The challenge for a more sustainable society: catalysis for chemicals and fuels from renewables

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Divisione di Chimica Industriale della SCI
Gruppo Interdivisionale di Catalisi

Avogadro Colloquia2019

SESSION: ELEMENTS OF THE PERIODIC TABLE IN ENERGY SAVING AND RECYCLING

Saving and recycling, with a focus on catalysis to convert CO_2 into fuels, CH_4 to CH_3OH and **biomasses to added-value products**.
Novel approaches based on non-noble metals such as **Fe, Mn and Cu** will be proposed and discussed to fulfill this goal.

When can a catalyst for the production of fuels and chemicals be considered sustainable ?

in the synthesis of catalysts

IUPAC Periodic Table of the Elements

Key:

atomic number
Symbol
name
conventional atomic weight
standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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3 **Li** lithium 6.94 [6.938, 6.997]	4 **Be** beryllium 9.0122											5 **B** boron 10.81 [10.806, 10.821]	6 **C** carbon 12.011 [12.009, 12.012]	7 **N** nitrogen 14.007 [14.006, 14.008]	8 **O** oxygen 15.999 [15.999, 16.000]	9 **F** fluorine 18.998	10 **Ne** neon 20.180
11 **Na** sodium 22.990	12 **Mg** magnesium 24.305 [24.304, 24.307]											13 **Al** aluminium 26.982	14 **Si** silicon 28.085 [28.084, 28.086]	15 **P** phosphorus 30.974	16 **S** sulfur 32.06 [32.059, 32.076]	17 **Cl** chlorine 35.45 [35.446, 35.457]	18 **Ar** argon 39.95 [39.792, 39.963]
19 **K** potassium 39.098	20 **Ca** calcium 40.078(4)	21 **Sc** scandium 44.956	22 **Ti** titanium 47.867	23 **V** vanadium 50.942	24 **Cr** chromium 51.996	25 **Mn** manganese 54.938	26 **Fe** iron 55.845(2)	27 **Co** cobalt 58.933	28 **Ni** nickel 58.693	29 **Cu** copper 63.546(3)	30 **Zn** zinc 65.38(2)	31 **Ga** gallium 69.723	32 **Ge** germanium 72.630(8)	33 **As** arsenic 74.922	34 **Se** selenium 78.971(8)	35 **Br** bromine 79.904 [79.901, 79.907]	36 **Kr** krypton 83.798(2)
37 **Rb** rubidium 85.468	38 **Sr** strontium 87.62	39 **Y** yttrium 88.906	40 **Zr** zirconium 91.224(2)	41 **Nb** niobium 92.906	42 **Mo** molybdenum 95.95	43 **Tc** technetium	44 **Ru** ruthenium 101.07(2)	45 **Rh** rhodium 102.91	46 **Pd** palladium 106.42	47 **Ag** silver 107.87	48 **Cd** cadmium 112.41	49 **In** indium 114.82	50 **Sn** tin 118.71	51 **Sb** antimony 121.76	52 **Te** tellurium 127.60(3)	53 **I** iodine 126.90	54 **Xe** xenon 131.29
55 **Cs** caesium 132.91	56 **Ba** barium 137.33	57-71 lanthanoids	72 **Hf** hafnium 178.49(2)	73 **Ta** tantalum 180.95	74 **W** tungsten 183.84	75 **Re** rhenium 186.21	76 **Os** osmium 190.23(3)	77 **Ir** iridium 192.22	78 **Pt** platinum 195.08	79 **Au** gold 196.97	80 **Hg** mercury 200.59	81 **Tl** thallium 204.38 [204.38, 204.39]	82 **Pb** lead 207.2	83 **Bi** bismuth 208.98	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
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International Year
of the Periodic Table
of Chemical Elements

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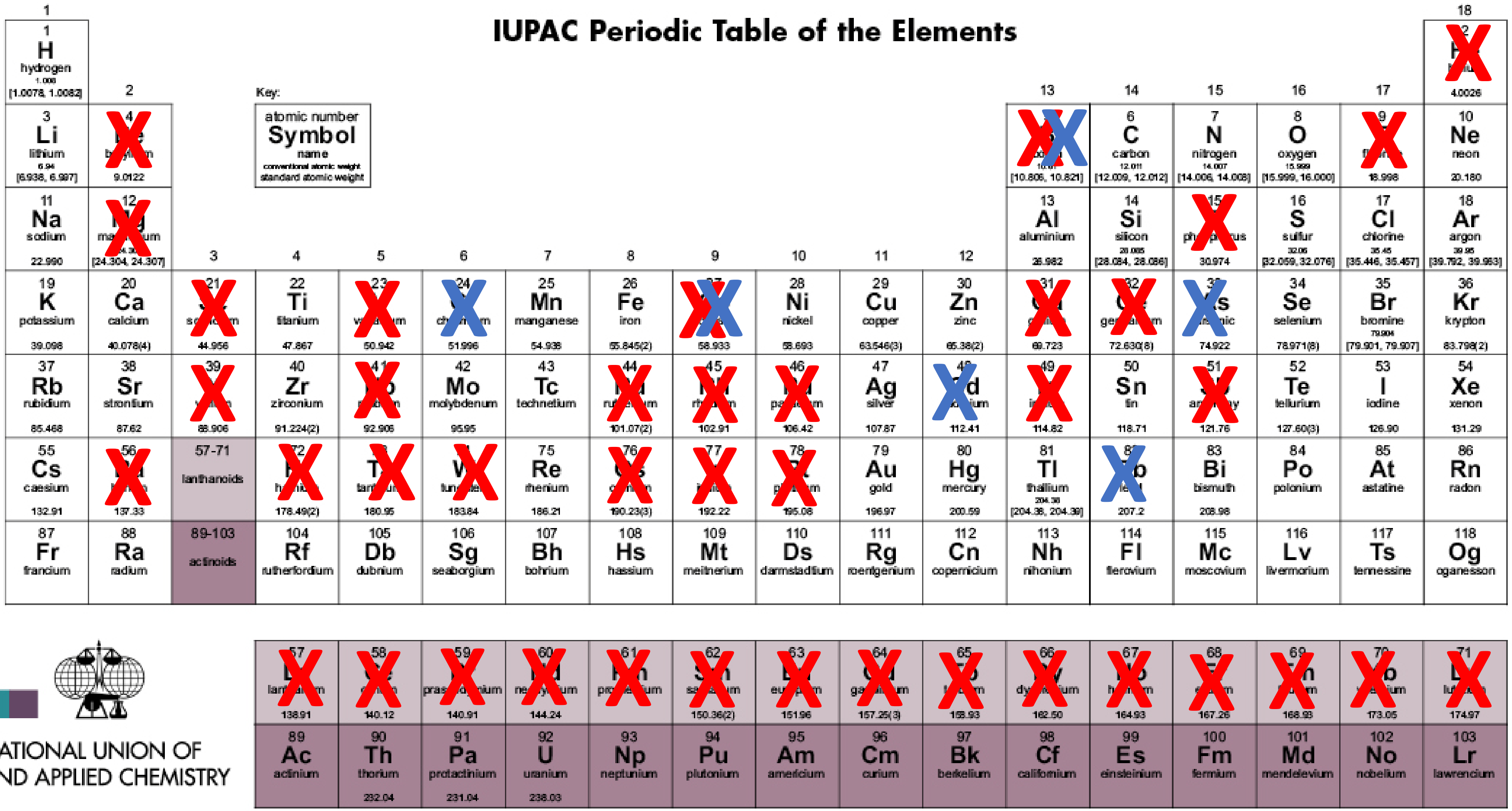
X critical (for EU) raw materials



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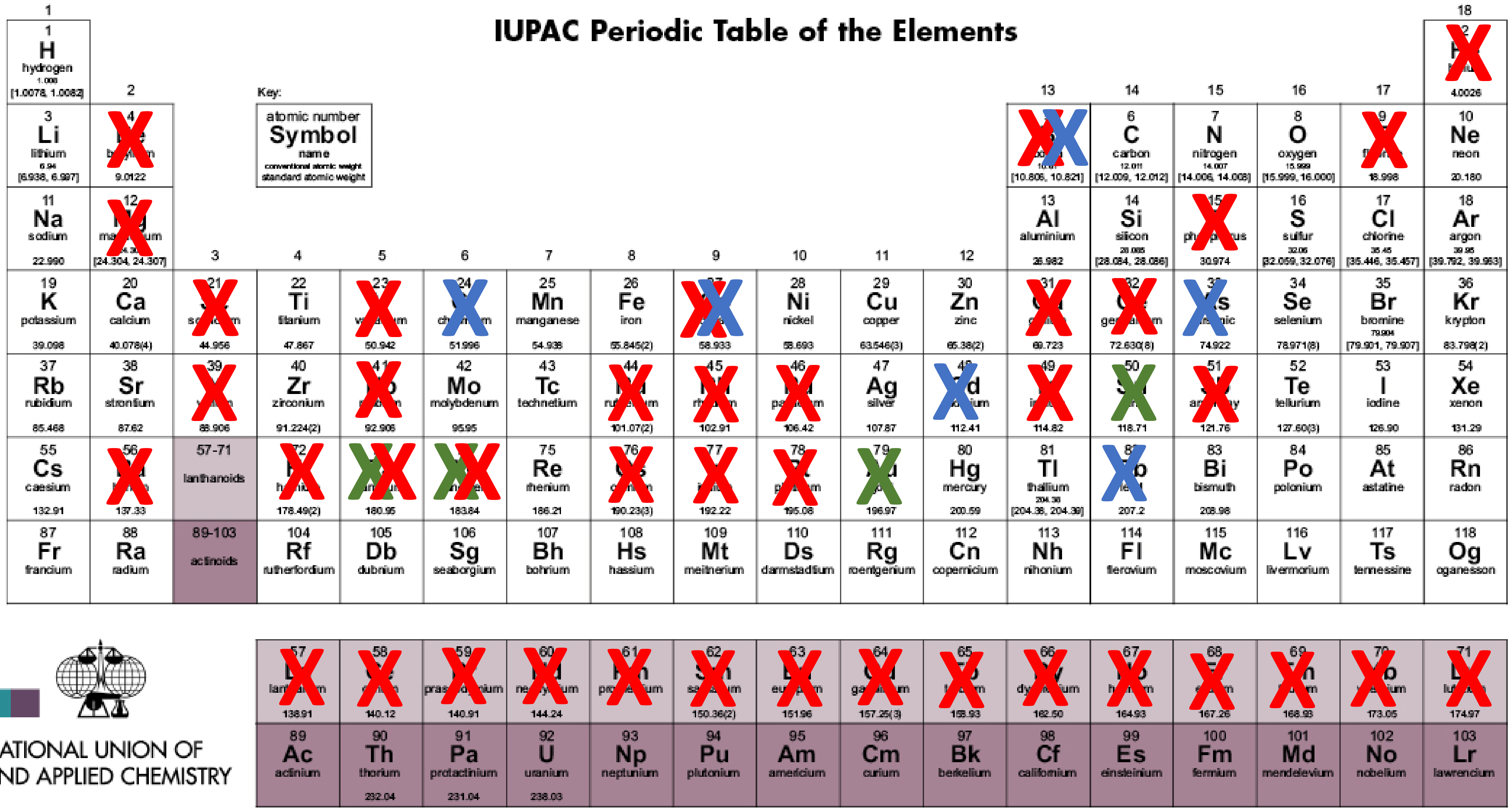

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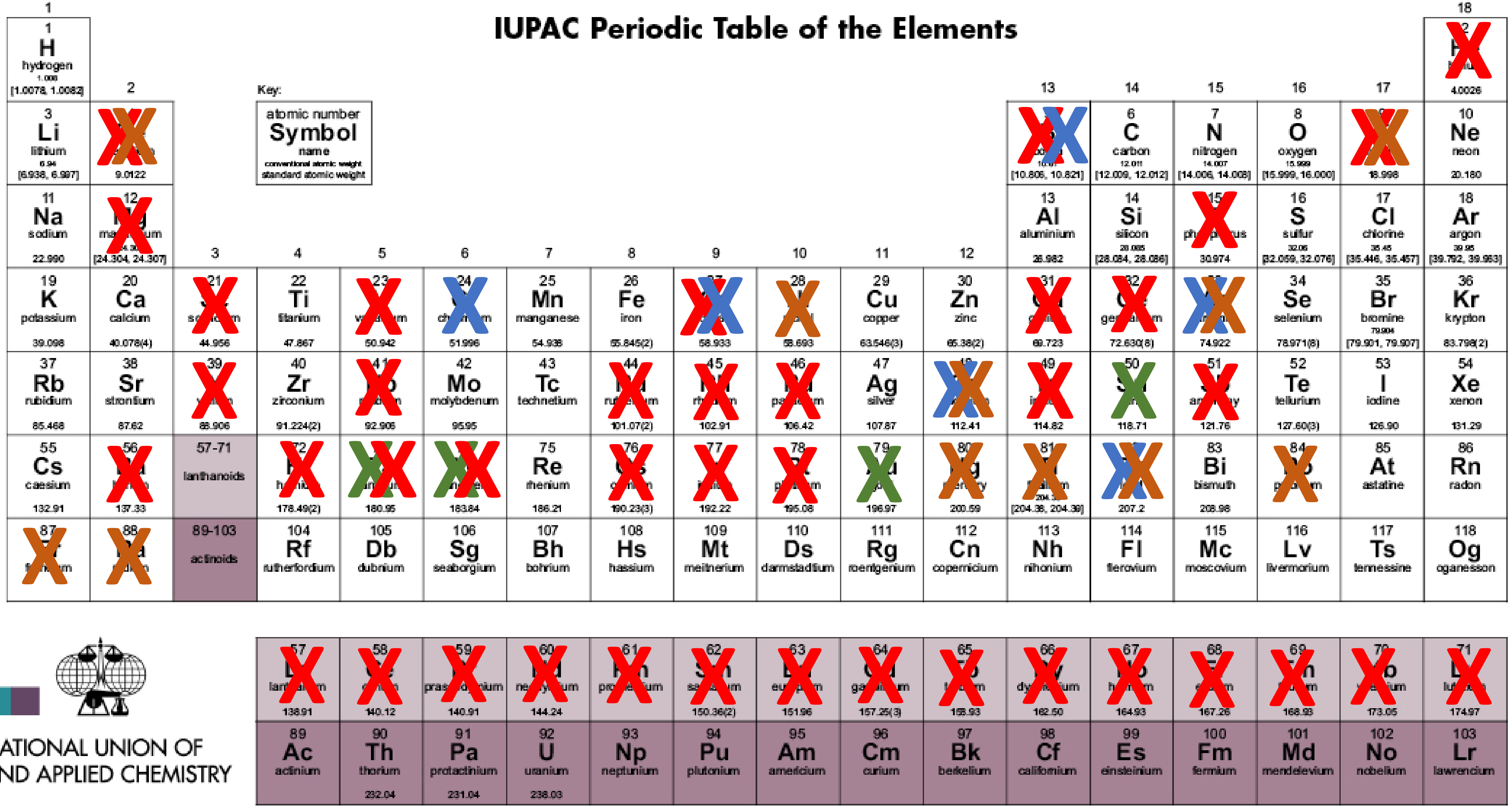

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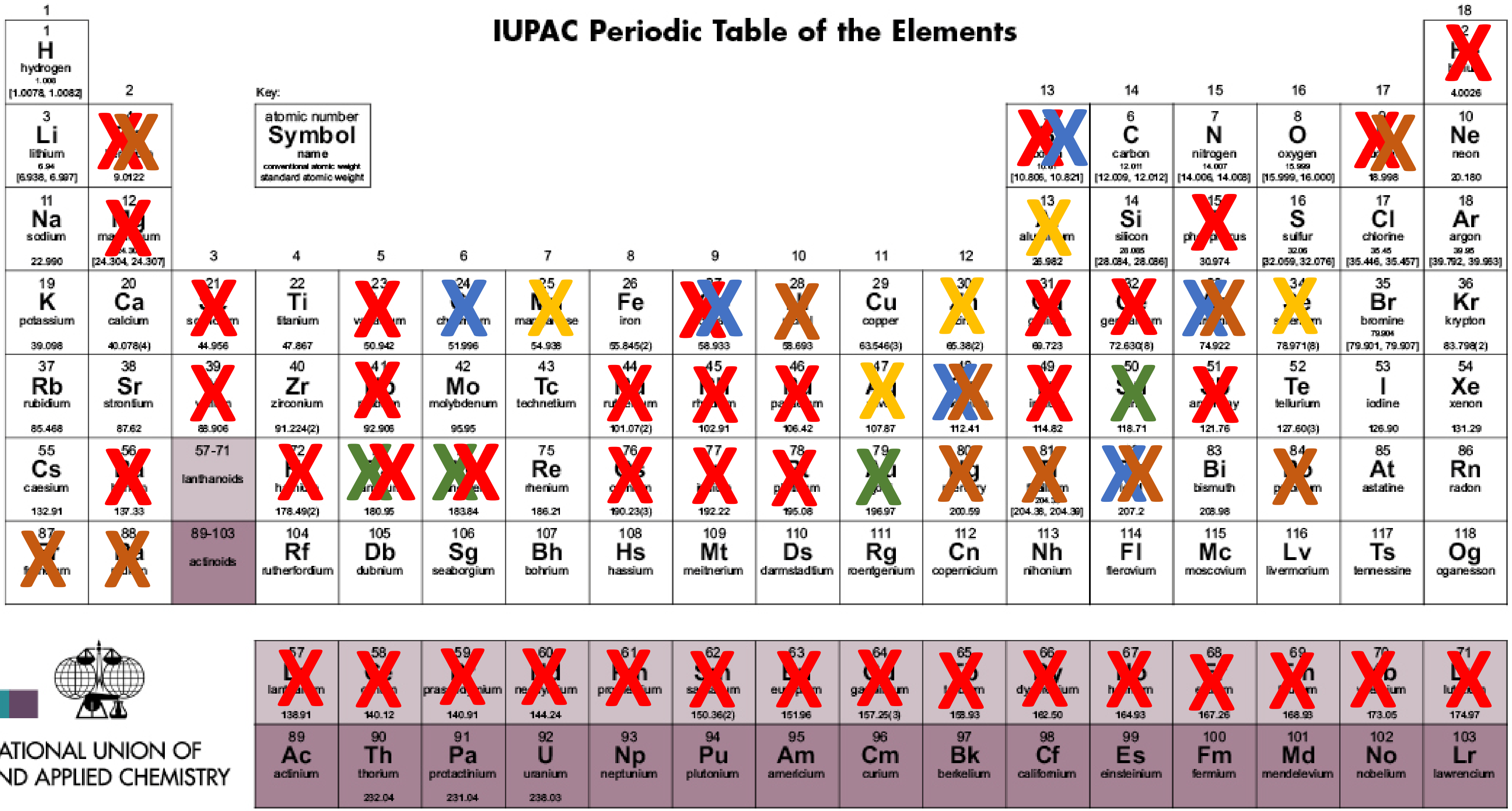

