A Unique Chemical Infrastructure Complex for Developing and Scaling Up High-Tech Processes of Renewable Feedstock Conversion into Valuable Products

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An urgent social challenge for chemists:

To create new raw materials basis for the sustainable development

An important task: how to convert available renewable feedstock (mainly biomass or the primary products of biotechnology and forest chemistry) into valuable products?

The aim of the presentation:

To attract attention of possible EC partners to the existing infrastructure of the Boreskov Institute of Catalysis which can be used for the development, demonstration and scaling up new high-tech processes of the conversion of renewable feedstock into valuable chemical products

United Institute of Catalysis (UIC)
(established in 1997)

UIC

Boreskov Institute of Catalysis
(established in 1958)

Institute for Hydrocarbon Processing (Omsk)
(established in 2004)

Leading institute
(Novosibirsk)

St-Petersburg Division

Volgograd Division

***Personnel*: overall 1300 including 450 researchers**

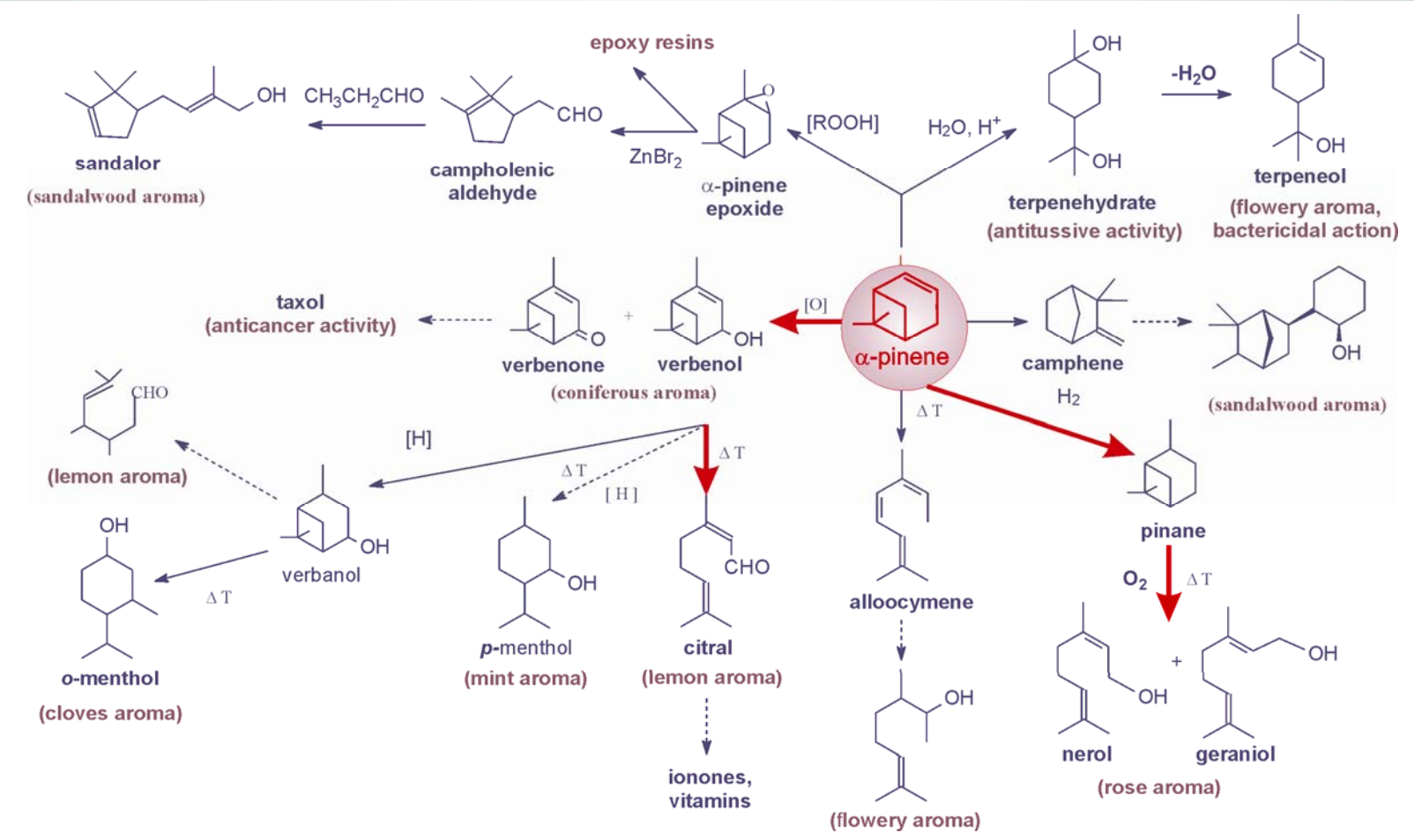
- ***Pilot plant for fine synthesis***
- ***Pilot Plant for Technical Carbon Preparation***
- ***Pilot Plant for Catalysts and Adsorbents Preparation***

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

- Transformation of α-pinene
- Transformation of lactic acid
- Transformation of starch
- Transformation of tallic acids
- Transformation of rice husk and other large-ash-biomass
- Utilization of bioethanol
- Hydrogenation of vegetable-oils
- Production of biodiesel

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Transformation of α-pinene

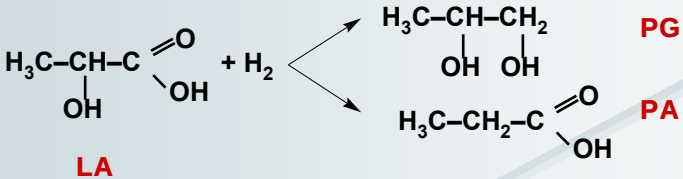


α-pinene is the main component of available pine-tar oil

Dr. N.V. Maksimchuk

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Transformation of lactic acid



