# Hydroconversion of lignocellulose-derived molecules over oxide-supported catalysts

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Tezpur University, 28. 11. 2023













### **Location of Hungary**



Hungary Area: 93,030 km<sup>2</sup> Population: 9,678,000 Capital: Budapest Official language: Hungarian Currency: Forint (HUF)

### Hungary



## **Budapest**





## Budapest

![](_page_4_Picture_1.jpeg)

![](_page_4_Picture_2.jpeg)

![](_page_4_Picture_3.jpeg)

![](_page_4_Picture_4.jpeg)

![](_page_4_Picture_5.jpeg)

#### **Research Centre for Natural Sciences**

![](_page_5_Picture_1.jpeg)

• the new building was inaugurated in 2013

![](_page_5_Picture_3.jpeg)

![](_page_5_Picture_4.jpeg)

#### **Instruments**

![](_page_6_Picture_1.jpeg)

![](_page_6_Picture_2.jpeg)

![](_page_6_Picture_3.jpeg)

![](_page_6_Picture_4.jpeg)

![](_page_6_Picture_5.jpeg)

![](_page_6_Picture_6.jpeg)

#### **Instruments**

![](_page_7_Picture_1.jpeg)

![](_page_7_Picture_2.jpeg)

![](_page_7_Picture_3.jpeg)

![](_page_7_Picture_4.jpeg)

![](_page_7_Picture_5.jpeg)

#### **Trip to Tezpur (By walk ③)**

![](_page_8_Picture_1.jpeg)

### **Trip to Tezpur (By plane and car ~ 25 hr)**

![](_page_9_Picture_1.jpeg)

#### INDO-HUNGARIAN INTER-GOVERNMENTAL SCIENCE & TECHNOLOGY COOPERATION PROGRAMME

From February 1, 2021 to January 31, 2024

Applied research and development for industrial realization of lignin recycling and conversion to value-added international market products
Theme and tasks of this project

![](_page_10_Figure_3.jpeg)

- From July 1, 2016 to June 30, 2019
- ✓ Biochemicals and biofuels from lignocellulosic biomass by green catalytic processes

### Lignocellulose as source of carbon and energy

#### Current carbon and energy resources

![](_page_11_Figure_2.jpeg)

![](_page_11_Figure_3.jpeg)

#### <u>Utilization of waste biomass</u> (agriculture, forestry, food- and paper industry)

Organic compounds  $\implies$  CO<sub>2</sub> + H<sub>2</sub>O + energy  $\uparrow$  photosynthesis

- $\succ$  less CO<sub>2</sub> emission
- keep biological carbon in bound form as long as possible (fuel, chemical)
- > Our goal is to establish the scientific background for biotechnological processes

#### **Structure of lignocellulose**

![](_page_11_Figure_10.jpeg)

![](_page_11_Figure_11.jpeg)

Gy. Onyestyák, Gy. Novodárszki et al., Catal. Sci. Technol. 6 (2016) 4516 Chem. Soc. Rev. 41 (2012) 8075 2016,6,

![](_page_11_Figure_13.jpeg)

## **Conversion of lignocellulosic biomass to useful materials**

![](_page_12_Figure_1.jpeg)

#### Levulinic acid-based chemicals

![](_page_13_Figure_1.jpeg)

Gy. Novodárszki et al., RSC Adv. 4 (2014) 2081; J. Tukacs, Gy. Novodárszki et al., Green Chem. 14 (2012) 2057

### Catalysis

![](_page_14_Picture_1.jpeg)

![](_page_14_Figure_2.jpeg)

- Catalyst lowers the activation energy for both forward and reverse reactions
- Catalysts increase reaction rate without themselves being changed
- The design of catalysts implies a compromise involving mechanical, physico-chemical, and catalytic properties

### **Catalysis: homogeneous, heterogeneous**

![](_page_15_Figure_1.jpeg)

- > The catalyst usually is a solid material, whereas the reactants are gaseous or liquid substances
- Easy separation of the product and recycling of the catalyst allows for efficient processes on large scales

#### **Consecutive reactions of Levulinic Acid**

![](_page_16_Figure_1.jpeg)

Metal and acid site concentrations of the catalysts and their relative amount determine the dominating reaction path of LA conversion to GVL and in GVL hydrogenolysis.