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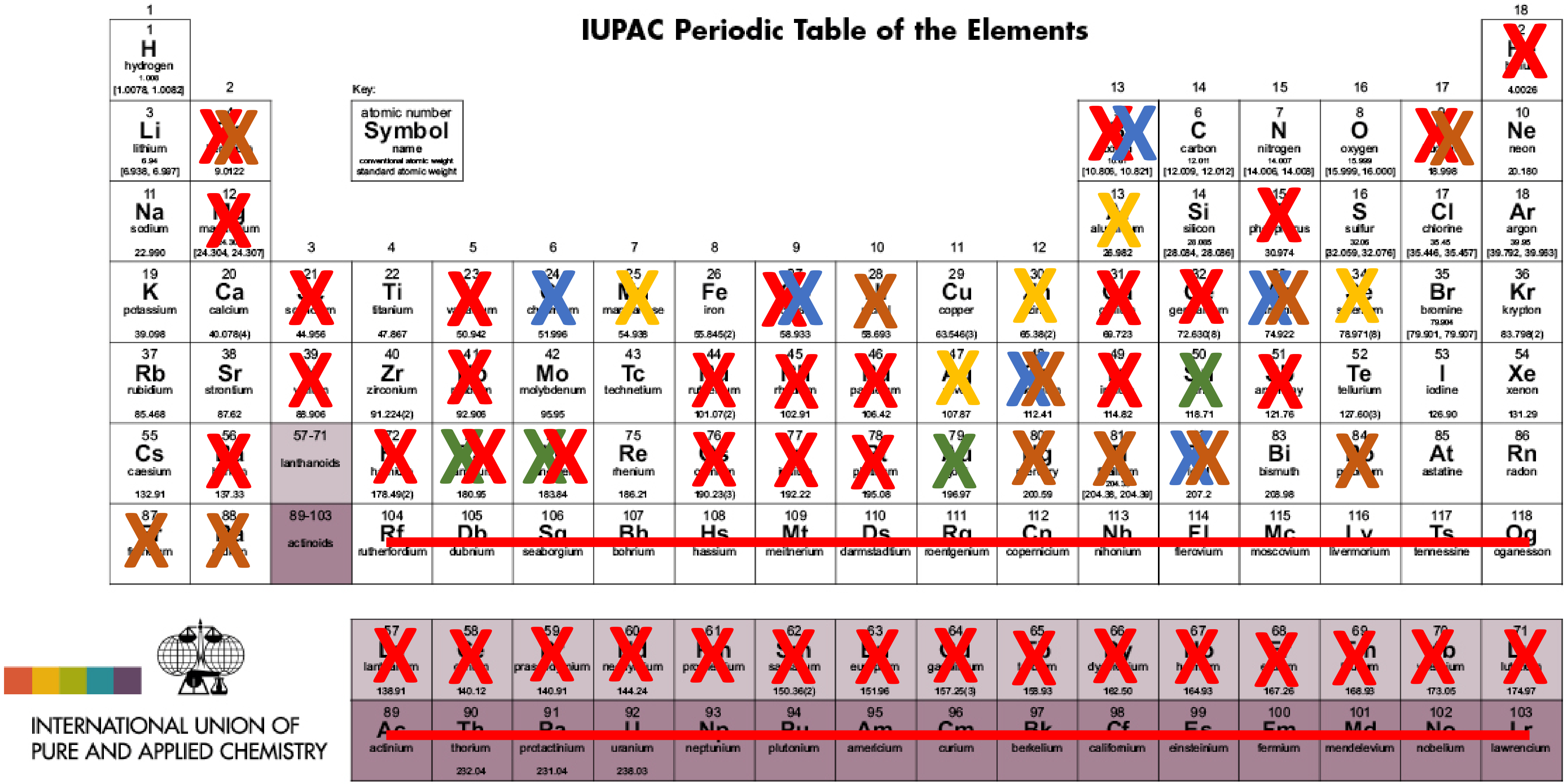

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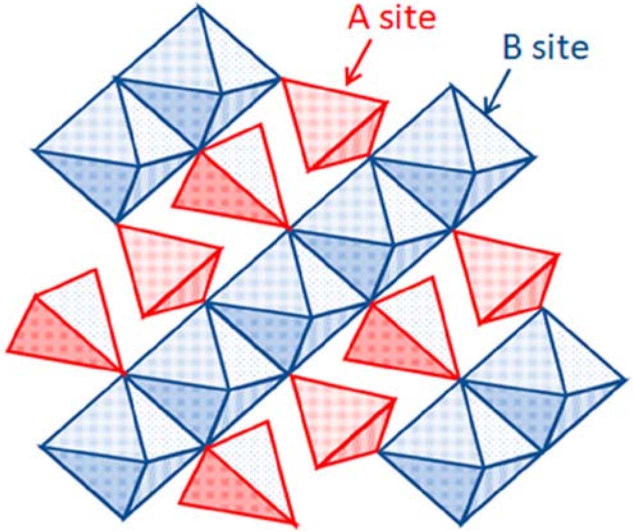
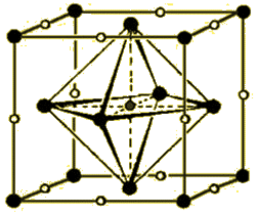
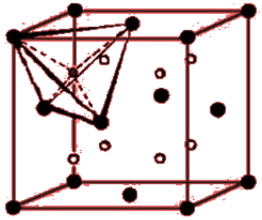
Spinel-type Ferrites




Octahedral Site


Tetrahedral Site

Reaction
Oxidative cleavage of styrene to benzaldehyde with H_2O_2
Oxidation of cyclohexane to cyclohexanol/cyclohexanone with O_2 or H_2O_2
Hydroxylation of benzene/phenol to phenol/diphenols with H_2O_2
Oxidation of vanyllol to vanillin with air
Oxidation of benzyl alcohol to benzaldehyde with H_2O_2
Oxidation of monoterpenic alkenes with O_2
Oxidation of 5-hydroxymethylfurfural to 2,5-furandicarboxylic acid (hmf to fdca) with H_2O_2 or O_2
Oxidation of aniline to azoxybenzene with H_2O_2
Oxidation of toluene to benzaldehyde with H_2O_2
Oxidation of ethanol to acetaldehyde with O_2
Oxidation of veratryl alcohol to veratryl aldehyde with O_2
Ketonisation of butanol to heptanone
Total oxidation of voc with air
Friedel–crafts acylation
Knoevenagel condensation
Reduction of ketones
Reduction of nitroarenes
Methylation (alkylation) of phenolics, aniline, pyridine
Methanol, ethanol reforming (by means of chemical-loop)

Preparation Method
Coprecipitation
Sol–gel
Hydrothermal
Solvothermal
Microemulsion/Reverse micelles
Template
Mechanical milling
Plasma
Flux growth
Solid phase
Combustion
Microwave combustion
Microwave hydrothermal
Pechini method
Electrochemical
Electrospinning
Thermal treatment
Ultrasonic wave-assisted ball milling
Spray pyrolysis
Aerosol
Forced hydrolysis
Glycol-thermal
Refluxing

Spinel-type mixed ferrites as e^-/O^{2-} carriers for H_2 production from H_2O

THERMOCHEMICAL CYCLES

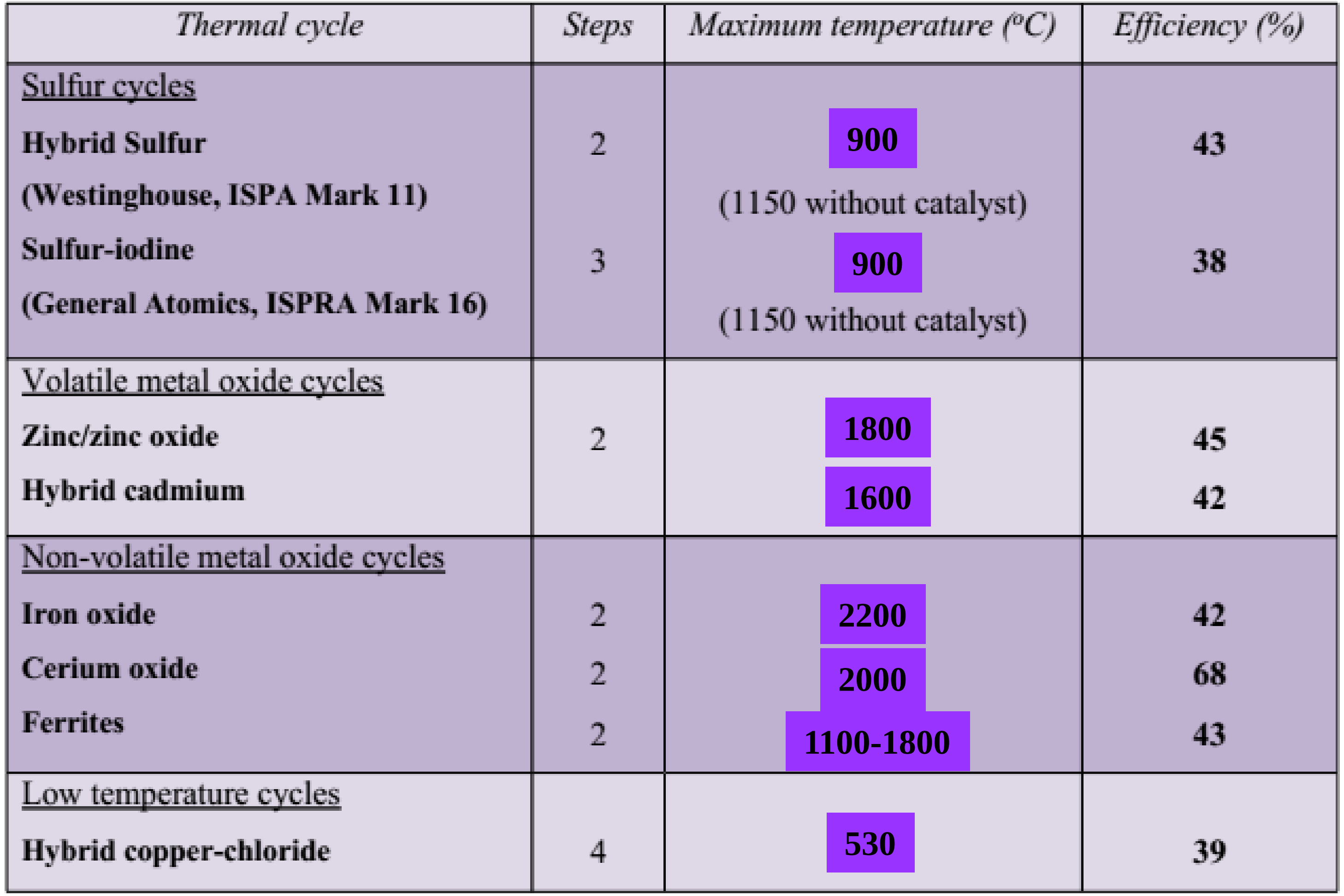
Thermal splitting of H_2O

$$H_2O \rightarrow H_2 + \tfrac{1}{2}O_2,\ \Delta 3300K$$

Thermochemical splitting of H_2O

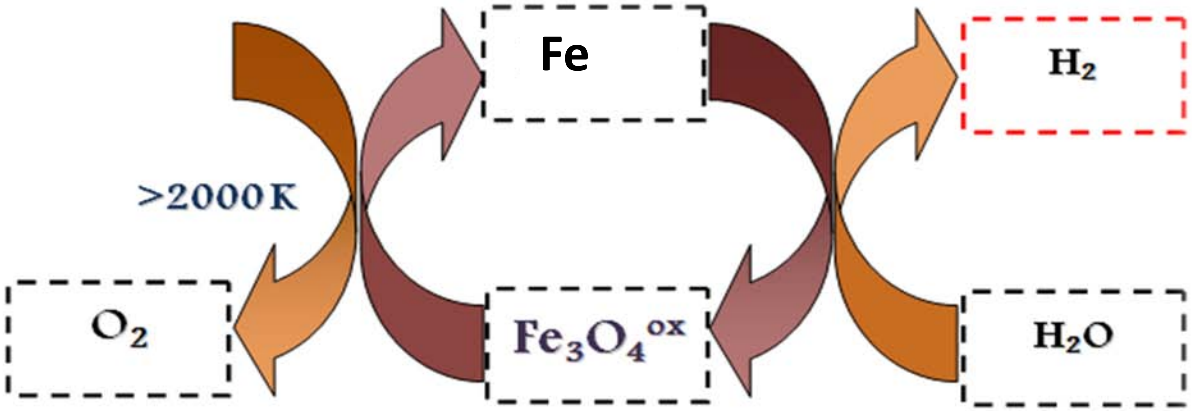
$$A\text{-}O \rightarrow A + \tfrac{1}{2}O_2$$
$$A + H_2O \rightarrow H_2 + A\text{-}O$$

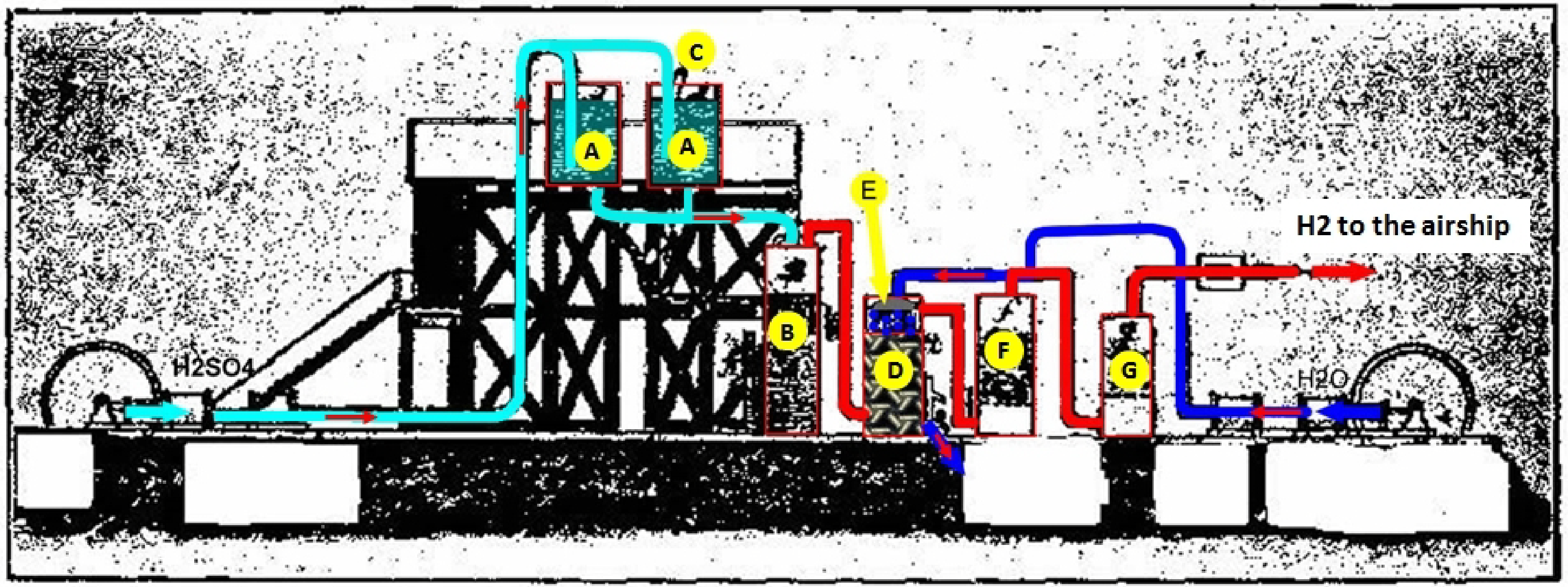
The two-step process eliminates the need for H_2/O_2 separation

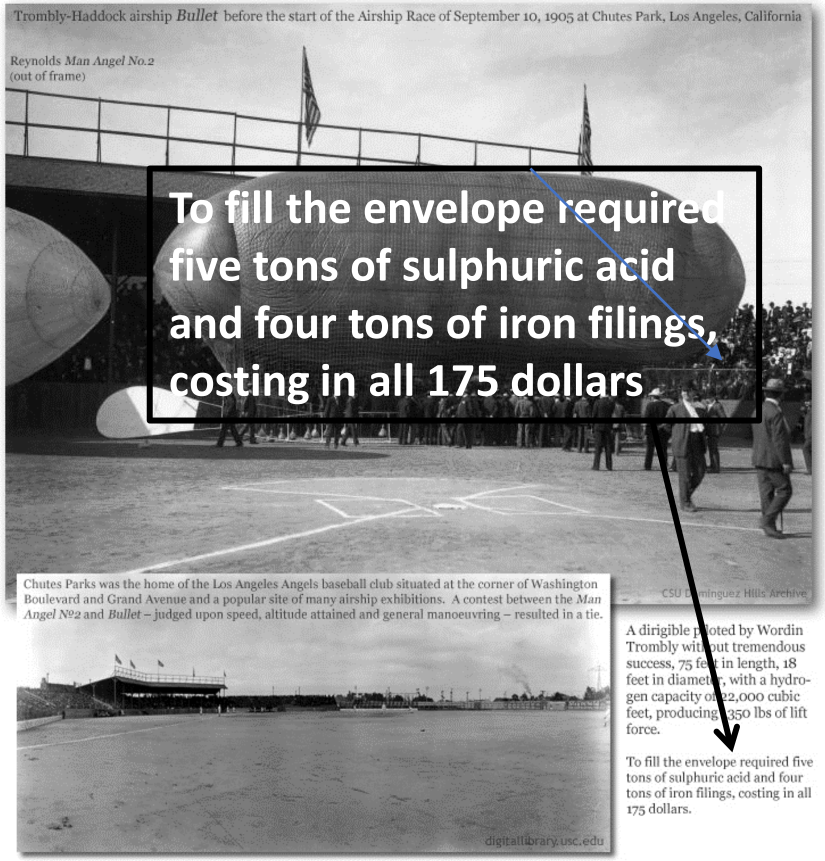


Thermal cycle	*Steps*	*Maximum temperature (°C)*	*Efficiency (%)*
Sulfur cycles			
Hybrid Sulfur (Westinghouse, ISPA Mark 11)	2	**900** (1150 without catalyst)	**43**
Sulfur-iodine (General Atomics, ISPRA Mark 16)	3	**900** (1150 without catalyst)	**38**
Volatile metal oxide cycles			
Zinc/zinc oxide	2	**1800**	**45**
Hybrid cadmium		**1600**	**42**
Non-volatile metal oxide cycles			
Iron oxide	2	**2200**	**42**
Cerium oxide	2	**2000**	**68**
Ferrites	2	**1100-1800**	**43**
Low temperature cycles			
Hybrid copper-chloride	4	**530**	**39**