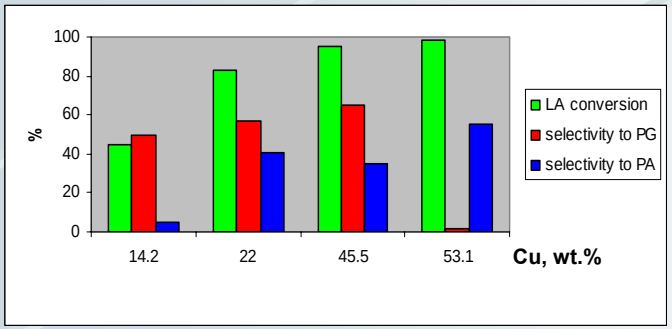
Commercial production of propylene glycol, PG, is currently petroleum-based and involves the high pressure and high temperature hydrolysis of propylene oxide. A catalytic method starting from *lactic acid* obtained by fermentation of crude biomass is a perspective way PG synthesis

PROPYLENE GLYCOL, PG

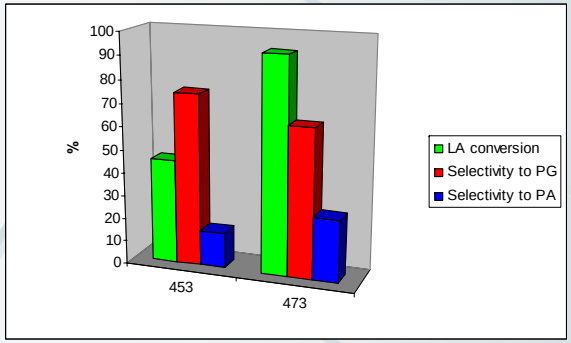
Annual world production ~ 1.5–2 million tons with growth 5 to 7 % per year

Application

Polymer production (45 %)
Detergent production (7 %)
Nontoxic anifreeze (5 %)
Plasticizing agent, solvent
Cosmetics, Pharmaceutics



Effect of copper loading on catalytic properties of Cu/SiO_2. Reaction conditions: T = 180 °C, $P(H_2)$ = 1 bar WHSV = 0,08 h^{-1}



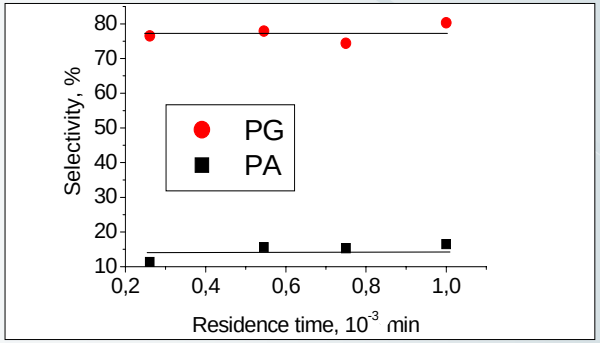
Effect of temperature on catalytic properties of 50 at. % Cu/SiO_2 catalyst Reaction conditions: $P(H_2)$ = 1 bar WHSV = 0,08 h^{-1}

Catalytic activity and selectivity of catalysts in lactic acid hydrogenation Reaction conditions: T = 473 K, $P(H_2)$ = 1 bar, WHSV = 0,08 h^{-1}

Process parameter	10 wt.% Cu/SiO_2 [1]	45,5 wt.% Cu-Si [2]
Lactic acid conversion, %	7,3	95
Selectivity to propylene glycol, %	75	65