Gy. Novodárszki et al., Catal. Sci. Technol. 9 (2019) 2291; Gy. Novodárszki et al., Reaction Kinetics, Mechanisms and Catalysis 126 (2019) 795

#### **Catalyst preparation for Levulinic Acid hydroconversion**

Catalyst	Precursor	Support	
<b>4,6Co/SiO</b> <sub>2</sub> ( <b>I</b> )			
<b>8,1Co/SiO</b> <sub>2</sub> (I)		SiO <sub>2</sub> (Cabosil M5; 200 m <sup>2</sup> /g)	
13,3Co/SiO <sub>2</sub> (I)			
8,0Co/SiO <sub>2</sub> (II)	<b>Co(NO<sub>3</sub>)<sub>2</sub>*6H<sub>2</sub>O</b>	SiO <sub>2</sub> (Cabosil EH5; 385 m <sup>2</sup> /g)	
7,7Co/Al <sub>2</sub> O <sub>3</sub>		γ-Al <sub>2</sub> O <sub>3</sub> (Ketjen CK300; 170 m <sup>2</sup> /g)	
7,2Co/HBETA		H-Beta (Valfor Cp; Si/Al = 12,5; 582 m <sup>2</sup> /g)	
6,6Ni/SiO <sub>2</sub> (II)	Ni(CH <sub>3</sub> COO) <sub>2</sub> *4H <sub>2</sub> O	SiO <sub>2</sub> (Cabosil EH5; 385 m <sup>2</sup> /g)	

Impregnation: metal salt solution

> Calcination: 500 °C, 2 h 
$$\longrightarrow \frac{\text{Co}_3\text{O}_4}{\text{NiO}}$$
  
> In situ reduction: 450 °C, 2 h, H<sub>2</sub> $\longrightarrow \frac{\text{Co}^0}{\text{Ni}^0}$ 

> Catalytic experiments were carried out in a continuous flow-through fixed-bed microreactor

#### **Determination of crystallite size: X-ray diffraction (XRD)**

![](_page_18_Figure_1.jpeg)

- $\succ$  With thermal decomposition of precursors 20-40 nm Co<sub>3</sub>O<sub>4</sub> and NiO crystallites were formed
- > On the reduced catalysts: Ni<sup>0</sup>: 6-10 nm (higher hydrogenation activity)

#### **Co<sup>0</sup> : 20-40 nm**

- > The size of the metal particles does not change on the used catalysts
- $\blacktriangleright$  The specific surface area of the SiO<sub>2</sub> support does not affect the size of the Co oxide and metallic Co crystallites

Gy. Novodárszki et al., Microporous and Mesoporous Materials 360 (2023) 112732; Gy. Novodárszki et al., Catalysis Today 336 (2019) 50

#### **Reducibility** (H<sub>2</sub>-TPR) and acidity (FT-IR spectra of adsorbed pyridine)

![](_page_19_Figure_1.jpeg)

- $\succ$  The degree of reduction at 450 °C:
  - SiO<sub>2</sub> supported  $\sim 90 \%$
  - $Al_2O_3$  supported ~55 %
  - H-Beta supported ~65 %

- > 1446/1597 cm<sup>-1</sup> : pyridine coordinating to the silanol group by H-bonding
- >  $1450/1608 \text{ cm}^{-1}$  : pyridine coordinated at Lewis acid (L) sites
- >  $1545/1637 \text{ cm}^{-1}$ : the pyridinium ion formed at the Brönsted acid (B) sites
- The interaction of the unreduced Co and Ni oxide species with the silica support create weak Lewis acid sites.