The steam-iron process






Trombly-Haddock airship *Bullet* before the start of the Airship Race of September 10, 1905 at Chutes Park, Los Angeles, California

Reynolds *Man Angel No.2* (out of frame)

To fill the envelope required five tons of sulphuric acid and four tons of iron filings, costing in all 175 dollars

CSU Dominguez Hills Archive

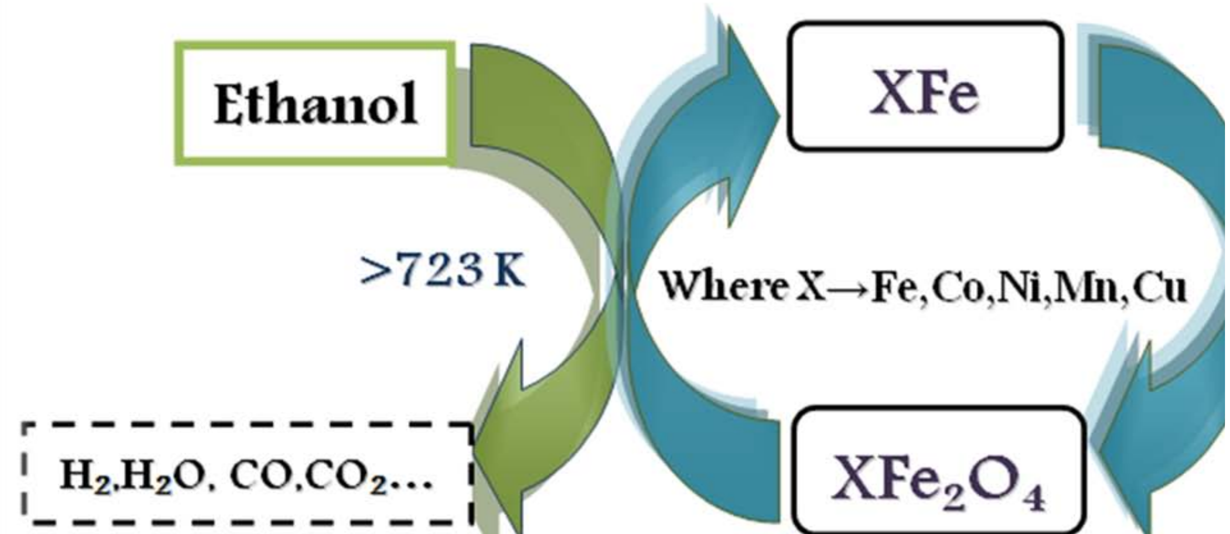
Chutes Parks was the home of the Los Angeles Angels baseball club situated at the corner of Washington Boulevard and Grand Avenue and a popular site of many airship exhibitions. A contest between the *Man Angel №2* and *Bullet* – judged upon speed, altitude attained and general manoeuvring – resulted in a tie.

digitallibrary.usc.edu

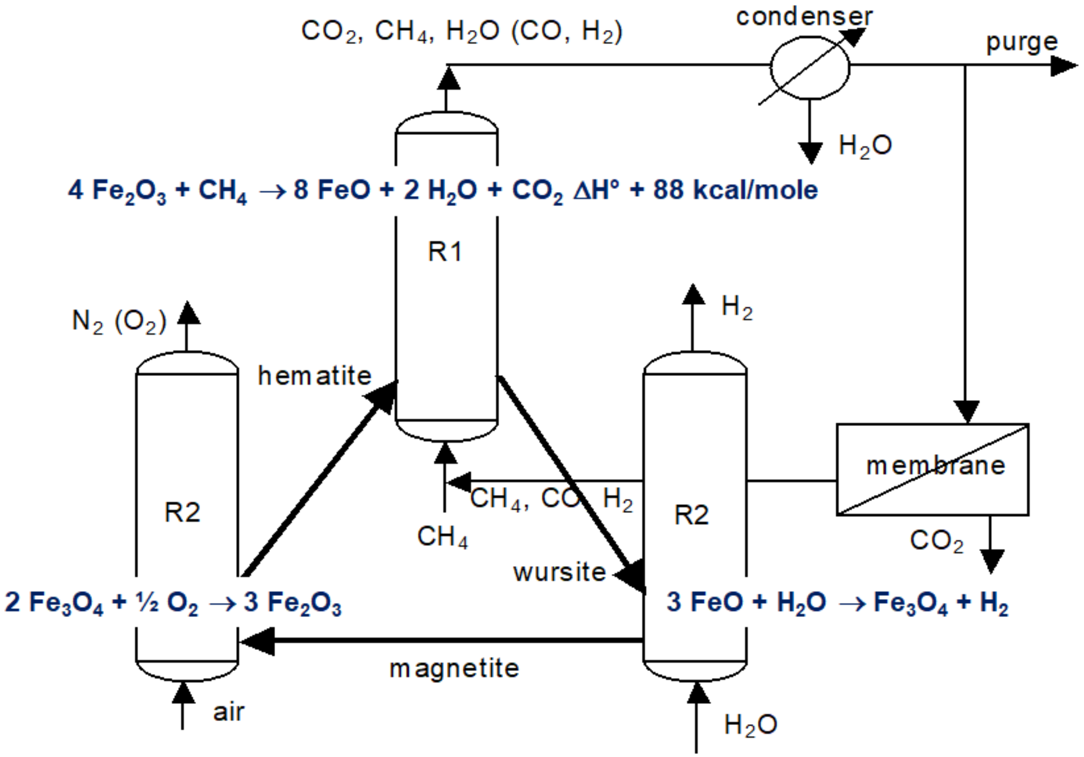
A dirigible piloted by Wordin Trombly without tremendous success, 75 feet in length, 18 feet in diameter, with a hydrogen capacity of 22,000 cubic feet, producing 350 lbs of lift force.

To fill the envelope required five tons of sulphuric acid and four tons of iron filings, costing in all 175 dollars.

A chemical-loop reforming of bio-alcohols



…but also chemicals

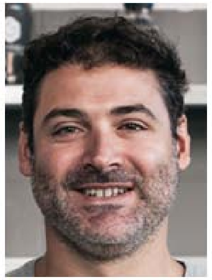


Overall: $CH_4 + 2/3\ H_2O + 2/3\ O_2 \rightarrow CO_2 + 8/3\ H_2$ (in R1+R2+R3)

L. Calvillo, et al, **J. Mater. Chem. A**, 2018, 6, 7034–7041
F. Carraro, et al, **J. Mater. Chem. A**, 2017, 5, 20808–20817
O. Vozniuk, et al, **ChemCatChem** 2017, 9, 2219-2230
C. Trevisanut, et al, **Topics Catal.** 59 (2016) 1600–1613
O. Vozniuk, et al, **Green Chem.,** 2016, 18, 1038–1050
C. Trevisanut, et al, **Intern. J. Hydr. Energy**, 40 (2015) 5264-5271
C. Trevisanutet al, **Catal. Sci. Technol**., 5, (2015) 1280–1289
S. Cocchi, et al, **Appl. Catal. B** 152–153 (2014) 250–261
J. Velasquez Ochoa, et al, **J. Phys. Chem. C** 117 (2013) 23908–23918
V. Crocellà, et al, **J. Phys. Chem. C** 116 (2012) 14998–15009

Ferrites for Chemical-loop reforming

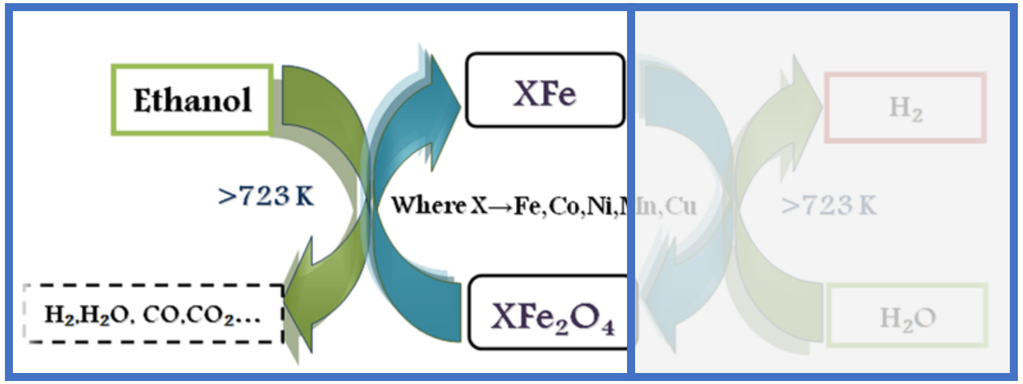

Stefano Cocchi

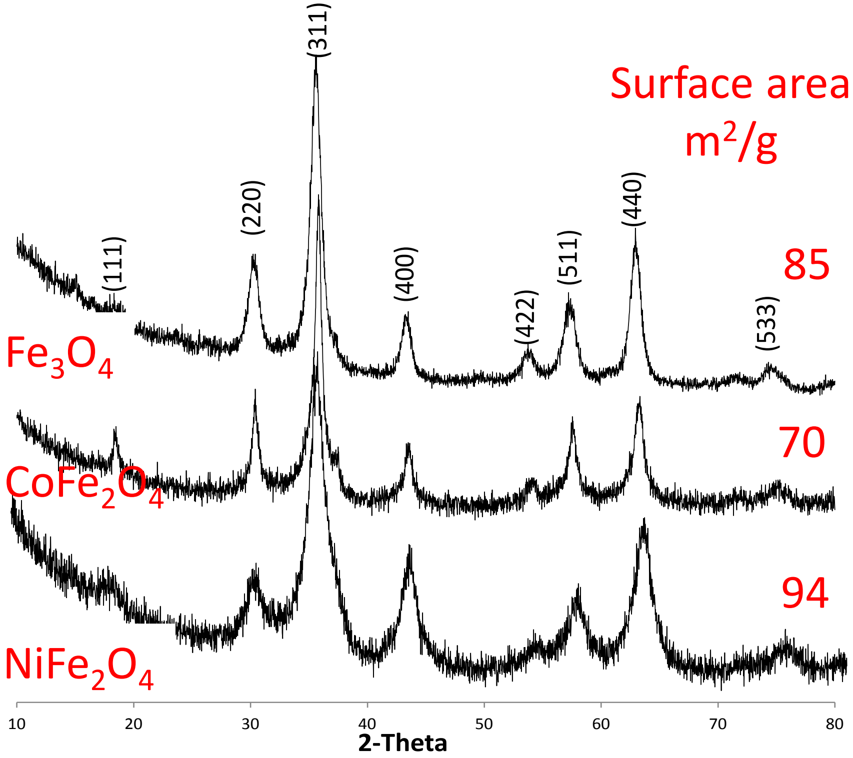

Cristian Trevisanut


Olena Vozniuk

enerBIO
Fondation Tuck

The first part of the loop: oxidised spinel + ethanol

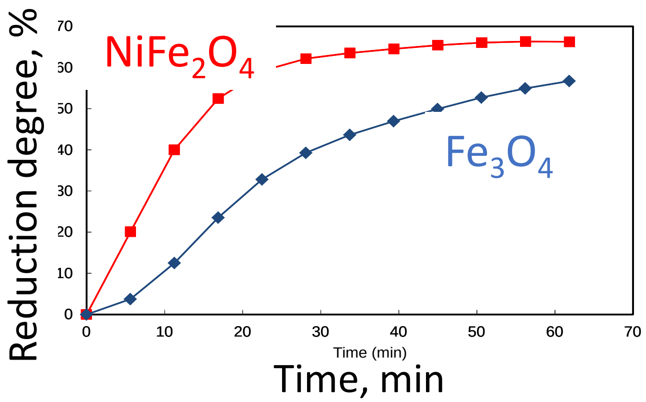


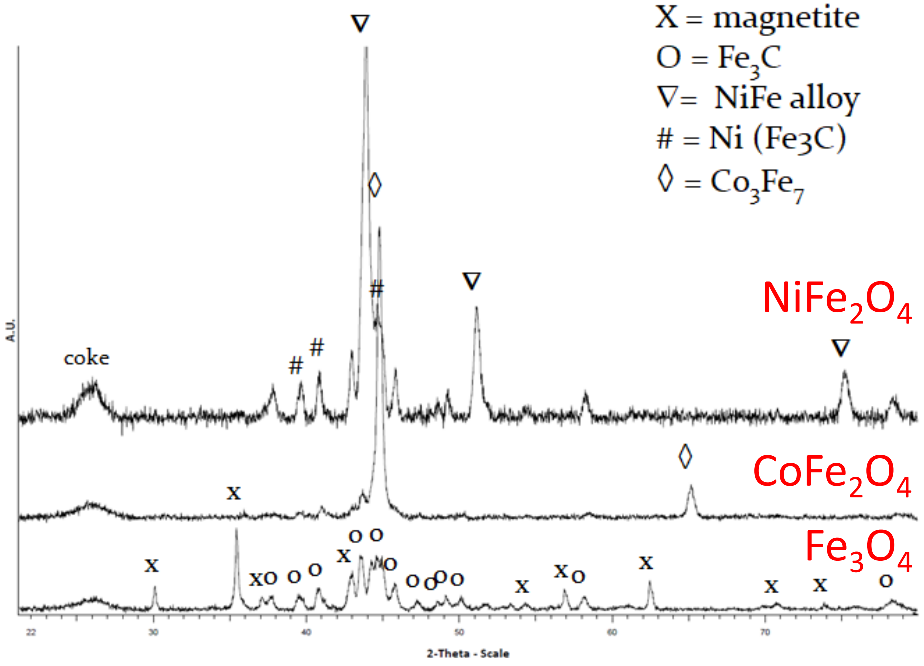


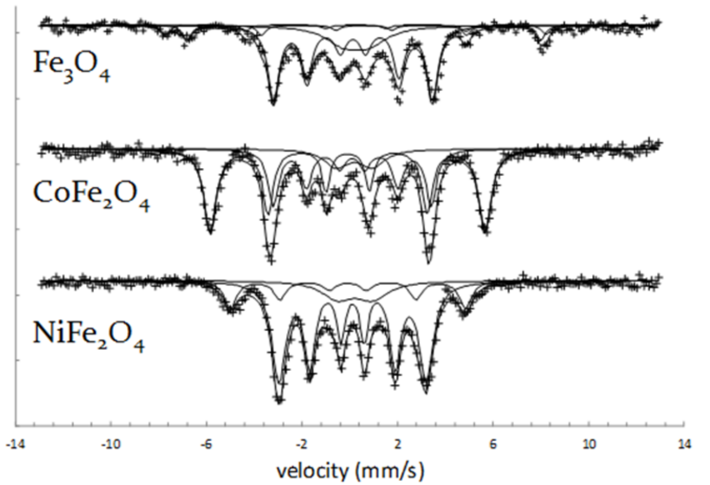
Samples treated in air at 450°C

60 min red with ethanol

450°C





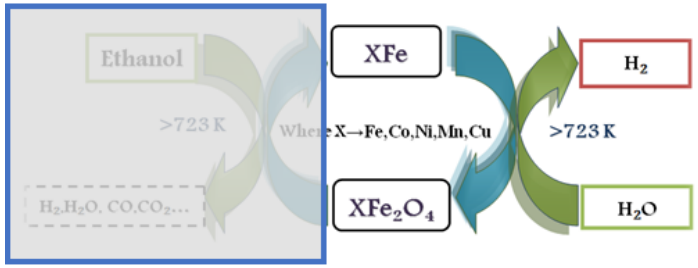


Fe_3O_4:
15 % Fe_3O_4
62 % Fe_3C
22 % Fe spm

$CoFe_2O_4$:
56 % Fe° (Co_3Fe_7)
33 % Fe_3C
11 % Fe spm

$NiFe_2O_4$:
17 % FeNi alloy
69 % Fe_3C
14 % Fe spm

The second part of the loop: reduced spinel + water



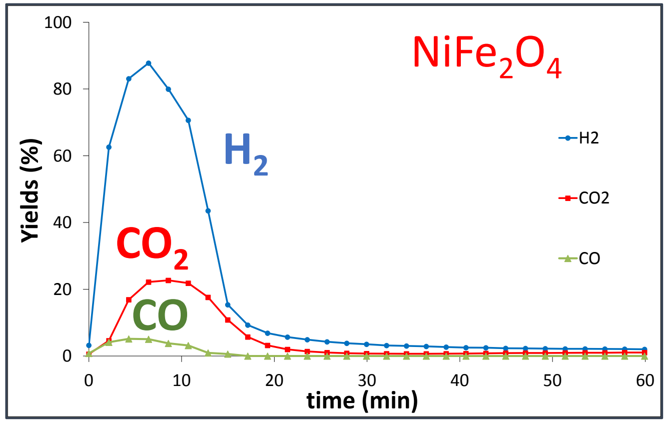
60 min oxid with steam

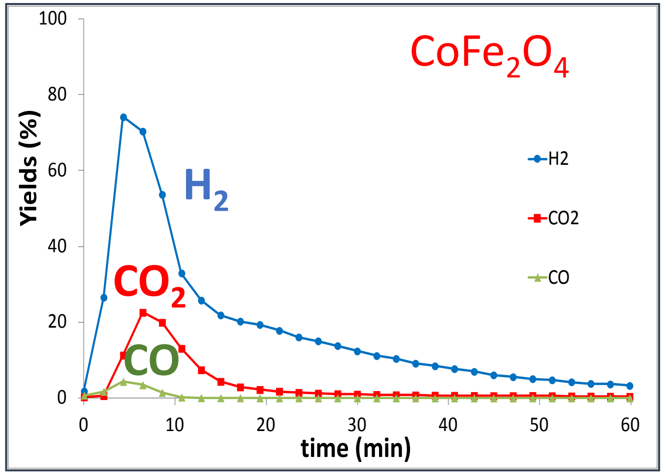
T 450°C

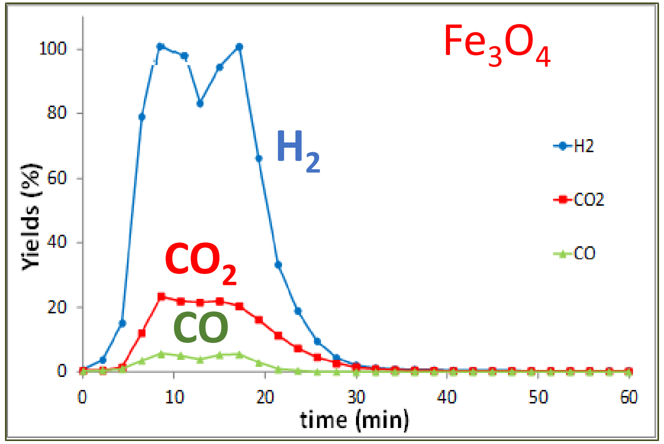
Fe + H_2O → FeO + H_2
3FeO + H_2O → Fe_3O_4 + H_2
Fe_3C + H_2O → 3Fe + CO + H_2
Fe_3C + 2H_2O → 3Fe + CO_2 + 2H_2