1. R.D. Cortright et al. Applied Catalysis B 39 (2002) 353-359

2. I.L. Simakova et al., Pat. RF 2290994

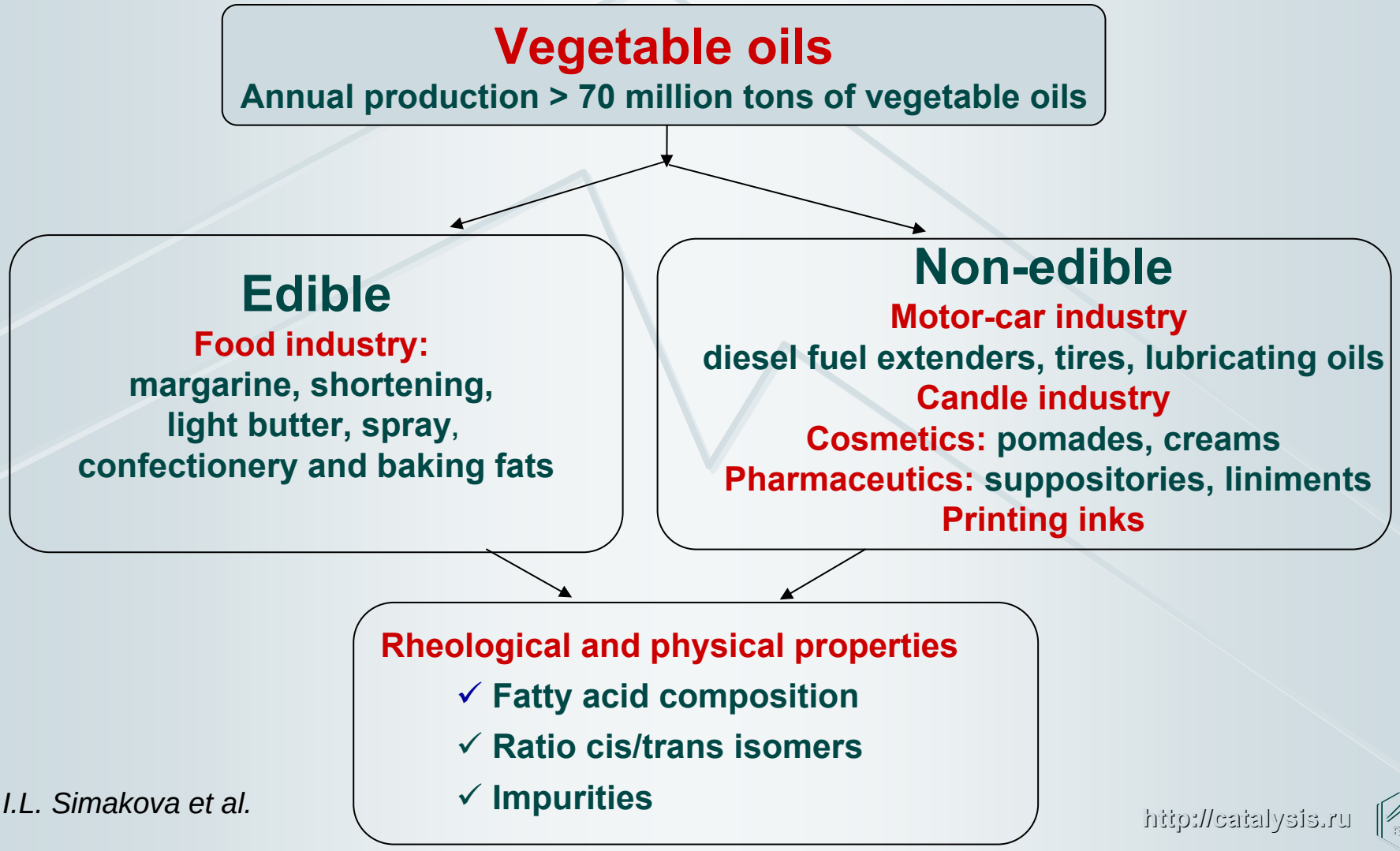


Effect of contact time on PG and PA selectivity Reaction conditions: 50 at.% Cu/SiO_2 T = 180 °C $p(H_2)$ = 1 bar WHSV = 0,06–0,23 h^{-1}

Dr. I.L. Simakova et al.

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

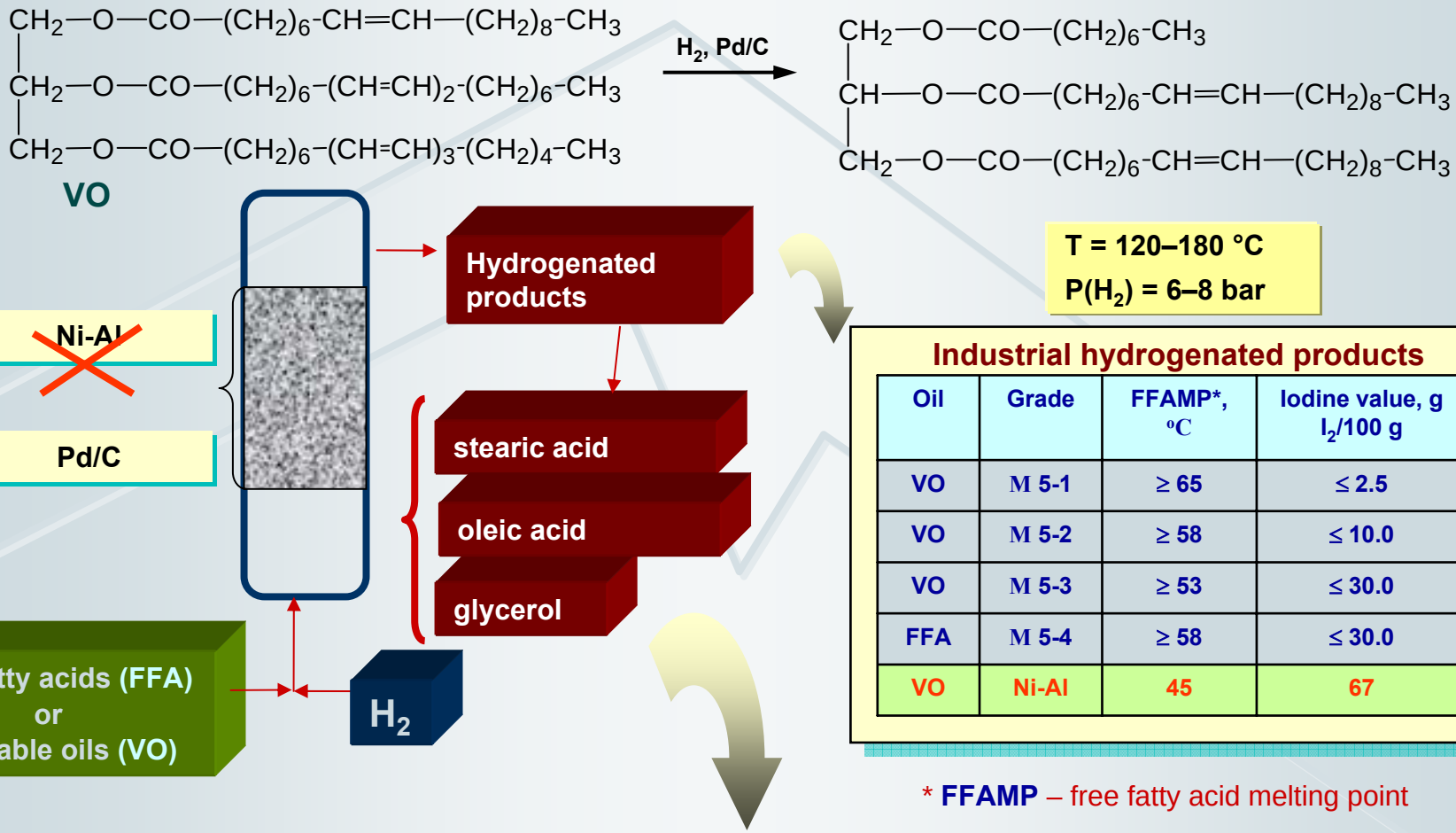
Valorization of vegetable oil resources: vegetable oils and free fatty acids hydrogenation



Dr. I.L. Simakova et al.

