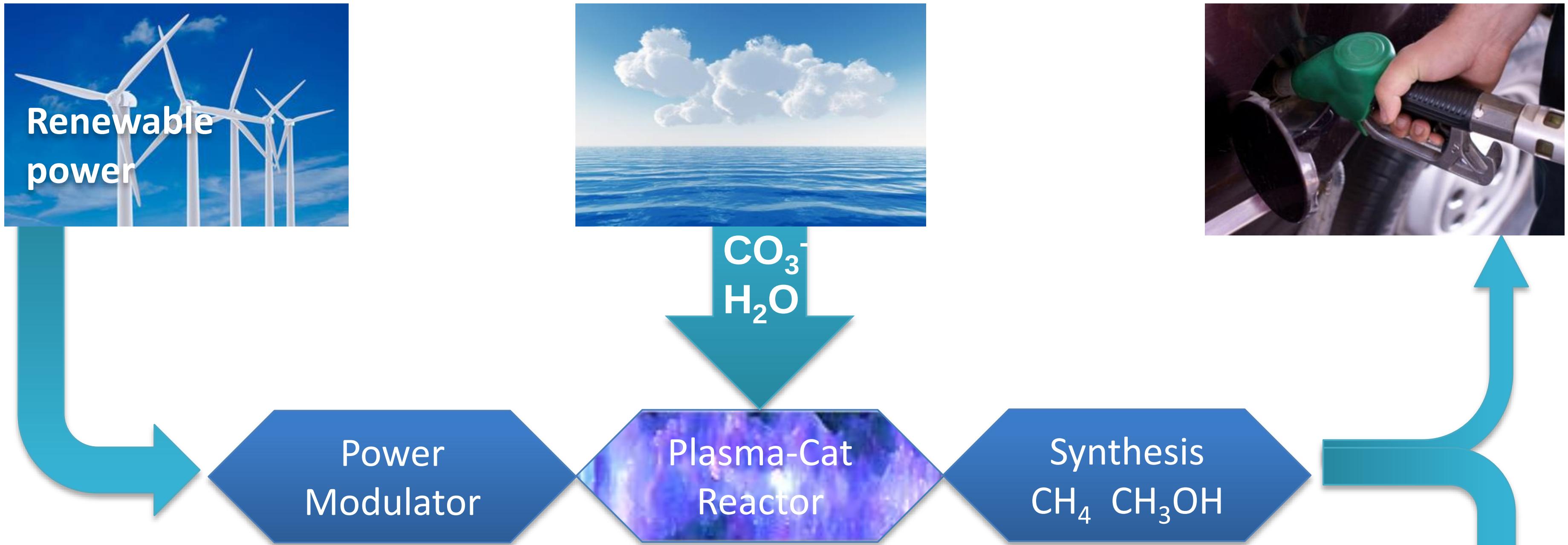
Renewable Power converted into Fuels
preliminary experiments are promising

We propose a plasma combined with a catalyst

Feedstock: renewable power and sea water or CO_2+water

The output is natural gas (and/or methanol)

Renewable Power into to Fuels

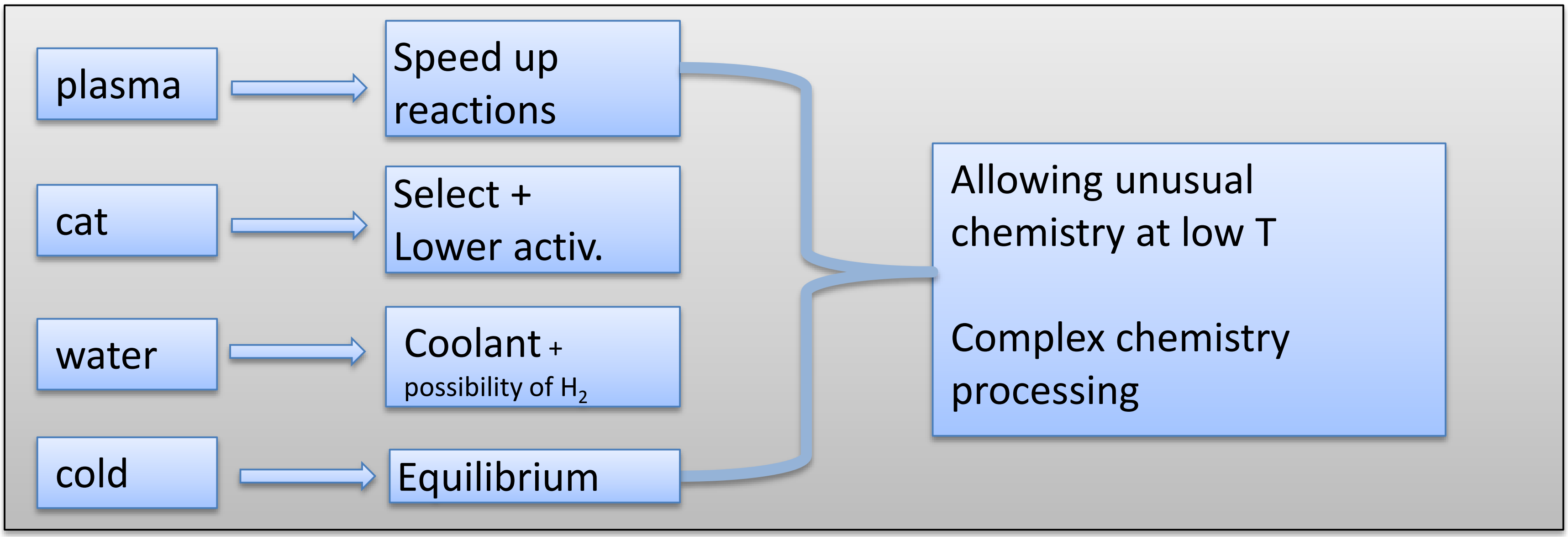


Our 1st result : dillute CH_4 from CO_2 and water

Cat: specifies reaction
Cat: lowers energy cost

Plasma: helps the cat
Plasma: reactions run at low p,T

Combined Approach



Electrical Power tuned for Processing

Concluding:

Tailoring electrical power for chemical processing

Successful in pollution control

Next target: pulsed plasma driven storage of renewable power