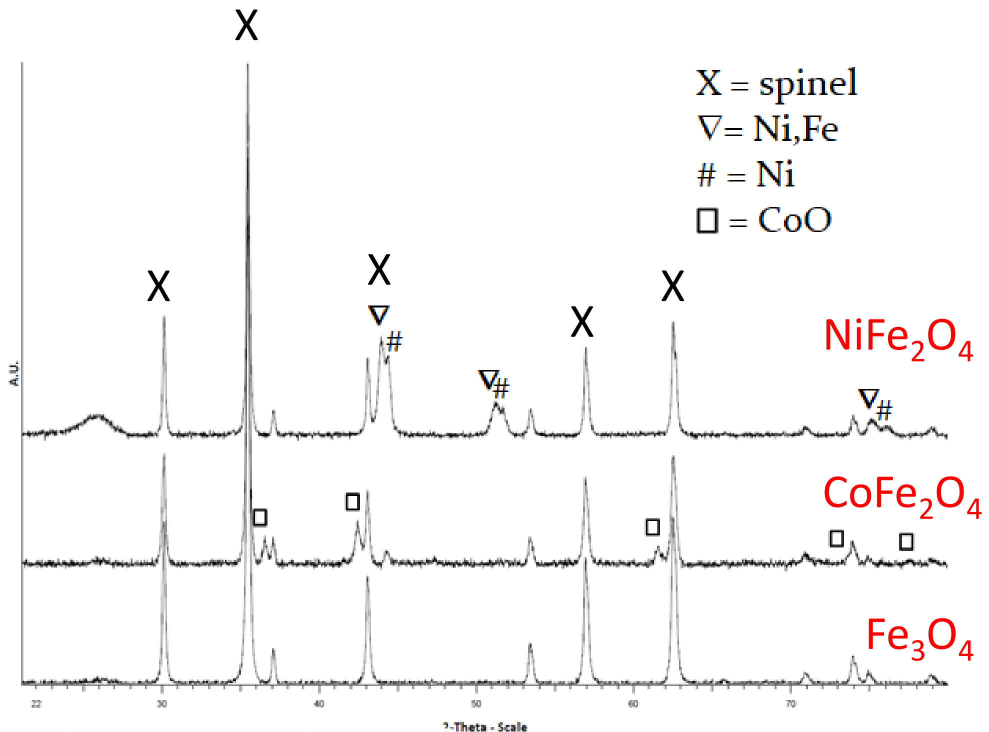
C + H_2O → CO + H_2
CO + H_2O → CO_2 + H_2

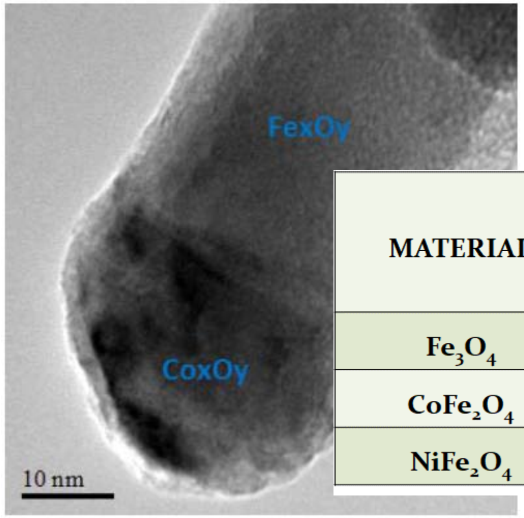
FeO + C → Fe + CO
2 FeO + C → 2 Fe + CO2
Fe_3O_4 + C → 3 FeO + CO





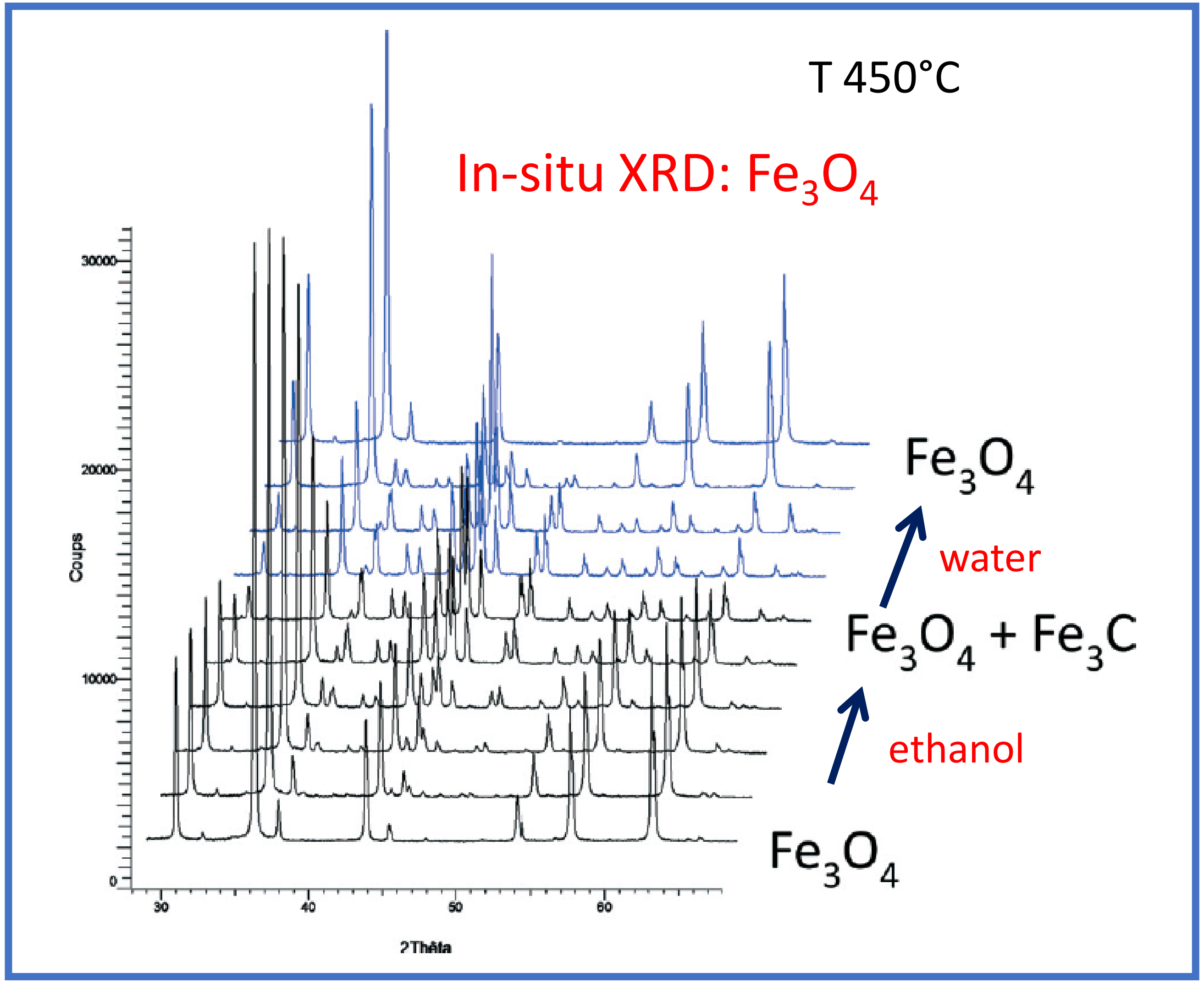






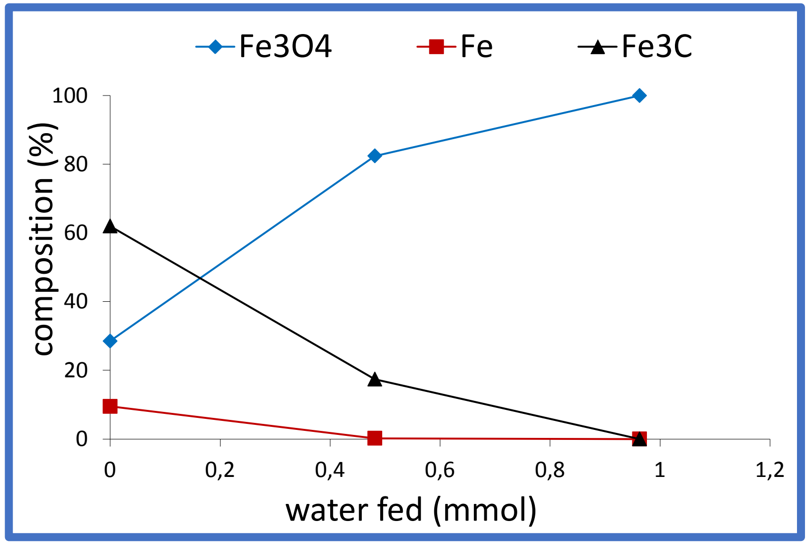
MATERIAL	% of C $^w/_w$ after 1h reduction	% of C $^w/_w$ after 1h re-oxidation
Fe_3O_4	41.0	28.6
$CoFe_2O_4$	43.8	36.9
$NiFe_2O_4$	49.1	39.3

$CoFe_2O_4$ sample after 1 cycle (red+ox)

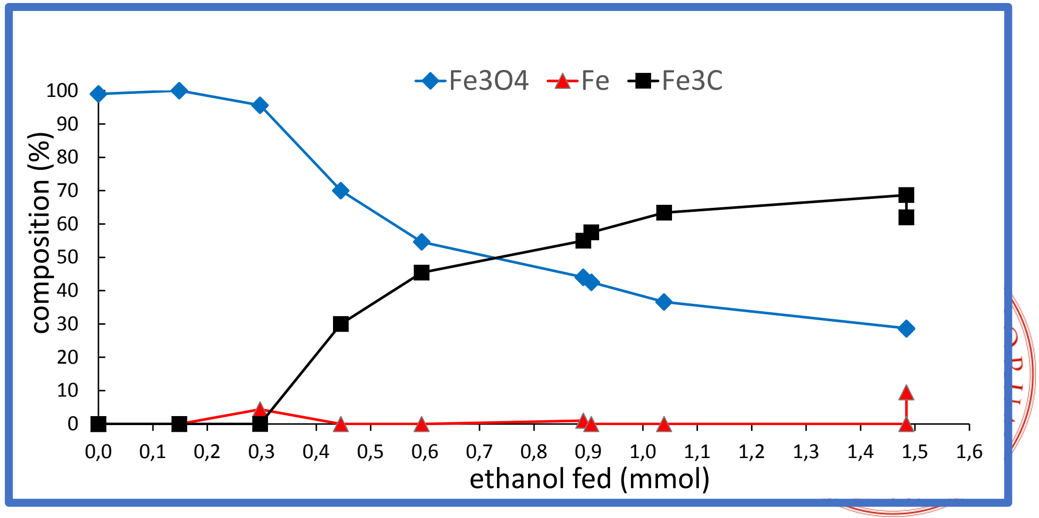

T 450°C

In-situ XRD: Fe_3O_4

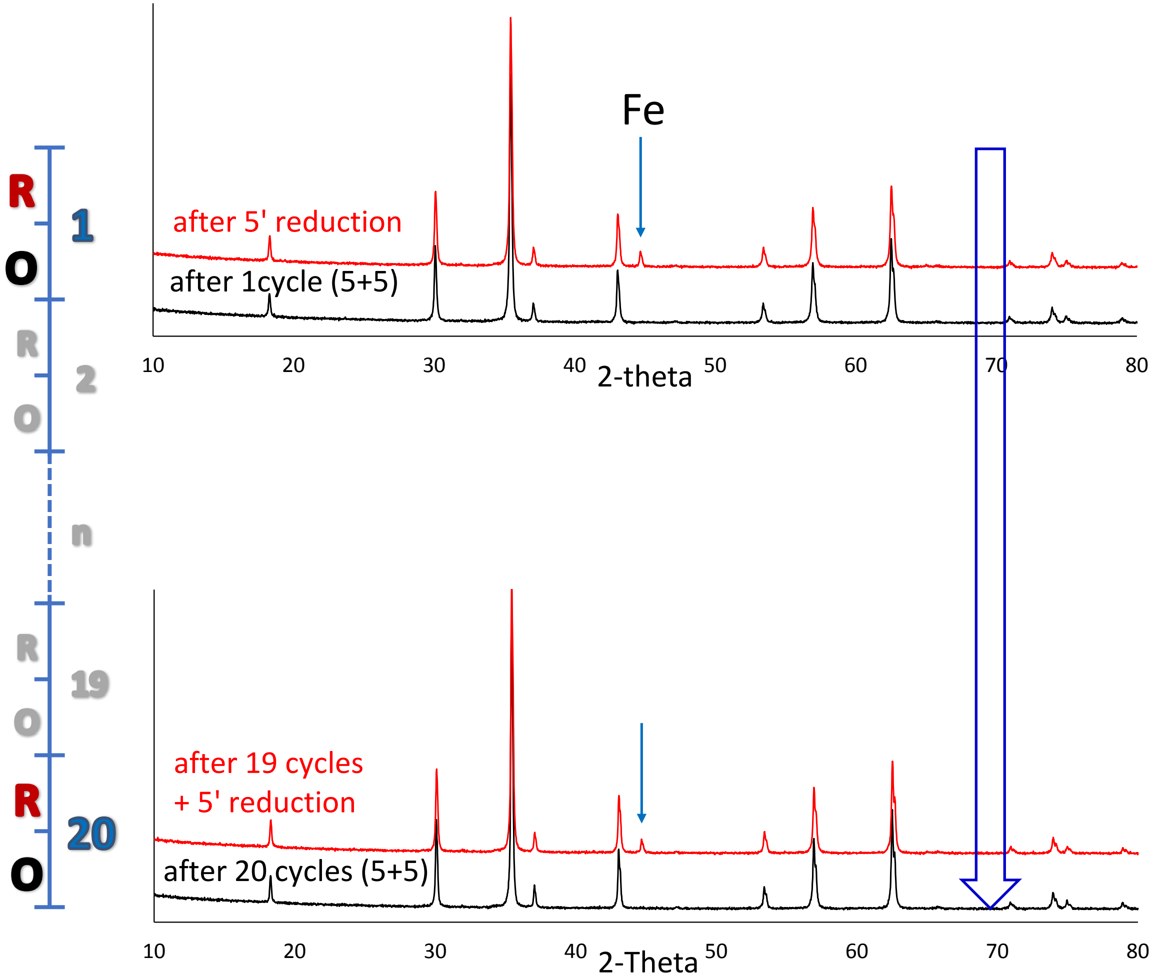
2nd step: oxidation with water



1st step: reduction with ethanol



5-min cycles (20 cycles)



No coke or **iron carbide** after reduction !

Mössbauer spectroscopy

SAMPLE	species	%
Fe_3O_4 after 5 minutes reduction	Fe^{3+}	35
	$Fe^{2,5+}$	63
	Fe^0	2
Fe_3O_4 after 1 complete cycle (5/5minutes)	Fe^{3+}	35
	$Fe^{2,5+}$	65
Fe_3O_4 after 19 cycles + 5 min reduction	Fe^{3+}	33
	$Fe^{2,5+}$	63
	Fe^0	4
Fe_3O_4 after 20 cycles	Fe^{3+}	37
	$Fe^{2,5+}$	63

With only traces of CO_2 and no CO during the second step of the cycle

20 min cycles (450°C)

Degree of reduction after 20 min

$CuFe_2O_4$ α~ 82%
$CoFe_2O_4$ α~ 82%
$Cu_{0.5}Co_{0.5}Fe_2O_4$ α~ 100%
$Cu_{0.5}Mn_{0.5}Fe_2O_4$ α~ 73%
$Co_{0.5}Mn_{0.5}Fe_2O_4$ α~ 10%
$MnFe_2O_4$ α~ 8%

Evaluation of COKE:

CHNS analysis

Sample	C $_{w\%}$(after 20 min reduction)
$CuFe_2O_4$	6.9
$CoFe_2O_4$	11.6
$Cu_{0.5}Co_{0.5}Fe_2O_4$	16.3
$Cu_{0.5}Mn_{0.5}Fe_2O_4$	6.1
$Co_{0.5}Mn_{0.5}Fe_2O_4$	1.5
$MnFe_2O_4$	1.7

Selectivity to H_2

Sample	H_2/CO_x
$CuFe_2O_4$	3
$CoFe_2O_4$	6
$Cu_{0.5}Co_{0.5}Fe_2O_4$	3
$Cu_{0.5}Mn_{0.5}Fe_2O_4$	6
$Co_{0.5}Mn_{0.5}Fe_2O_4$	15
$MnFe_2O_4$	15

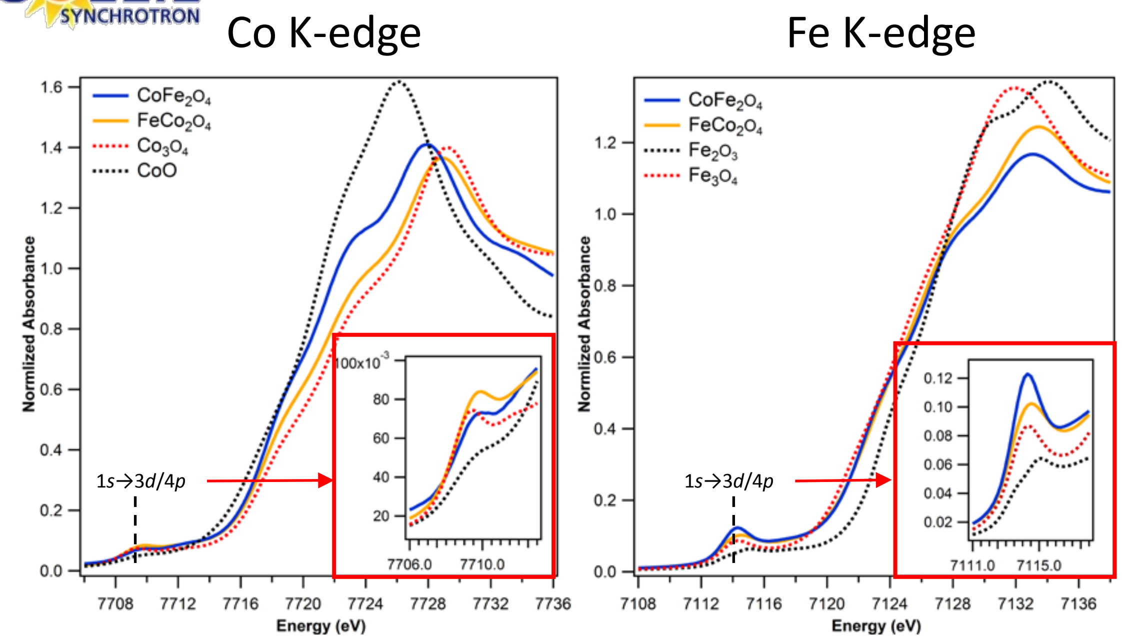
Redox properties, and more generally their catalytic activity, are strongly influenced by the nature of M and by the M^{n+} distribution among the 16 octahedral and 8 tetrahedral sites in the crystal lattice.