Gy. Novodárszki et al., Microporous and Mesoporous Materials 360 (2023) 112732; Gy. Novodárszki et al., Catalysis Today 336 (2019) 50; Gy. Novodárszki et al., Reac. Kin., Mech.and Cat. 126 (2019) 795

#### **Stabilization of the catalyst as a function of the Co content**

![](_page_20_Figure_1.jpeg)

> On the 4.6Co/SiO<sub>2</sub>(I) catalyst AL intermediate was detected in the product mixture from the  $13^{\text{th}}$  hour of the reaction

- > Angelica lactone is the intermediate in the production of GVL
- $\blacktriangleright$  GVL is formed on Co/SiO<sub>2</sub> and Co/Al<sub>2</sub>O<sub>3</sub> catalysts after the steady state

Gy. Novodárszki et al., Catal. Sci. Technol. 9 (2019) 2291

#### Effect of metal and support in the hydroconversion of LA

![](_page_21_Figure_1.jpeg)

> The hydroconversion of LA on the Ni catalyst does not stop at the formation of GVL

> On H-Beta zeolite due to the Brønsted acid centers of the support, the GVL ring opens in the direction of pentanoic acid formation

Gy. Novodárszki et al., Catal. Sci. Technol. 9 (2019) 2291; Gy. Novodárszki et al., Reaction Kinetics, Mechanisms and Catalysis 126 (2019) 795

#### Effect of temperature in the hydroconversion of LA

![](_page_22_Figure_1.jpeg)

- ➢ At higher reaction temperature LA can be converted into 2-MTHF
- $\blacktriangleright$  On Co/Al<sub>2</sub>O<sub>3</sub> catalyst GVL is selectively formed in the hydroconversion of LA in a wide temperature range

Gy. Novodárszki et al., Catal. Sci. Technol. 9 (2019) 2291

### **Selective 2-MTHF production on 8,1Co/SiO<sub>2</sub>(I)**

![](_page_23_Figure_1.jpeg)

- Surface carboxylate anions were detected
- > The enol form of levulinate, 4-hydroxy-3-pentenoate, is the activated form leading to the formation of GVL
- > At higher reaction temperature LA can be converted into 2-MTHF

Gy. Novodárszki et al., Catal. Sci. Technol. 9 (2019) 2291

### Hydrodeoxygenation of γ-valerolactone

![](_page_24_Figure_1.jpeg)

Conversion of GVL on catalysts with different acidity resulted in different product mixtures

Over Co/H-Beta catalyst containing strong Brønsted and Lewis acid sites PA was formed from GVL trough pentenoic acid intermediate
 On Co/Al<sub>2</sub>O<sub>3</sub> and Co/SiO<sub>2</sub> catalysts containing only Lewis acid sites 2-MTHF was formed

Gy. Novodárszki et al., Microporous and Mesoporous Materials 360 (2023) 112732; Gy. Novodárszki et al., Catalysis Today 336 (2019) 50; Gy. Novodárszki et al., Catalysts 13 (2023) 7

### **Mechanism of GVL ring opening**

![](_page_25_Figure_1.jpeg)

> Over Co/H-Beta catalyst pentanoic acid was formed through pentenoic acid intermediate

> On Co/Al<sub>2</sub>O<sub>3</sub> and Co/SiO<sub>2</sub> catalysts the intermediate of GVL hydroconversion to 2-MTHF is 2-hydroxy-5-methyltetrahydrofuran

Gy. Novodárszki et al., Microporous and Mesoporous Materials 360 (2023) 112732; Gy. Novodárszki et al., Catalysis Today 336 (2019) 50; Gy. Novodárszki et al., Catalysts 13 (2023) 7