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Vegetable oil hydrogenation



Industrial hydrogenated products

Oil	Grade	FFAMP*, °C	Iodine value, g I_2/100 g
VO	M 5-1	≥ 65	≤ 2.5
VO	M 5-2	≥ 58	≤ 10.0
VO	M 5-3	≥ 53	≤ 30.0
FFA	M 5-4	≥ 58	≤ 30.0
VO	Ni-Al	45	67

* **FFAMP** – free fatty acid melting point

The aim – to develop hydroprocessing of vegetable oil feedstock in form free fatty acids and triglycerides over Pd/C to product non-edible partial or total saturated fatty acids

Dr. I.L. Simakova et al.

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Biotechnologies for the production of food additives

Treacle from corn, wheat and potato starch

Biocatalyst *«Glucoamylase on Sibunit™»*

(ready for scaling up)

Invert sugar sweetener from beet and cane sugar

Biocatalyst *«Baker yeast membranes on Sapropel»*

(ready for scaling up)

Glucose-fructose syrups from glucose (dextrose) syrup

Biocatalyst *«Non-growing intact bacteria Arthrobacter sp.»*

(in progress)

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Contribution of BIC to modern technology of starch conversion

Starch suspension (40 %)
100–110 °C

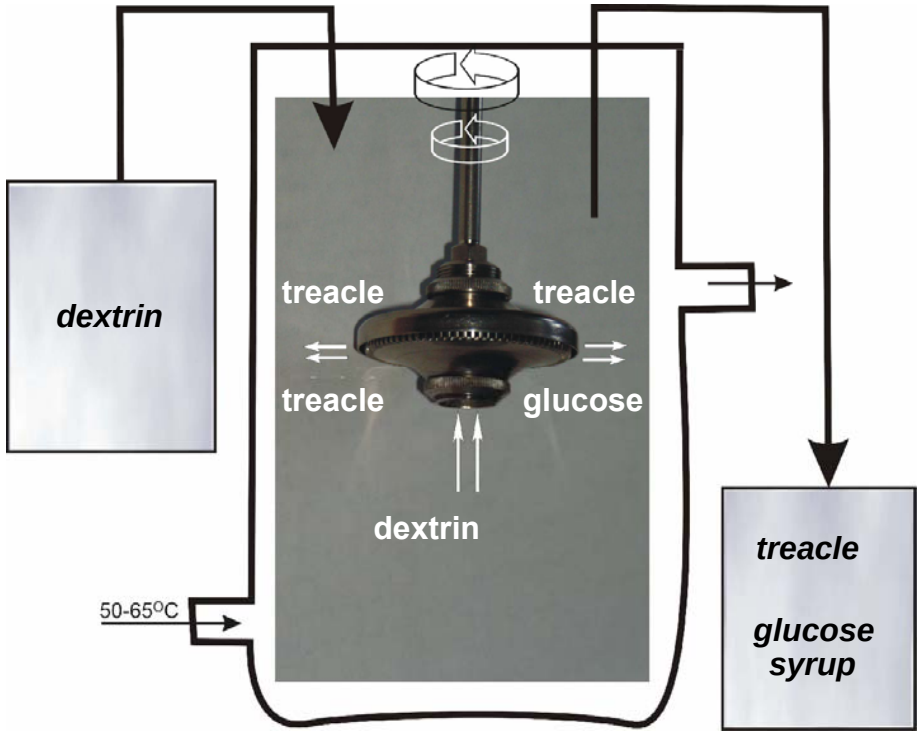
Enzymatic hydrolysis
(α-amylase, pullulanase)
60 °C, pH 6.5, 10–100 min 90 °C

Filtration,
~~ion exchange~~

Enzymatic hydrolysis of
dextrin (glucoamylase)
55–60 °C, pH 4.5, 24–96 h 2–6 h

~~Inactivation and
enzyme removal~~

Enzylene "Glucoamylase on Sibunit"
Immersible vortex reactor



Prof. G.A. Kovalenko

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

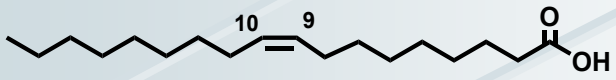
Oxidation of tallic oils (unsaturated acids)

tallic oils

35-37%

free fatty acids:

40-50%
resin acids

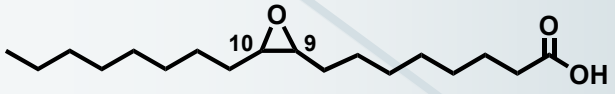


1, oleic acid

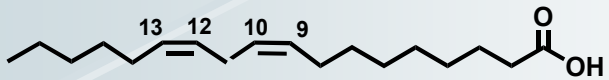
80%

H_2O_2

[Cat]



4, *cis*-9,10-epoxyoctadecanoic acid 98%

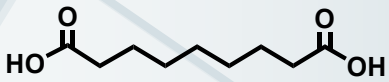


2, linoleic acid

7-8%

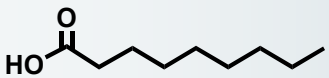
H_2O_2

[Cat]