$[A]^{tet}[B_2]^{oct}O_4$
Normal
$\gamma = 0$

(fraction of tetrah sites occupied by B)

$[B]^{tet}[A,B]^{oct}O_4$
Inverse
$\gamma = 1$

(ex situ) **XANES** (for oxidation states)



X-ray Absorption Near-Edge Structure (XANES) spectra at Co and Fe K-edges of references and investigated materials. The spectra were collected in transmission mode.

The cation distribution was determined by **EXAFS**. The **crystallographic site occupancy is defined by the inversion parameter γ.**

Sample	γ (EXAFS)	γ (Mössbauer 80K)	SSA, m^2/g (BET)	Crystallite size, nm (XRD)	Particle size, nm (BET)
$CoFe_2O_4$	0,7	0,74	69	12	16,2
$FeCo_2O_4$	0,6	0,56	4	32	275

$CoFe_2O_4$: $[Co(II)_{0.3}Fe(III)_{0.7}]^{Tet}[Co(II)_{0.7}Fe(III)_{1.3}]^{Oct}O_4$

$FeCo_2O_4$: $[Co(II)_{0.6}Fe(III)_{0.4}]^{Tet}[Co(II)_{0.4}Fe(III)_{0.6}Co(III)_{1}]^{Oct}O_4$

Investigation of the 1st step (reduction with ethanol)

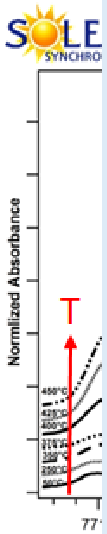
Time resolved experiments were carried out using the *QuickEXAFS procedure*, monitoring the reduction of the materials collecting a spectra every 5 seconds.

The **cobaltite** is completely reduced at a temperature lower than **ferrite**.

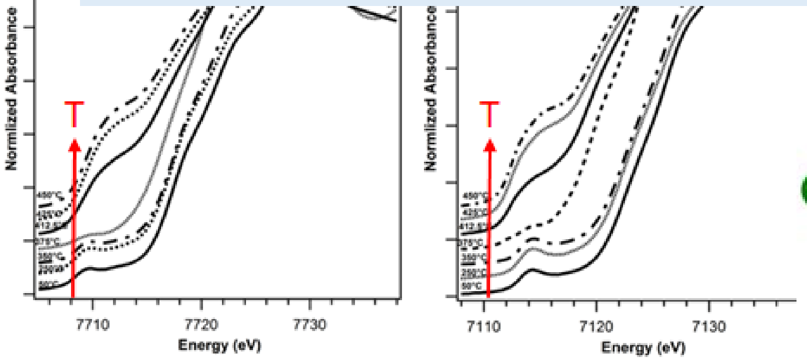
Cations in tetrahedral sites are more prone to reduction with the respect to those in **octahedral sites.**
Fe in cobaltite and Co in ferrite (cations A in AB_2O_4) are firstly totally reduced to metal phases.
Before reaching the metal phases, **CoO** is formed in **cobaltite** and **FeO** is formed in **ferrite**.

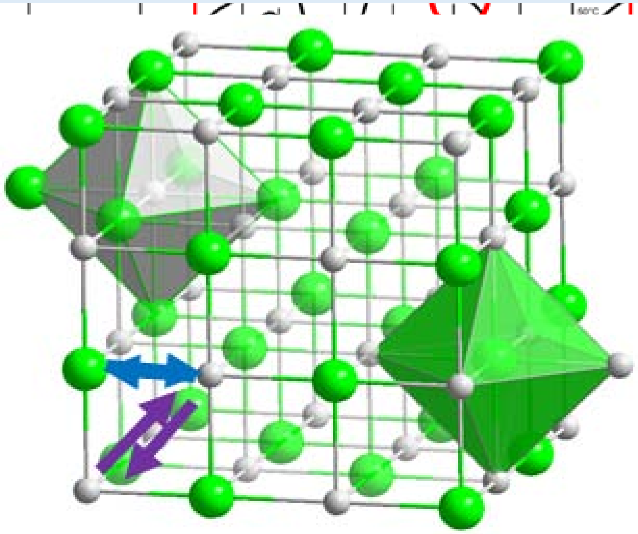
Despite the **good reducibility of $FeCo_2O_4$** imparted by the high amount of cobalt, its performance in the production of hydrogen is quite poor due to an inefficient oxidation by **water steam**, which is able to oxidize only the outer shell of the nanoparticles. In contrast, a higher iron fraction makes the system more reversible, because in this case an intermediate iron wustite phase, which is a better oxygen buffer, can be stably formed.

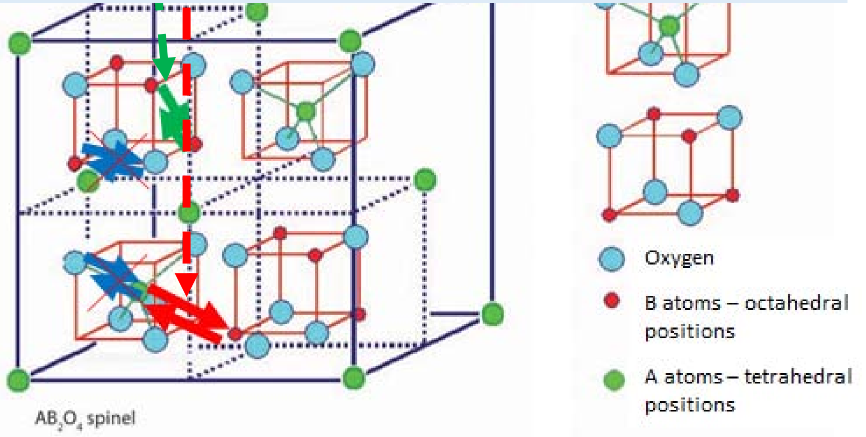
$CoFe_2O_4$

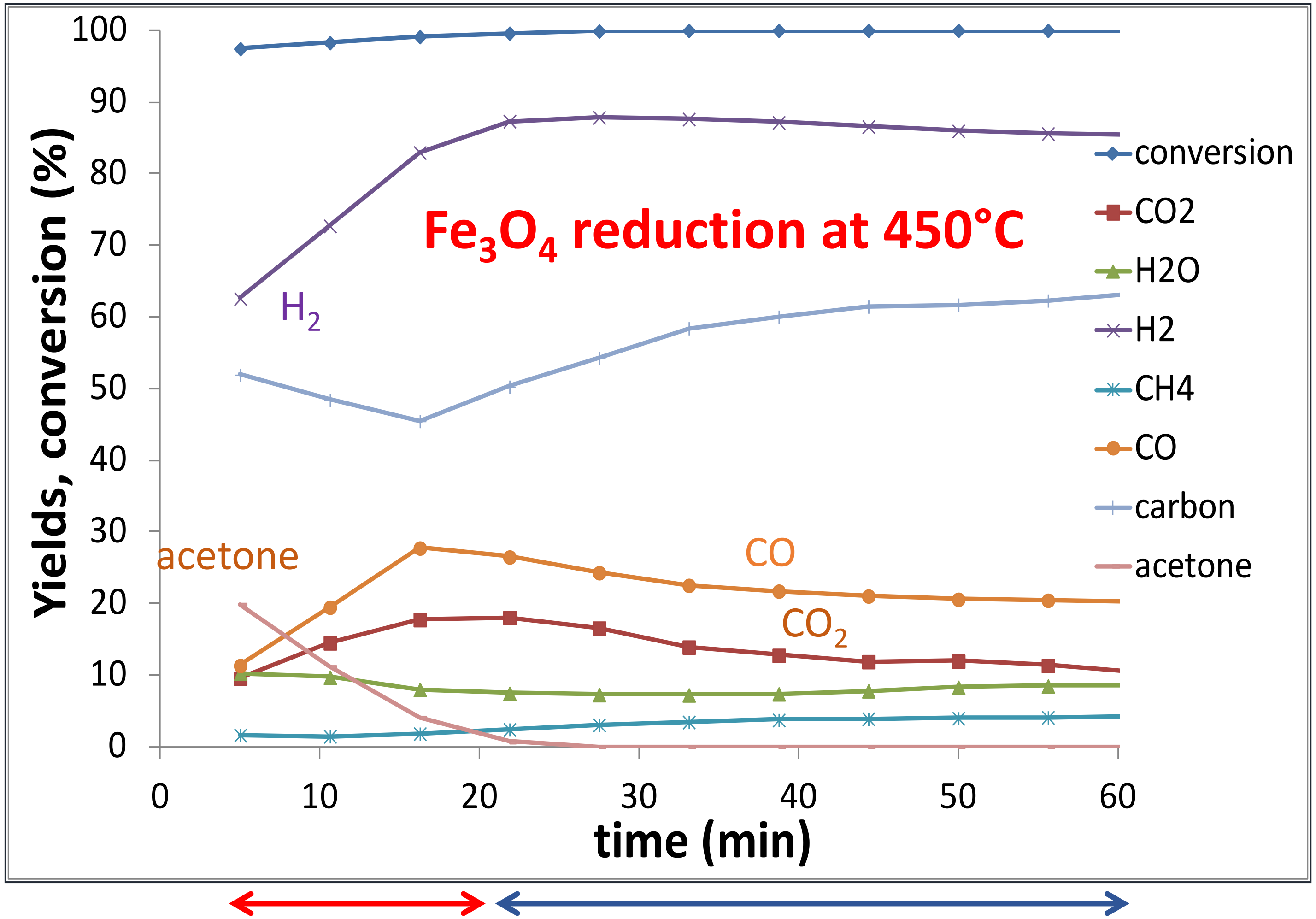


$FeCo_2O_4$









$Fe_3O_4 \rightarrow FeO \rightarrow Fe \rightarrow Fe_3C$

$Fe_3O_4 \rightarrow Fe_xO_yC \rightarrow Fe_3C$

$CH_3CH_2OH \rightarrow C + CO + 3\,H_2$

$CH_3CH_2OH \rightarrow 2\,C + H_2O + 2\,H_2$

Products formed at the beginning of the first step

Fe_3O_4: acetone (20%)

$NiFe_2O_4$: acetone (4%)

$CoFe_2O_4$: acetaldehyde and dimethylether (11%)

$CuFe_2O_4$: acetone (30%)

$MnFe_2O_4$: acetone (27%)

$Cu_{0.5}Mn_{0.5}Fe_2O_4$: acetone (40%)

$Cu_{0.5}Co_{0.5}Fe_2O_4$: acetone (30%)

Chemical-loop ethanol reforming with **short-time cycles** in order to:

- Minimise coke formation during the first step
- Produce cleaner H_2 during the second step
- Obtain higher yield to products (other than CO, CO_2, H_2 and H_2O: fuel gas)
- Also: modify catalyst composition in order to address the formation of more valuable compounds (C4)

Tools for cost saving in the production of bio-fuels: the bio-refinery concept

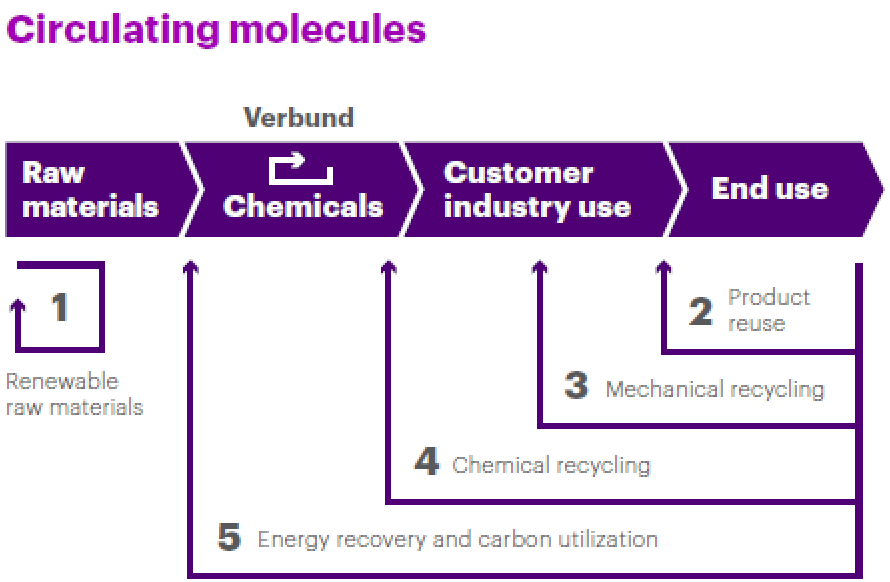
OPEX

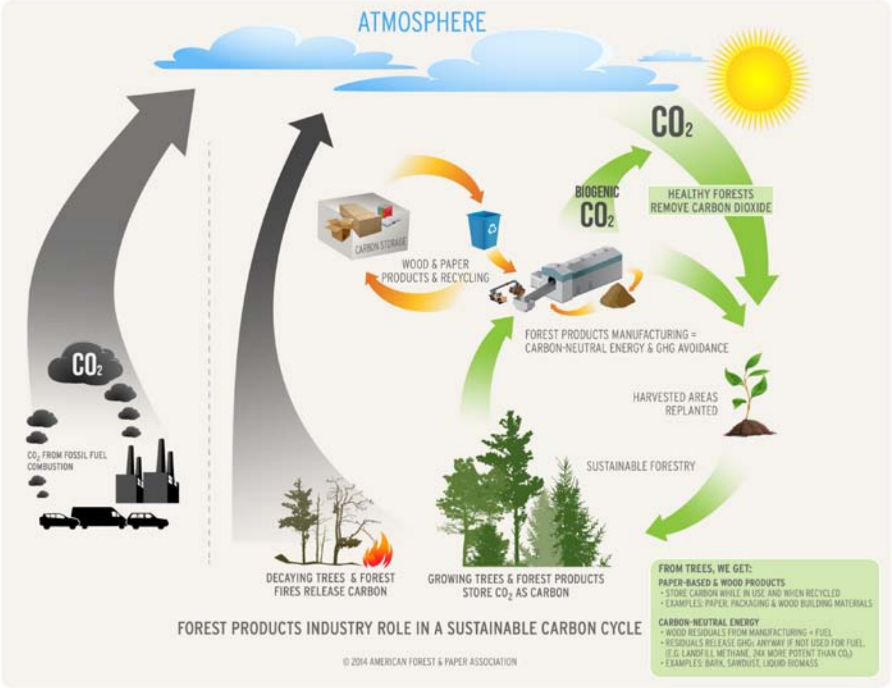
- In the **bio-refinery**, the production of both **bio-fuels** and **bio-chemicals** should be integrated
- **By-products** and **co-products** should also be valorised (***close the cycle*** in the exploitation of raw materials, in the recovery and reuse of by-products and wastes: **Circular Economy**)
- Technologies should be designed in such a way to follow the **Green Chemistry** and **Green Engineering rules**

CAPEX

- A **multifunctional approach**, in order to lower the number of steps in complex transformations
- In order to lower investment costs, adopt the **co-location principle**

A low-Carbon energy (and chemical) industry





FROM TREES, WE GET:

PAPER-BASED & WOOD PRODUCTS
- STORE CARBON WHILE IN USE AND WHEN RECYCLED
- EXAMPLES: PAPER, PACKAGING & WOOD BUILDING MATERIALS

CARBON-NEUTRAL ENERGY
- WOOD RESIDUALS FROM MANUFACTURING = FUEL
- RESIDUALS RELEASE GHGs ANYWAY IF NOT USED FOR FUEL (E.G. LANDFILL METHANE, 24X MORE POTENT THAN CO_2)
- EXAMPLES: BARK, SAWDUST, LIQUID BIOMASS

FOREST PRODUCTS INDUSTRY ROLE IN A SUSTAINABLE CARBON CYCLE

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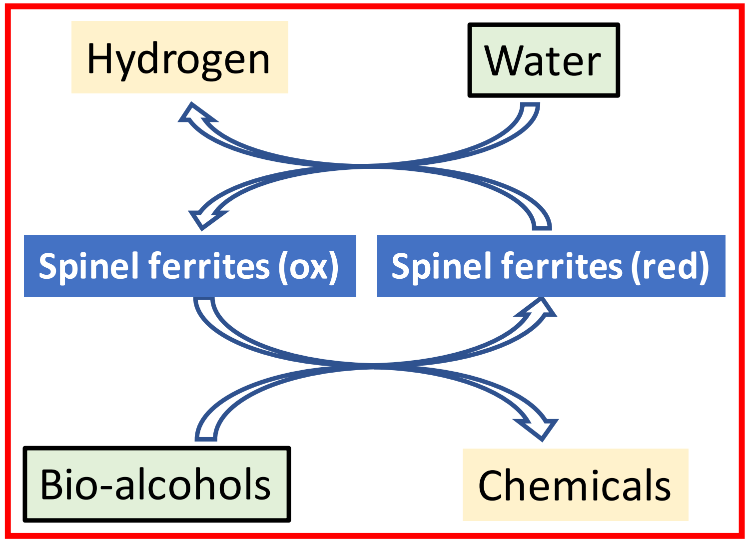
The value-chain for energy production: Bio-fuels and chemicals