## **Conclusions of LA and GVL hydroconversion**

- The interaction of the unreduced Co and Ni oxide species with the silica support create weak Lewis acid sites.
- Using Co/SiO<sub>2</sub> and Ni/SiO<sub>2</sub> catalysts consecutive steps of LA hydroconversion can be selectively directed to more valuable products, such as GVL, 2-MTHF or PA by applying appropriate reaction conditions.
- The most abundant surface species are Co-carboxylates formed from LA. The hydrogenation activity is affected also by the carboxylate coverage of the catalyst surface.
- Increasing the reaction temperature, the reaction of LA HDO over the Co/SiO<sub>2</sub> catalyst shifts from GVL formation to 2-MTHF formation. (the carboxylate coverage of the active cobalt centers is reduced)
- The C-O bond in the GVL ring breaks giving either 2-MTHF or PA primary products. Selectivity is controlled by the acidity of the supported Co catalyst.
- > Co/SiO<sub>2</sub> and Co/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalysts have high activity and selectivity in GVL hydroconversion to 2-MTHF.
- > Over Co/H-beta with Broensted acid sites the formation of pentanoic acid is preferred.

#### **Guaiacol-based chemicals**

![](_page_27_Figure_1.jpeg)

#### Products from GUA could replace the materials of fossil origin

Gy. Novodárszki et al., Molecules (2023), under review

### **Reaction pathways of guiacol hydrodeoxygenation**

![](_page_28_Figure_1.jpeg)

optimization of HDO catalysts

 $\succ$ 

Catalysts Precursors		Supports	
SiO <sub>2</sub>			
5Co/SiO <sub>2</sub>			
$10 \text{Co/SiO}_2$	$Co(NO_3)_2 \cdot 6H_2O$	SiO (Cabosil: EH5)	
$15 \text{Co/SiO}_2$		510 <sub>2</sub> (Cabosii, E115)	
$10Cu/SiO_2$	$Cu(CH_3Coo)_2 * H_2O$		
5Ni/SiO <sub>2</sub>	$Ni(NO_3)_2 \cdot 6H_2O$		
$Al_2O_3$			
$10Co/Al_2O_3$	$Co(NO_3)_2 \cdot 6H_2O$		
$5Ni/Al_2O_3$	$Ni(NO_2)$ · 6H <sub>2</sub> O	$\gamma$ -Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)	
20Ni/Al <sub>2</sub> O <sub>3</sub>			
$0,5Pd/Al_2O_3$	$Pd(NH_3)_4(NO_3)_2$		
$Al_2O_3(P)$			
$5Ni/Al_2O_3(P)$	$Ni(NO_2)_2 \cdot 6H_2O$	$\gamma$ -Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)	
$20 \text{Ni}/\text{Al}_2\text{O}_3(\text{P})$		impregnated with $H_3PO_4$ solution	
$0,5Pd/AI_2O_3(P)$	$Pd(NH_3)_4(NO_3)_2$		
H-BETA(12,5)			
10Co/HBETA(12,5)	$Co(NO_3)_2 \cdot 6H_2O$	Beta zeolit (Si/Al=12,5; CP814E)	
5N1/HBETA(12,5)	$N_1(NO_3)_2 \cdot 6H_2O$		
20N1/HBEIA(12,5)			
$\mathbf{\Pi} - \mathbf{D} \mathbf{E} \mathbf{I} \mathbf{A} (1 9)$		Data realit $(C_{1}^{2}/\Lambda_{1}, 10, CD_{2}^{2})$	
$\frac{JINI}{HDEIA} (19)$	$Ni(NO_3)_2 \cdot 6H_2O$	Beta Zeolii (SI/AI=19; CP814C)	
$\frac{20101}{100} = \frac{100}{100} $			
$A_1 O_3 (\Pi - D \Pi N)$			