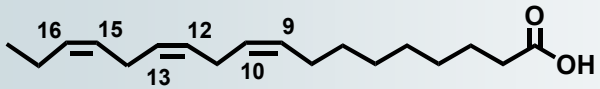


5, azelaic acid 86%

+



6, nonanoic acid 84%



3, linolenic acid

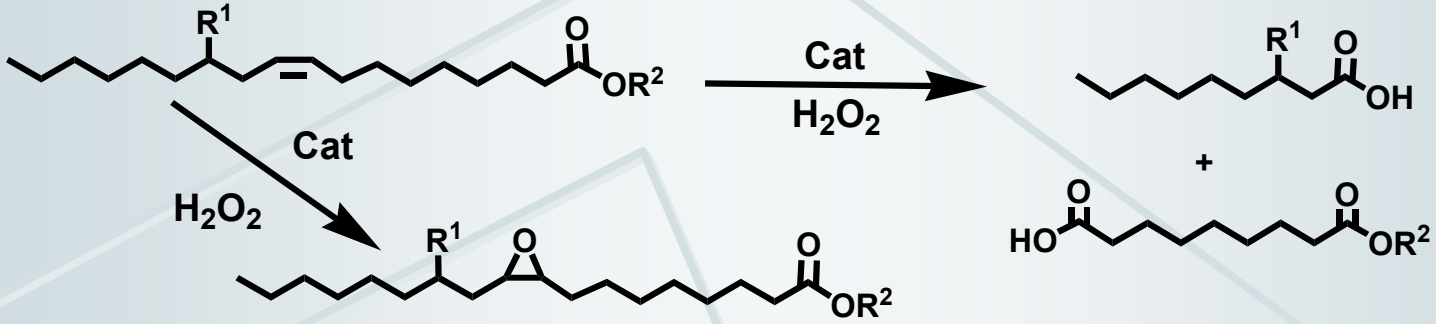
12%

Prof. Z.P. Pai

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Obtaining of epoxides, mono- and dicarboxylic acids from vegetable oils

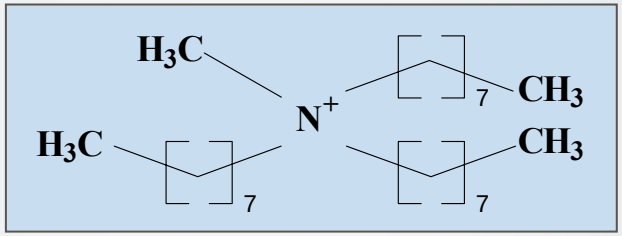
Vegetable oils, including tallic oils (30 % of unsaturated fatty acids), sunflower-seed, rapeseed, castor oil

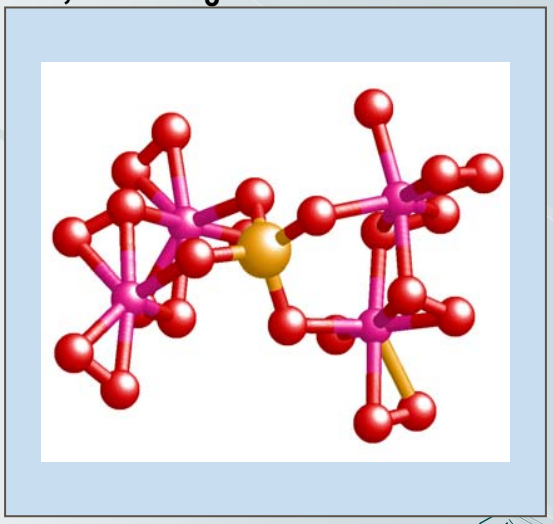


R^1=H, R^2=H R^1=H, R^2=CH_3 R^1=OH, R^2=H R^1=OH, R^2=CH_3

Catalyst methyltri-*n*-octylammonium tetrakis(oxodiperoxotungsto) phosphate

$[CH_3(n\text{-}C_8H_{17})_3N]_3\{PO_4[WO(O_2)_2]_4\}$





The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Transformation of rice husk and other high-ash biomass

High-ash biomass

(rice husk as an example)

Application of carbonaceous materials from the biomass:

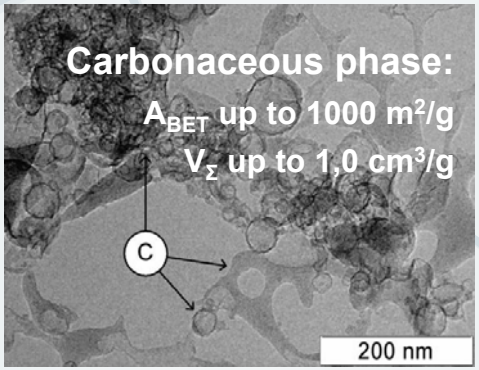
- Low cost bi-functional sorbents for the liquids and gases purification
- Reinforcing rubber extenders
- Bi-functional catalyst support
- Sorbents for gas purification and accumulation

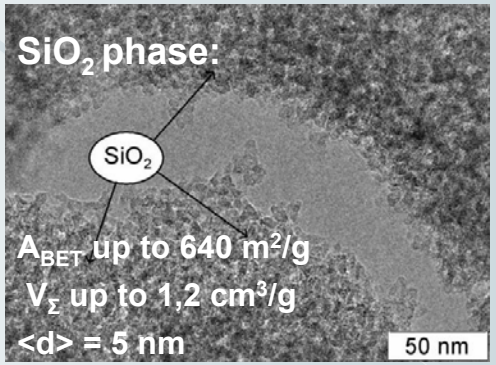
Carbon-silica composites*

Sample	A_{BET}, m^2/g	V_Σ, cm^3/g	Bulk ash, %	Surface ash, %
C/SiO_2 FCB450	32	0,04	37	35
C/SiO_2 FCB500	176	0,15	56	56
C/SiO_2 FCB550	246	0,21	69	69
C/SiO_2 FCB600	233	0,22	73	76

*(homogeneous distribution of C and SiO_2 phases)