Hydrogen

Water

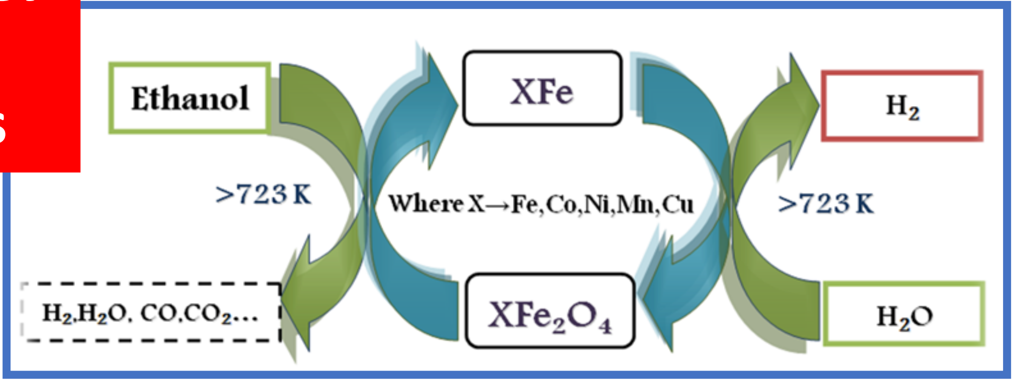
Spinel ferrites (ox)

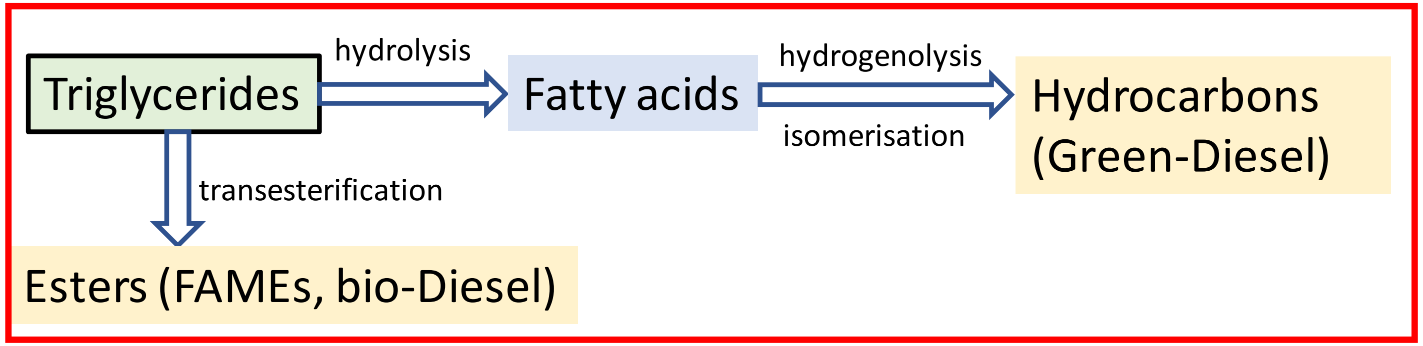
Spinel ferrites (red)

Bio-alcohols

Chemicals

Acetone
C4 chemicals





Triglycerides

hydrolysis

Fatty acids

hydrogenolysis

isomerisation

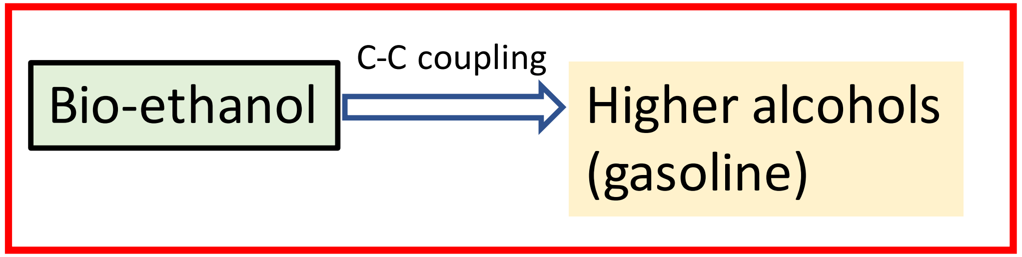
Hydrocarbons
(Green-Diesel)

transesterification

Esters (FAMEs, bio-Diesel)

glycerol

Co-product



Bio-ethanol

C-C coupling

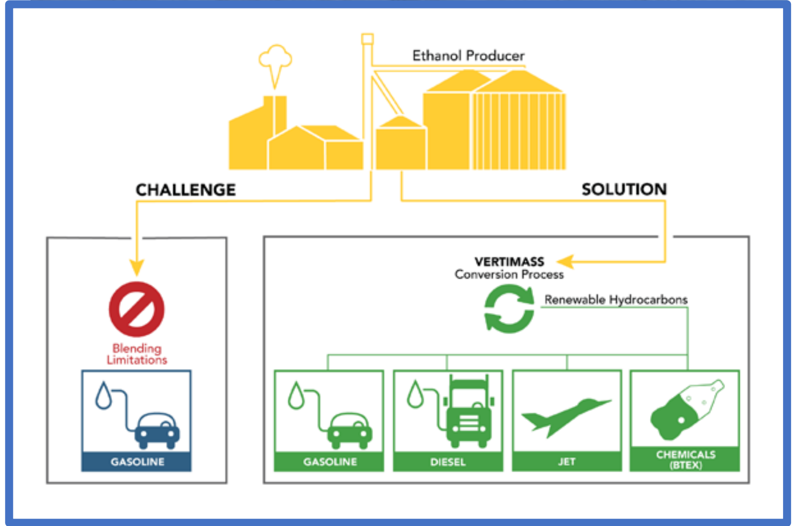
Higher alcohols
(gasoline)

1-butanol

By-product

butadiene

By-product



Bio-acrylic acid

ca 5 M tons/year

NIPPON SHOKUBAI

ARKEMA
INNOVATIVE CHEMISTRY

Other technologies by Metabolix, Novomer, Genomatica…

Myriant

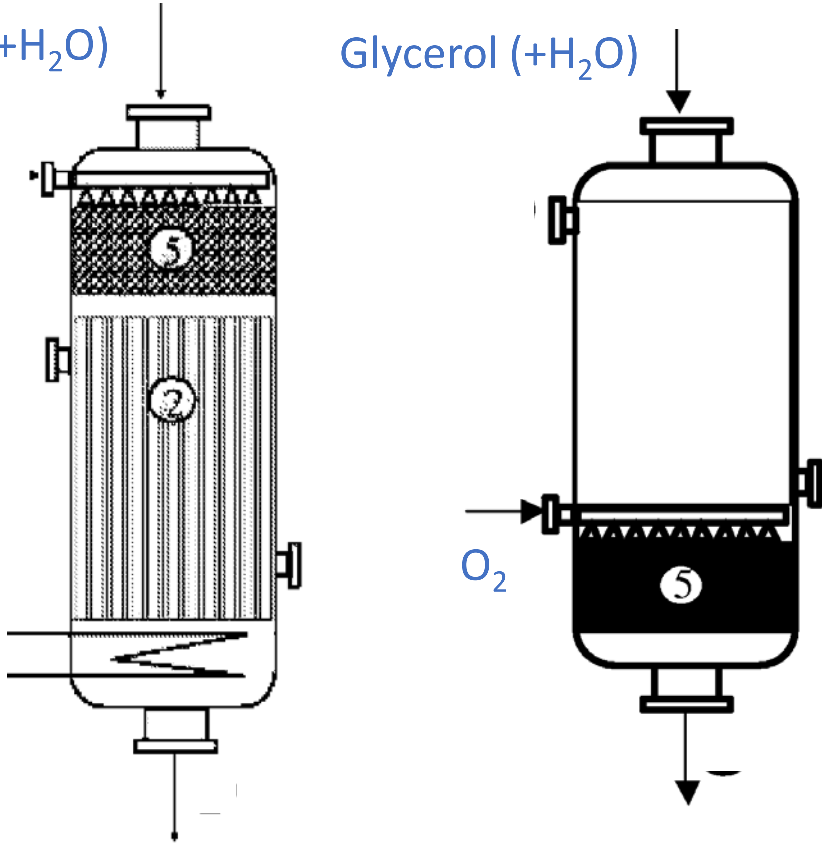
SGA Polymers
Green Acrylic Products

opxbio good chemistry.

DOW

BASF
Cargill
novozymes

Two-step process (in a single vessel)



Glycerol + O_2 (+H_2O)

Glycerol (+H_2O)

Acid catalyst for glycerol dehydration to acrolein (Zr/W/O)

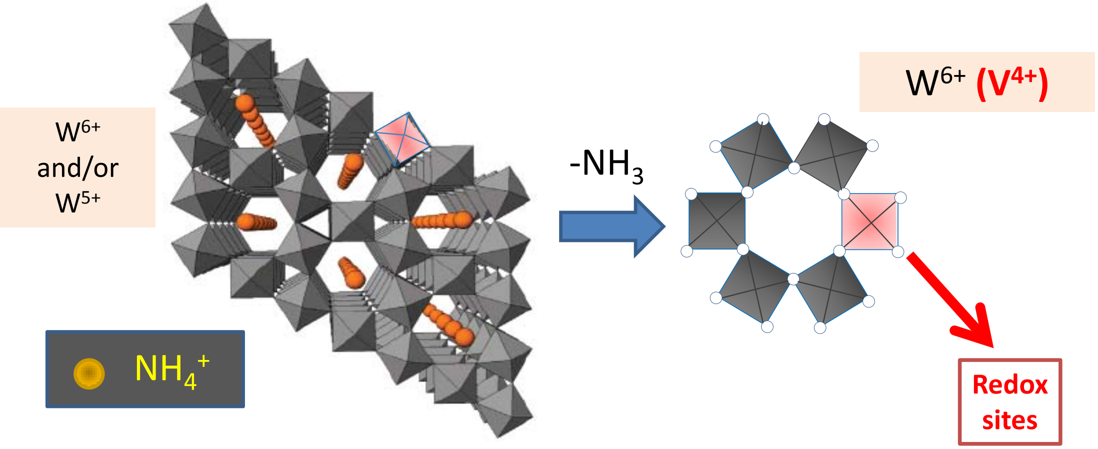
Redox catalyst for acrolein oxidation to acrylic acid (Mo/V/W/O)

O_2

Patents by Arkema

Acrylic acid (+ by-products)

One-pot process (with a single catalyst)



HEXAGONAL TUNGSTEN BRONZES: W/V/O

Chieregato et al, **Appl. Catal. B** 2014
Chieregato et al, **ChemSusChem** 2015
Cespi et al, **Green Chemistry** 2015
Chieregato et al, **Coord Chem Rev** 2015
Soriano et al, **Topics Catal** 2016
Chieregato et al, **ChemSusChem** 2017