Nanostructural re-precipitated carbon-silica composites





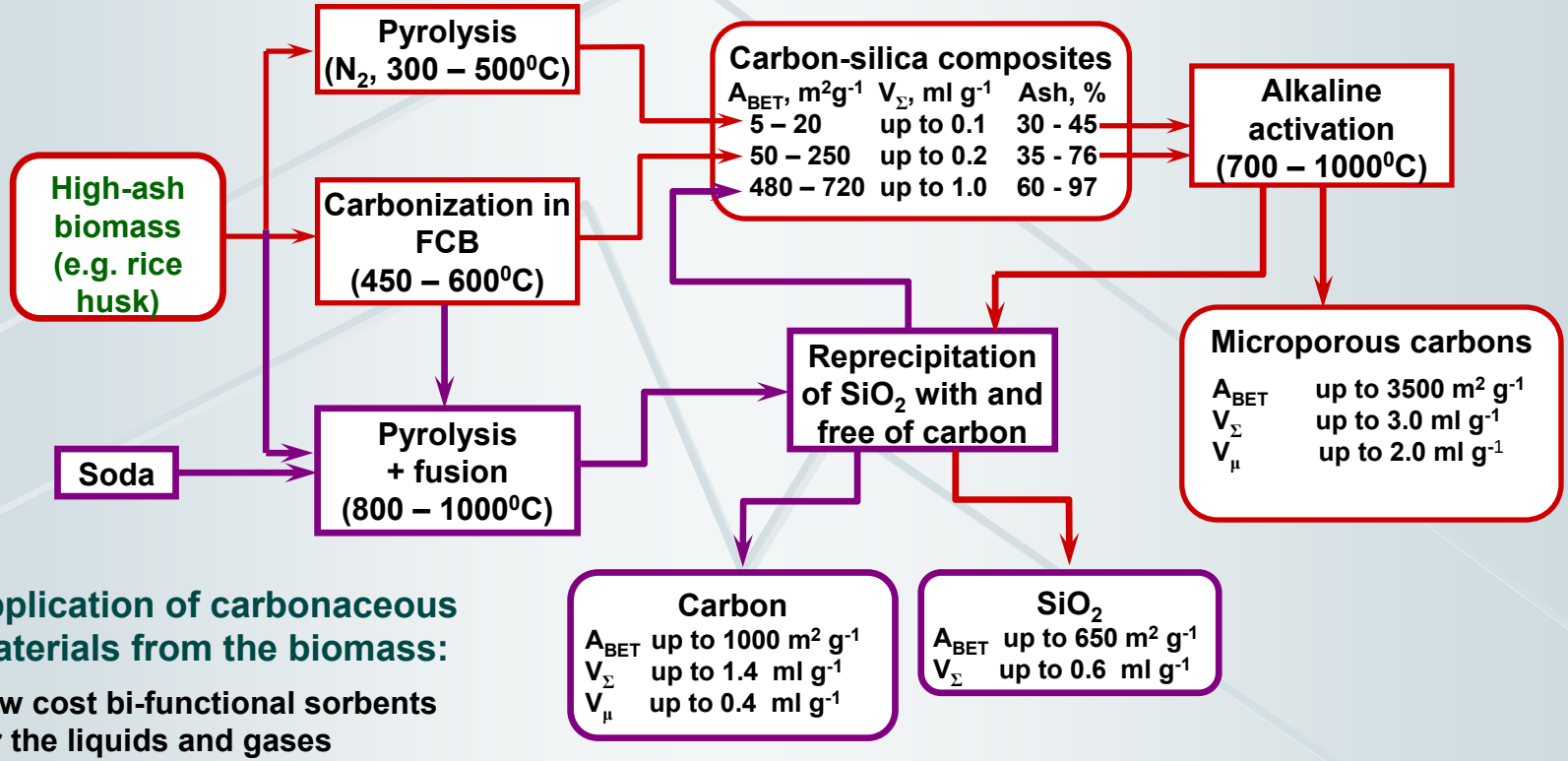
Microporous carbons

Sample	A_{BET}/A_μ, m^2/g	V_Σ / V_μ, cm^3/g	Adsorption of H_2 (77 K, 50 atm) % wt.	Adsorption of CH_4 (273 K, 60 atm) % wt.
MPC 50702K	3170/3060	1,77/1,45	4,7	28
MPC 50752K	3450/3270	2,01/1,68	5,7	27
MPC 50802K	3360/3100	2,18/1,87	6,3	33
MPC 50852K	3170/2680	2,26/1,74	5,8	34
MPC 50902K	3210/1730	2,97/1,48	6,2	41

Dr. B.A. Yakovlev

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Flow sheet of the production of carbonaceous composite materials from high-ash biomass



Application of carbonaceous materials from the biomass:

- Low cost bi-functional sorbents for the liquids and gases purification
- Reinforcing rubber extenders
- Bi-functional catalyst support
- Sorbents for gas purification and accumulation

Microporous carbons as sorbents:

H_2 adsorption at 77 K and 60 atm – 6,3 % wt.
CH_4 adsorption at 273 K and 50 atm – 41 % wt.

Dr. B.A. Yakovlev

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Steam reforming of bioethanol for fuel cells

Bioethanol is widely available renewable feedstock with the annual production in the world ≥ 70 mln. tonn per year

Bioethanol is an aqueous solution of ethyl alcohol produced by biotechnological conversion of various kind of vegetable biomass (wood, crops, agricultural wastes, etc.)

Main Reaction $C_2H_5OH + 3\ H_2O = 2\ CO_2 + 6\ H_2$

Side Reactions $CO_2 + H_2 = CO + H_2O$

$C_2H_5OH = C_2H_4 + H_2O$

$C_2H_5OH = CH_3CHO + H_2$

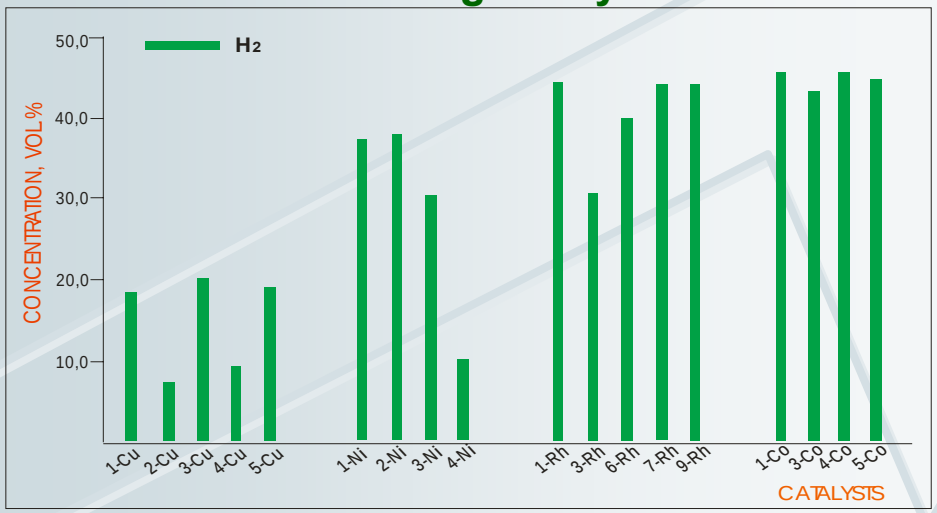
$C_2H_5OH = CH_4 + 2\ H_2 + CO$

The reaction of steam conversion can be performed on cobalt, rhodium, nickel and copper-nickel catalysts to yield CH_4, H_2, CO, CO_2, acetaldehyde and ethylene

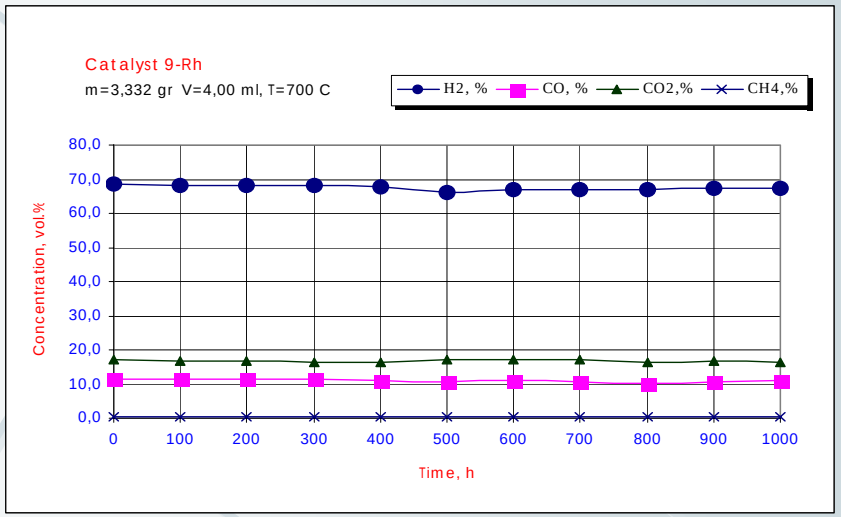
The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Development of catalysts for steam reforming of bioethanol for fuel cells

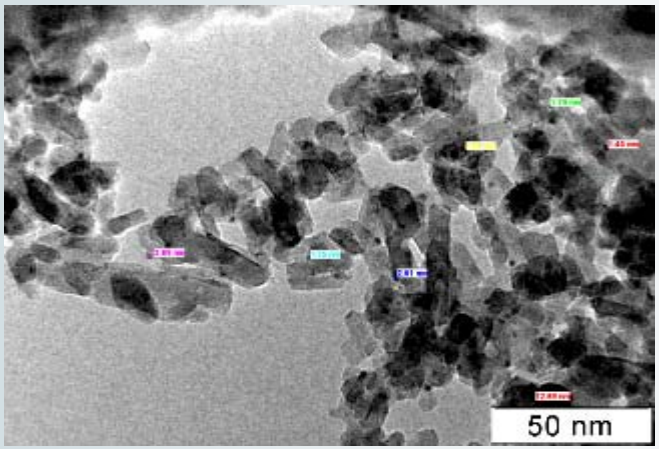
Results of testing Cu, Ni, Rh and Co containing catalysts