Claudia Bandinelli

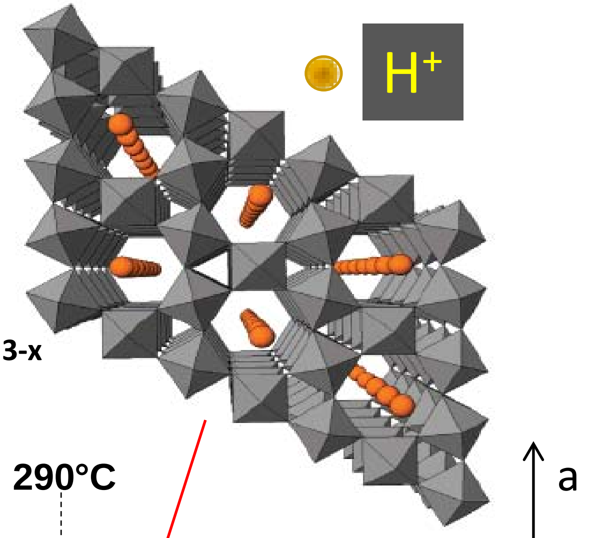

Alessandro Chieregato

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

Total Acidity: **135** μmolNH_3 g^{-1}

BAS/LAS: **33**

Surface area: 31 m^2/g



h-WO_{3-x}

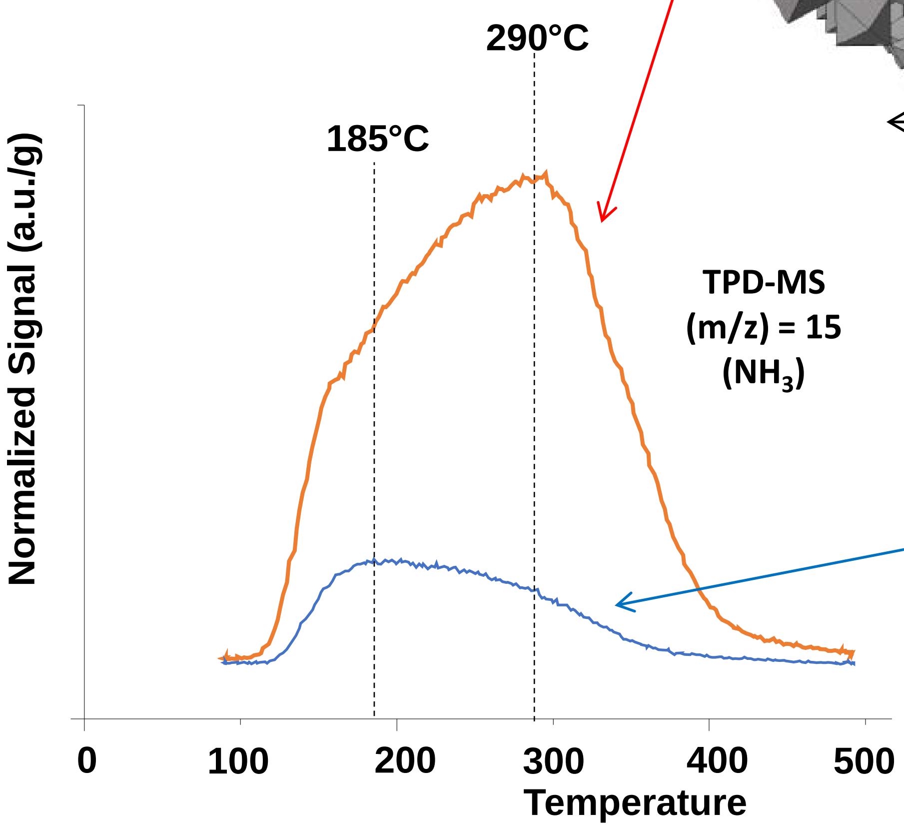
Lewis Acid

W^{n+}

$\xrightarrow{+H_2O}$

Brønsted Acid

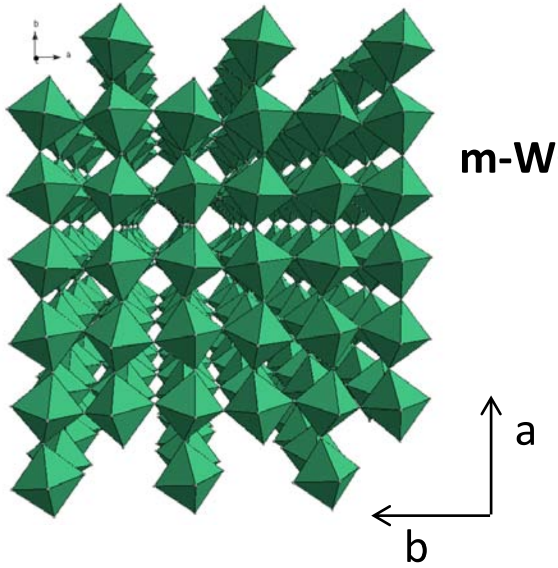
$-W^{n+}-OH$



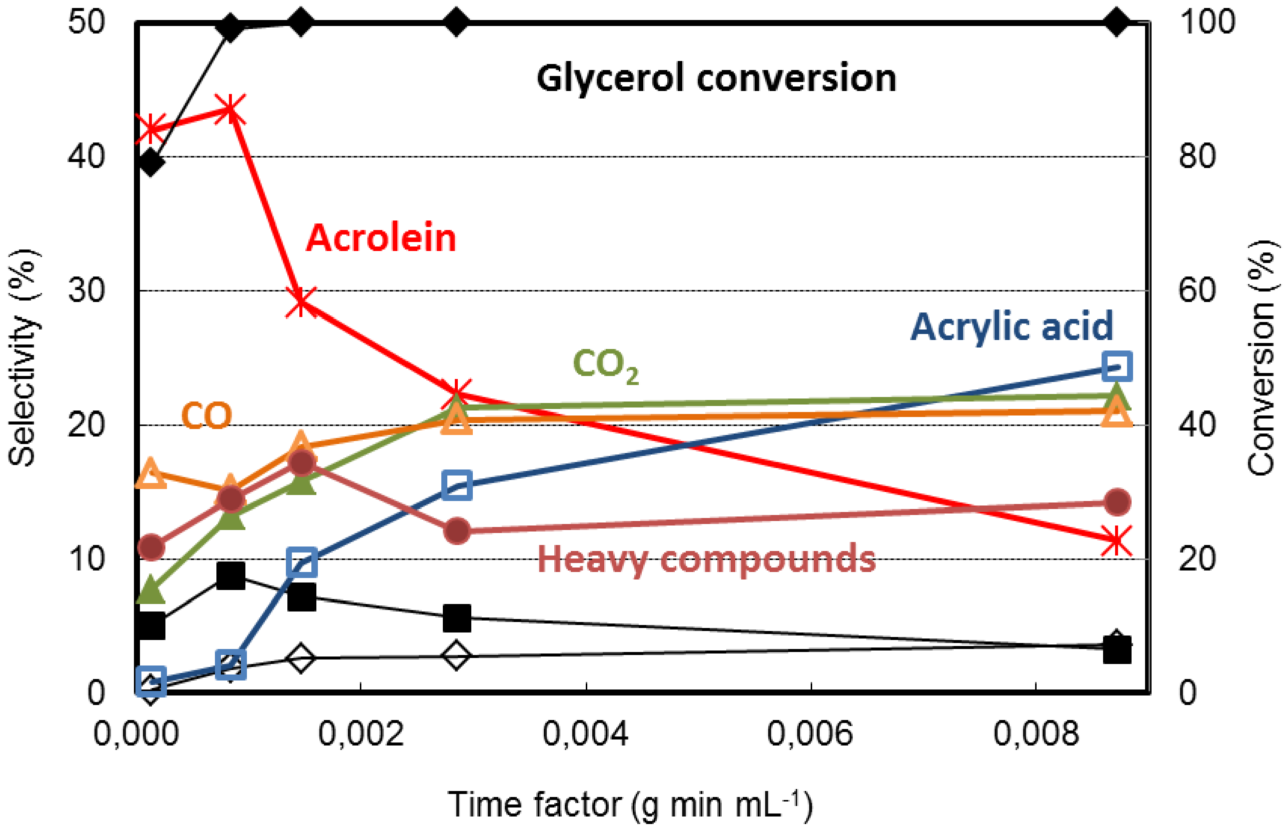
Total Acidity: **23** μmolNH_3 g^{-1}

BAS/LAS: **7**

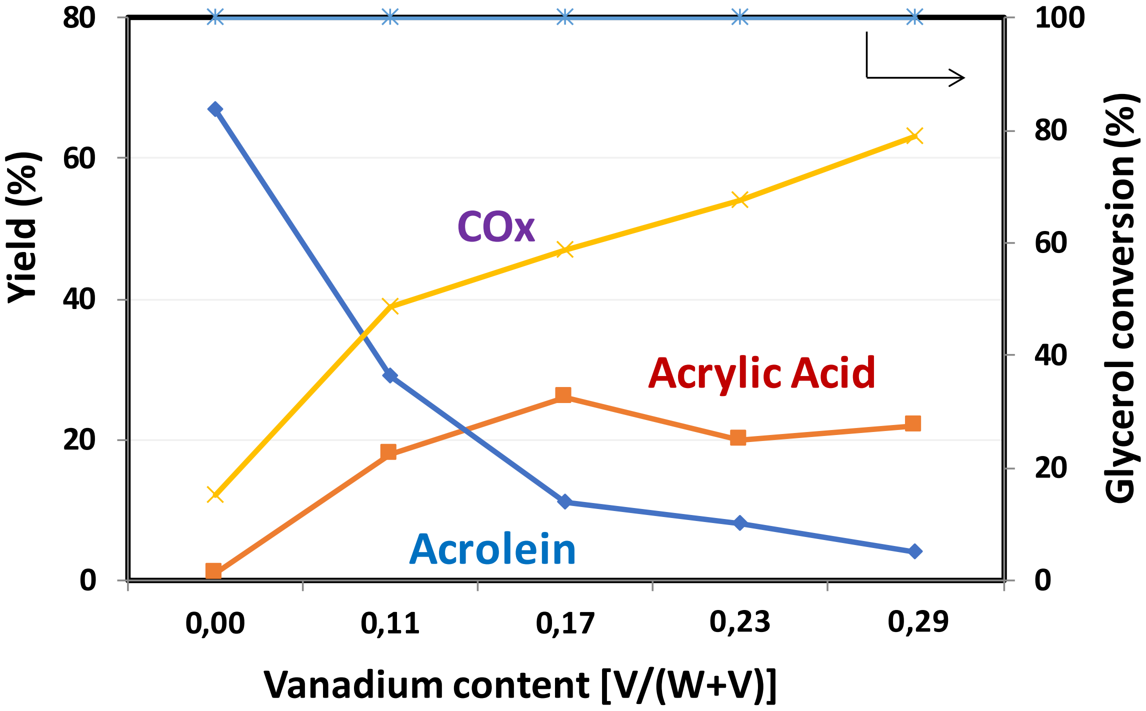
Surface area: 2 m^2/g



m-WO_3



W1V0.2, T 318°C, feed 2% glycerol 4% oxygen, 54% steam



Conditions: 290 °C, Tau 0.4 s,
feed: Gly-Ox-H_2O = 2-4-40 %mol

Best yield from glycerol:
26% AA + 10% acrolein
Sample composition: $W_1V_{0.17}O_X$ **Feed (Gly/O2/H_2O) : 2/4/40**

W-V-Nb-O Hexagonal Tungsten bronze (monophasic)

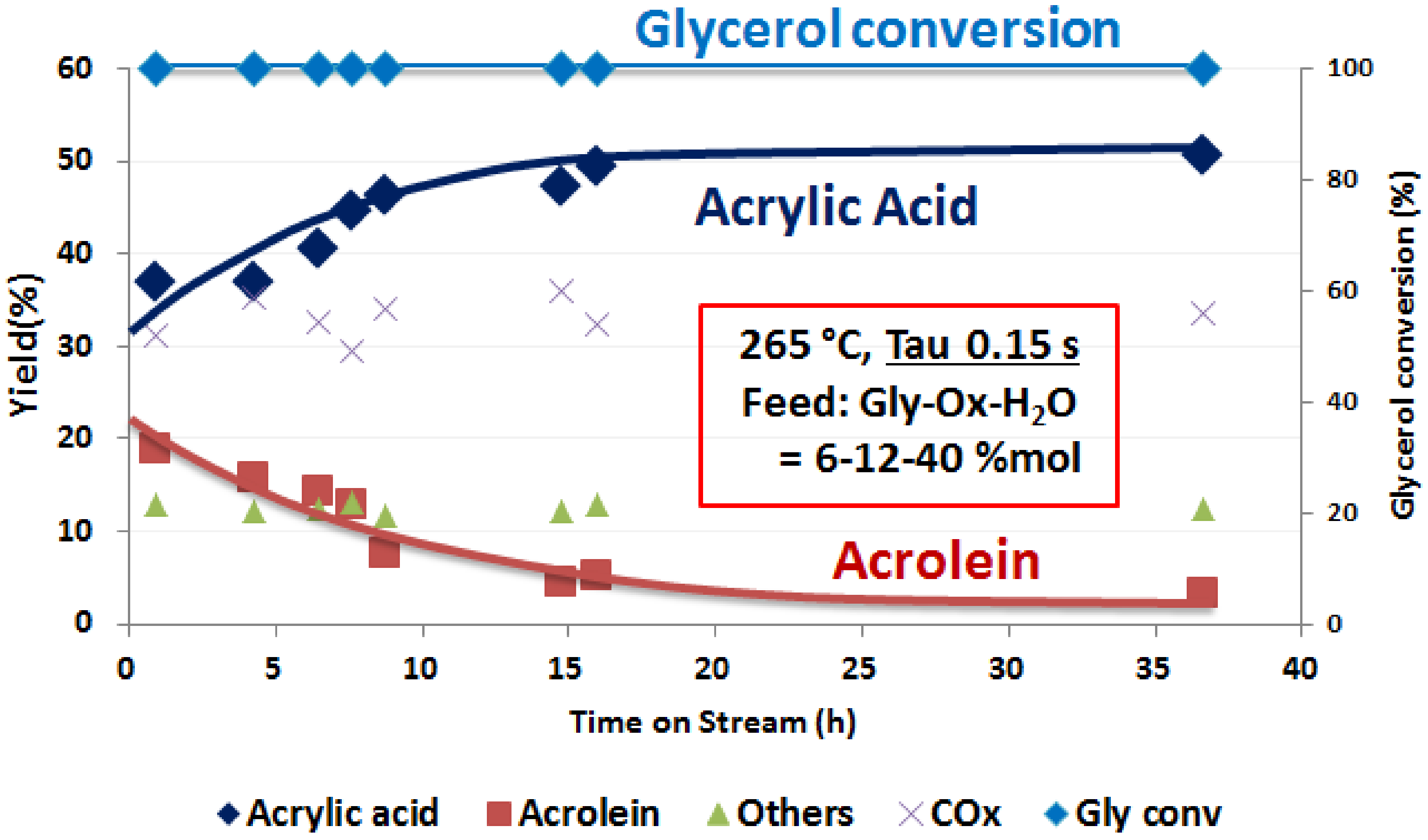
Catalyst	Acrolein Yield (%)	Acrylic Acid Yield (%)	Temperature (°C)	Residence Time (s)	Productivity (A+AA) $\frac{Kg}{L_{CT} * day}$
W-V	10	26	300	0.38	4
W-V-Nb	18	33	290	0.15	16

Tests with oxygen

Surface area of **W-V** HTB: **20** m^2/g

Surface area of **W-V-Nb** HTB: **57** m^2/g

$W_1V_{0.20}Nb_{0.15}O_x$



265 °C, Tau 0.15 s

Feed: Gly-Ox-H_2O

= 6-12-40 %mol


existing carbohydrate feedstocks


emergent lignocellulosic feedstocks

Bio-ethanol

C-C coupling

Higher alcohols (gasoline)

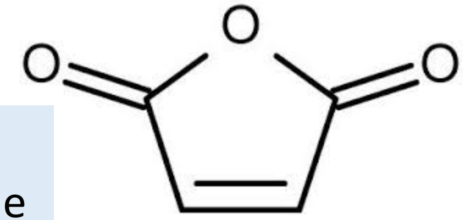
1-butanol

butadiene

Elastomers

oxidation

Maleic anhydride



n-butane

Fuels

Natural gas, shale gas

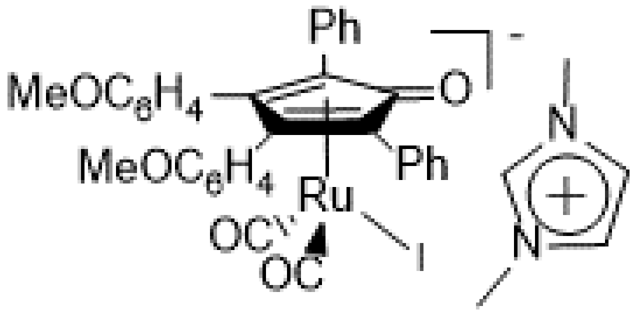
Guerbet reaction

Bio-ethanol → C-C coupling → Higher alcohols (gasoline)

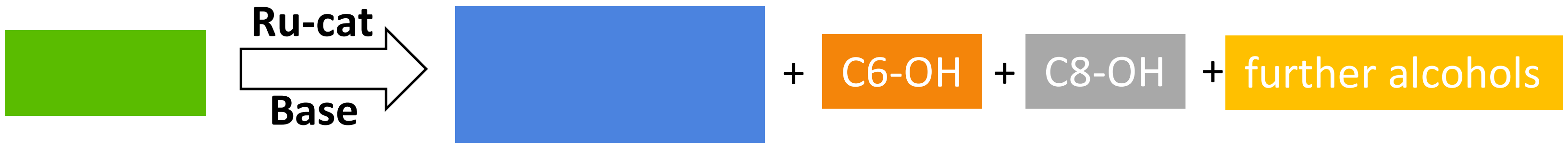
→ Higher alcohols

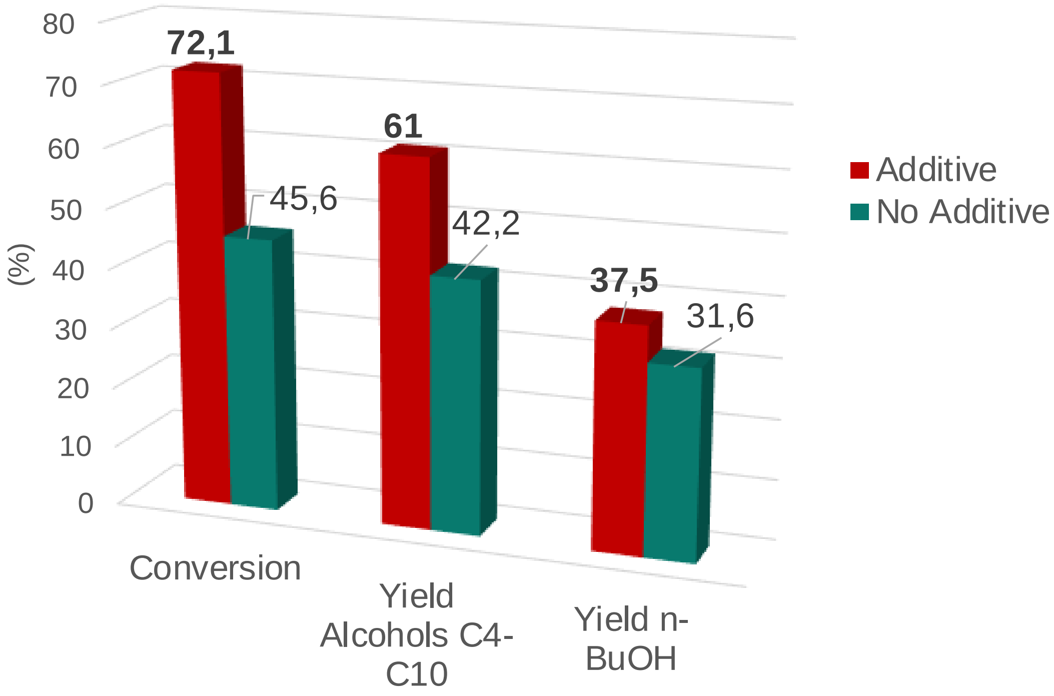
- ✓ Sustainable feedstock;
- ✓ Solventless;
- ✓ H_2 efficiency = 100%;

Guerbet Reaction in our conditions



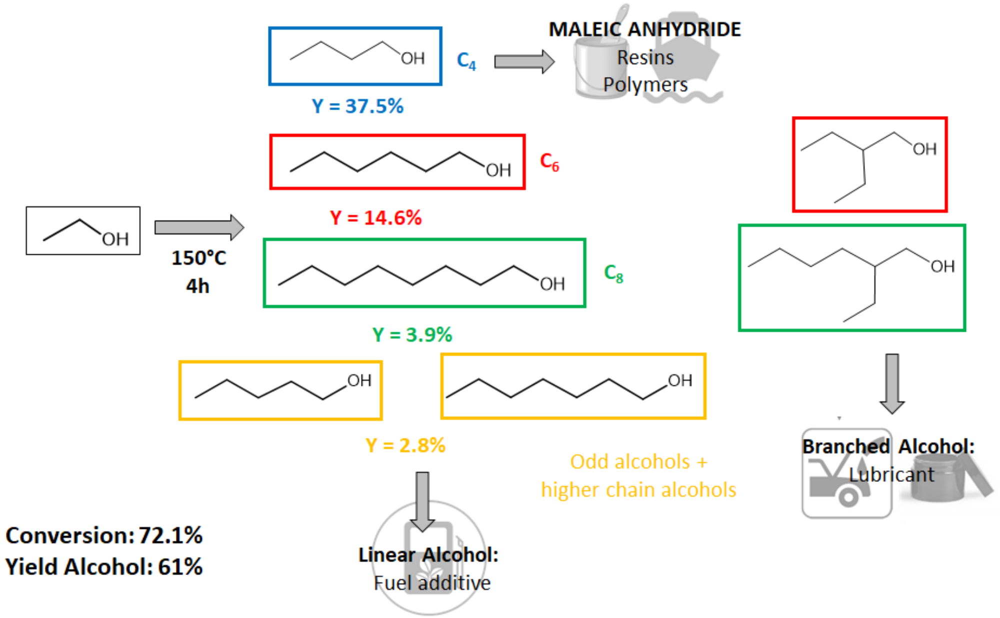
BEST REACTION CONDITIONS: T = 150 °C; AUTOGENIC PRESSURE; Ru-cat 0.2%; t = 4h; NaOEt = 20%.





Catalyst **3**: 0.2%mol, NaOEt 20%mol, Additive: 1.5%mol.

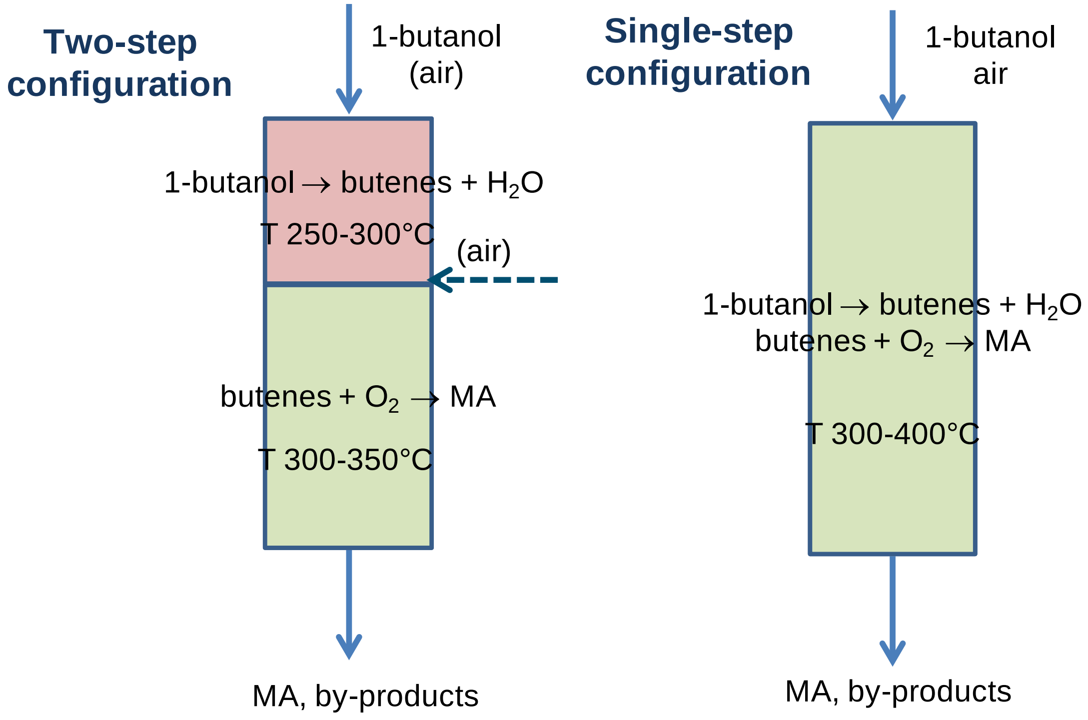
Mazzoni et al, **ACS Sustainable Chem. Eng.** 2019



Conversion: 72.1%
Yield Alcohol: 61%

In collaboration with the team of
Valerio Zanotti
Rita Mazzoni
and coworkers

Maleic anhydride from bio-butanol



Two-step configuration

1-butanol (air)

1-butanol → butenes + H_2O

T 250-300°C

(air)

butenes + O_2 → MA

T 300-350°C

MA, by-products

Single-step configuration

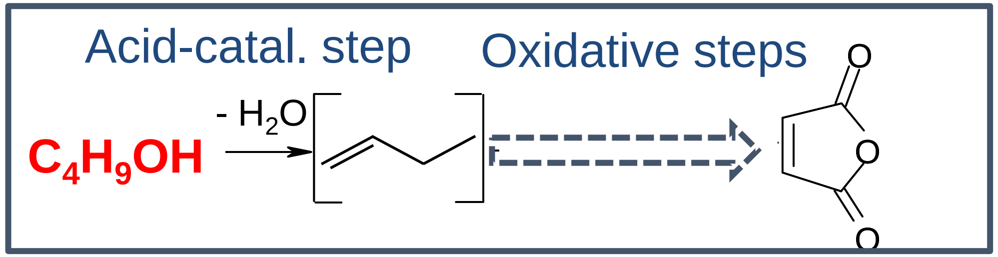
1-butanol air

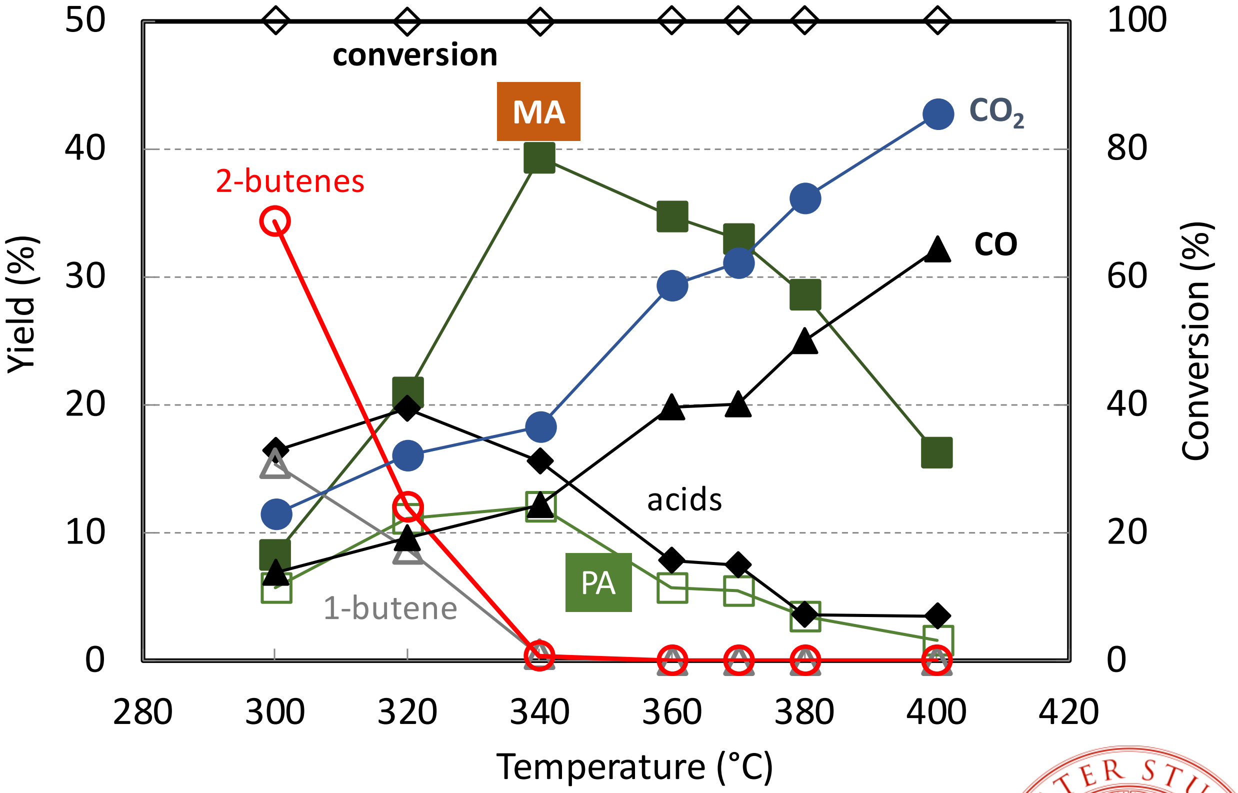
1-butanol → butenes + H_2O

butenes + O_2 → MA

T 300-400°C

MA, by-products



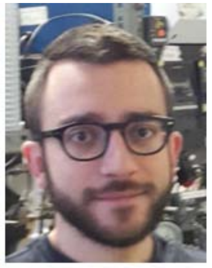


Reaction conditions: 1% 1-butanol in air, W/F 1,3 g· s/mL

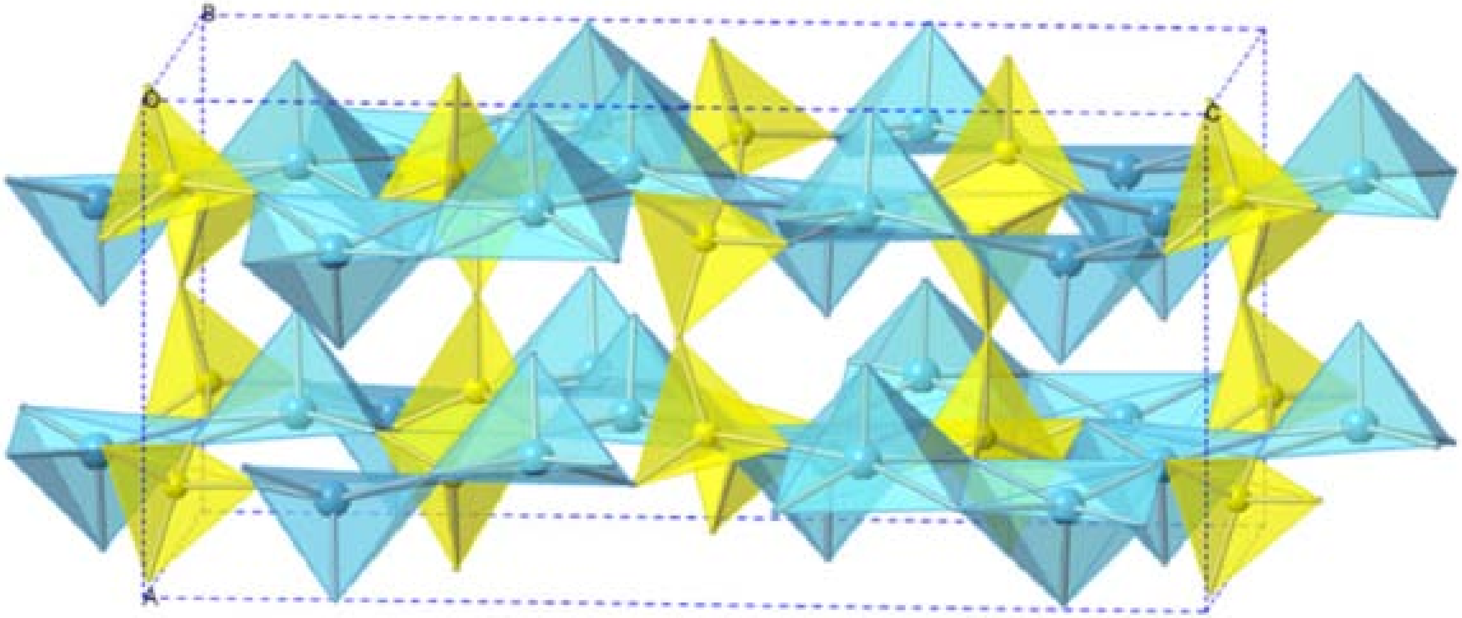
Pavarelli et al, ChemSusChem 2015, 8, 2250

Giulia Pavarelli

Aurora Caldarelli



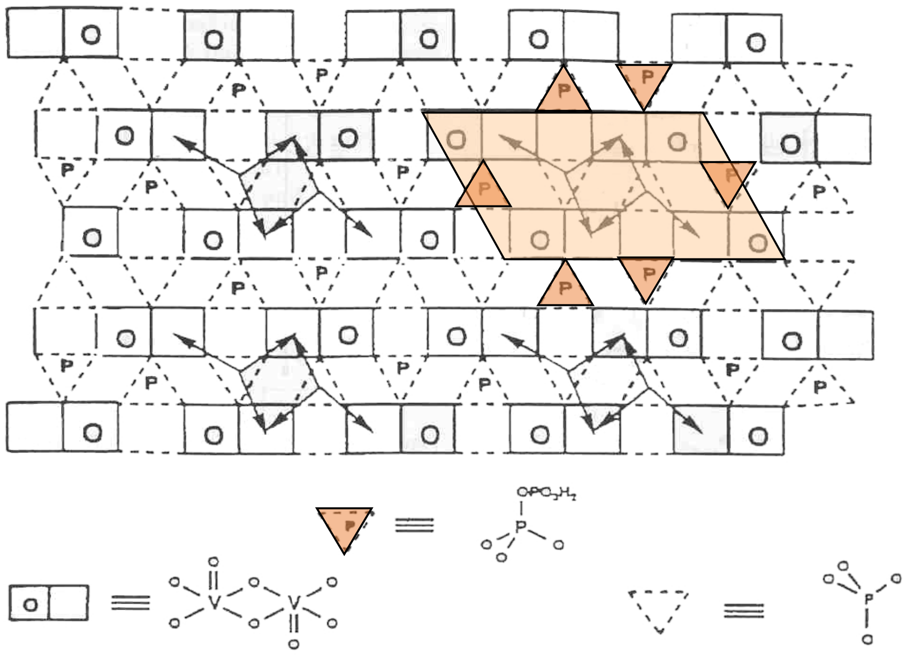
Francesco Puzzo

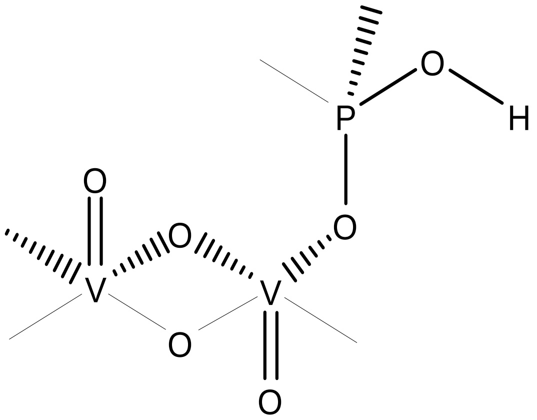


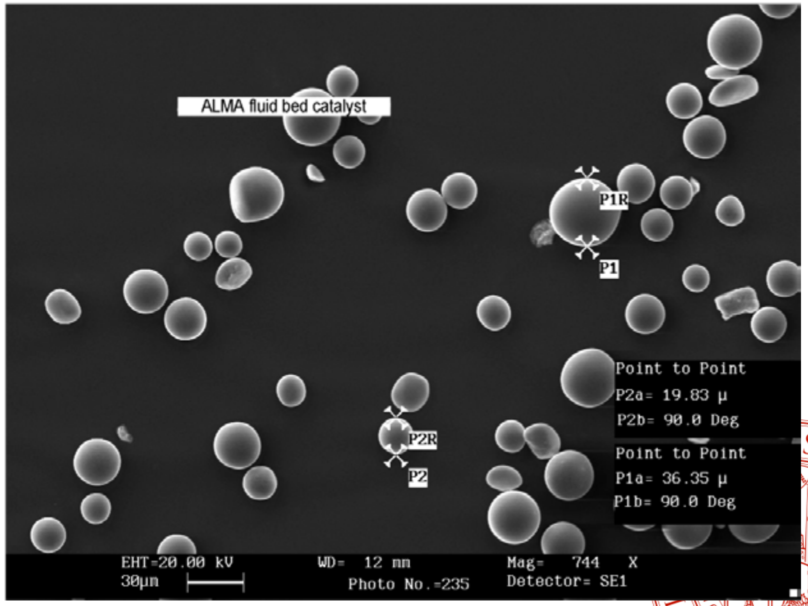
$(VO)_2P_2O_7$ catalyst

V redox properties

Surface acidity



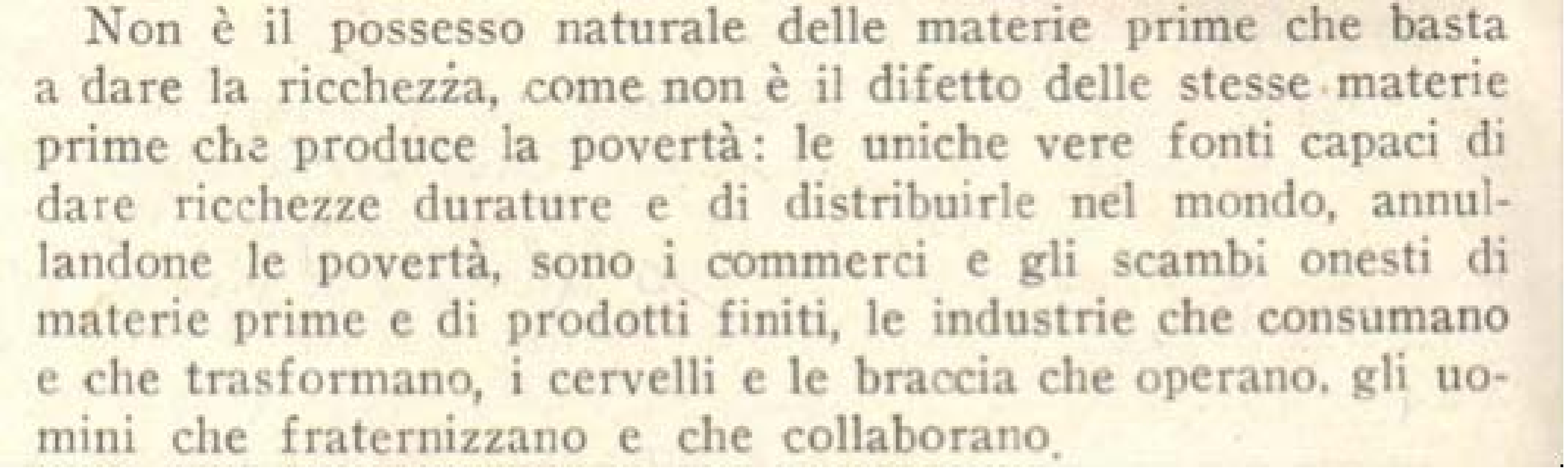




Point to Point
P2a= 19.83 µ
P2b= 90.0 Deg

Point to Point
P1a= 36.35 µ
P1b= 90.0 Deg

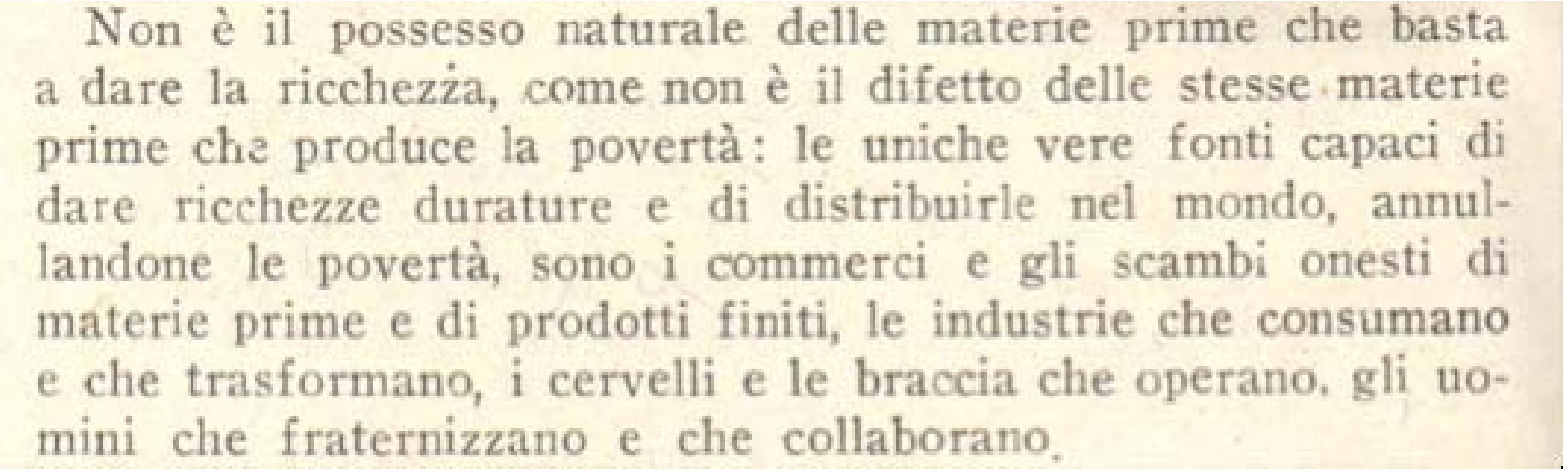
EHT=20.00 kV
30µm
WD= 12 mm
Photo No.=235
Mag= 744 X
Detector= SE1



Non è il possesso naturale delle materie prime che basta a dare la ricchezza, come non è il difetto delle stesse materie prime che produce la povertà: le uniche vere fonti capaci di dare ricchezze durature e di distribuirle nel mondo, annullandone le povertà, sono i commerci e gli scambi onesti di materie prime e di prodotti finiti, le industrie che consumano e che trasformano, i cervelli e le braccia che operano, gli uomini che fraternizzano e che collaborano.

MARIO GIACOMO LEVI, *L'industria chimica italiana e le possibilità del suo avvenire,* in "La chimica e l'industria", Milano, novembre-dicembre 1945, anno XXVII, nn. 11-12, pp. 189-195

It is not the possession of natural raw materials that is sufficient to give the richness, as is not the defect of the same raw materials that produces poverty: the only true sources capable of giving lasting riches and distributing them in the world, eliminating poverty, are the trade and honest exchanges of raw materials and finished products, the industries that consume and transform, the brains and the arms that work, the men who fraternize and work together



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R. SCUOLA SUPERIORE DI CHIMICA INDUSTRIALE
annessa alla R. Università ed alla R. Scuola d'Applicazione per gli Ingegneri
DI BOLOGNA

ANNO I
1921-1922

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