Results of the catalyst life test



P = 1 atm, H_2O/C_2H_5OH = 4, GHSV = 2500 h^{-1}, T = 700 °C



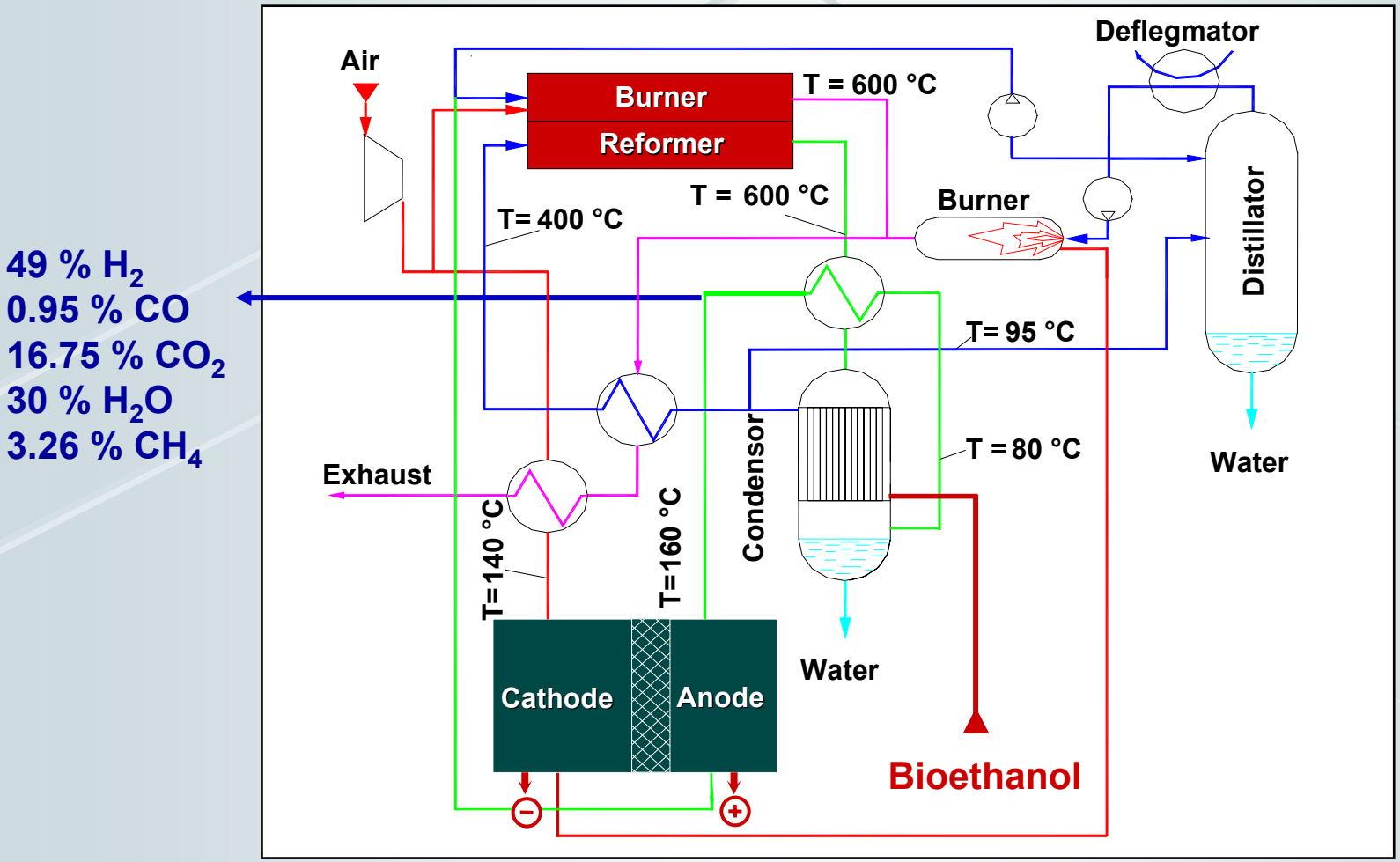
Micrograph of the catalyst after 1000 h of the life tests

Prof. V.A. Kirillov

http://catalysis.ru

The processes of the bio-feedstock conversion under development in the Boreskov Institute of Catalysis:

Flow-sheet of a Power Plant based on HT PEMFCs with direct reforming of crude bio-ethanol



Molar ratio of H_2O : C_2H_5OH = 20

The main problem of transfer of new chemical high-tech processes into practice:

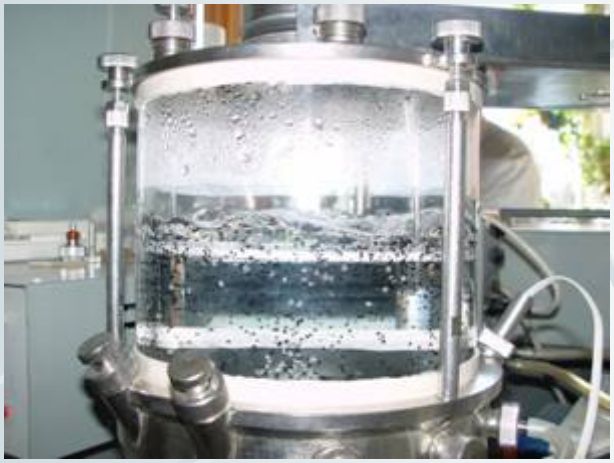
- demonstration
- scaling up

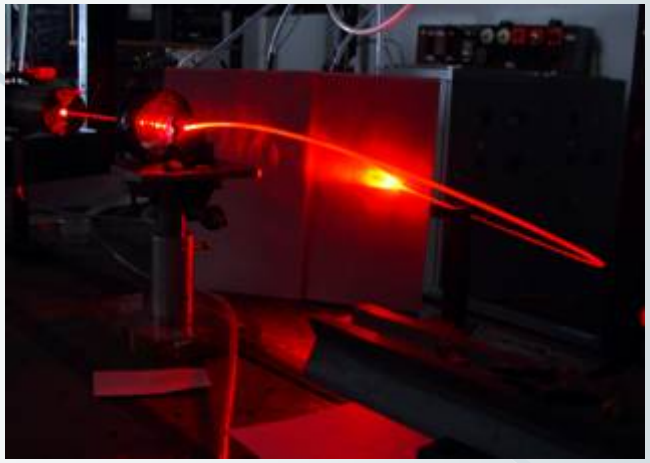
Pilot facilities of the Boreskov Institute of Catalysis for the demonstration and scaling up

- pilot chemical facility, 3625 m^2 (Novosibirsk)
- building for new technologies, 6100 m^2 (under commissioning, Novosibirsk)
- pilot plant for fine organic synthesis, 29,000 m^2 (Volgograd)

Pilot chemical facilities of BIC, Novosibirsk

Testing of the newest catalytic technologies





Pilot chemical facilities of BIC, Novosibirsk

Pilot testing of the newest catalytic technologies






Pilot chemical facilities of BIC, Novosibirsk

Testing of the newest catalytic technologies







Pilot chemical facilities of BIC, Novosibirsk

Scaling up the newest catalytic technologies

Pilot chemical facilities of BIC, Novosibirsk

Testing of the newest technologies for catalyst manufacturing

The BIC's Volgograd pilot plant for fine organic synthesis

Laboratory building, 5500 m²

The BIC's pilot plant for fine organic synthesis, Volgograd

Scaling up and production facilities, 23,000 m²

New BIC's building for development of new technologies in Novosibirsk

(6100 m², under end of construction and commissioning)

New Building is waiting for new projects!

The BIC's authorities are ready to make a sufficient contribution for the potential EC partners in R&D&D of the high-tech biomass conversion

The author are grateful to:

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Dr. N.V. Maksimchuk

Dr. B.A. Yakovlev

Mr. A.P. Kovalenko (Volgograd)

Mr. A.A. Spiridonov

for the help in preparing the presentation