Catalysts	Precursors	Supports	
SiO <sub>2</sub>			
5Co/SiO <sub>2</sub>			
$10$ Co/SiO $_2$	$Co(NO_3)_2 \cdot 6H_2O$	SiO (Cabosil: EH5)	
$15 \text{Co/SiO}_2$		$SIO_2$ (Cabosii, EII5)	
10Cu/SiO <sub>2</sub>	$Cu(CH_3Coo)_2*H_2O$		
5Ni/SiO <sub>2</sub>	$Ni(NO_3)_2 \cdot 6H_2O$		
$Al_2O_3$			
10Co/Al <sub>2</sub> O <sub>3</sub>	$Co(NO_3)_2 \cdot 6H_2O$		
$5Ni/Al_2O_3$	Ni(NO <sub>2</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	$\gamma$ -Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)	
20Ni/Al <sub>2</sub> O <sub>3</sub>			
$0,5Pd/Al_2O_3$	$Pd(NH_3)_4(NO_3)_2$		
$Al_2O_3(P)$			
$5Ni/Al_2O_3(P)$	$Ni(NO_2)_2 \cdot 6H_2O$	$\gamma$ -Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)	
$\frac{20Ni}{Al_2O_3(P)}$		impregnated with $H_3PO_4$ solution	
$0,5Pd/Al_2O_3(P)$	$Pd(NH_3)_4(NO_3)_2$		
H-BETA(12,5)			
10Co/HBETA (12,5)	) $\operatorname{Co}(\mathrm{NO}_3)_2 \cdot 6\mathrm{H}_2\mathrm{O}$	Beta zeolit (Si/Al=12,5; CP814E)	
5N1/HBETA(12,5)	$N_1(NO_3)_2 \cdot 6H_2O$		
20N1/HBETA (12,5)			
H-BETA(19)			
SN1/HBETA(19)	$Ni(NO_3)_2 \cdot 6H_2O$	Beta zeolit (Si/AI=19; CP814C)	
20N1/HBETA(19)	N 3' L L		
$AI_2O_3$ (HI-BIM)		$\gamma$ -Al <sub>2</sub> O <sub>3</sub> (Bimodal; Alfa Aesar)	
$SN1/AI_2O_3$ (HI-BIM)	) $N_1(NO_3)_2 \cdot 6H_2O$		

#### **Catalyst preparation for Guaiacol hydroconversion**

Catalyst	Precursor	Support
5Ni/SiO <sub>2</sub>		SiO <sub>2</sub> (Cabosil EH5; 385 m <sup>2</sup> /g)
5Ni/Al <sub>2</sub> O <sub>3</sub>		γ-Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)
20Ni/Al <sub>2</sub> O <sub>3</sub>	Ni(NO <sub>3</sub> ) <sub>2</sub> ·6H <sub>2</sub> O	
<b>5Ni/Al<sub>2</sub>O<sub>3</sub>(P)</b>		γ-Al <sub>2</sub> O <sub>3</sub> (Alfa Aesar)
<b>20Ni/Al<sub>2</sub>O<sub>3</sub>(P)</b>		impregnated with H <sub>3</sub> PO <sub>4</sub> solution
5Ni/HBETA		H-Beta (Valfor Cp; Si/Al = 12,5; 582 m <sup>2</sup> /g)

![](_page_31_Figure_2.jpeg)

Catalytic experiments were carried out in a continuous flow-through fixed-bed microreactor

### **Catalysts structure and reducibilty**

![](_page_32_Figure_1.jpeg)

- γ-Al<sub>2</sub>O<sub>3</sub> is the only detectable phase of catalysts with low metal loading (NiO crystallites are well dispersed on the Al<sub>2</sub>O<sub>3</sub> surface)
- The XRD pattern of 20Ni/Al<sub>2</sub>O<sub>3</sub> and 20Ni/Al<sub>2</sub>O<sub>3</sub>(P) catalysts show the reflections of NiO

![](_page_32_Figure_4.jpeg)

Gy. Novodárszki et al., Molecules (2023), under review; Gy. Novodárszki et al., Reaction Kinetics, Mechanisms and Catalysis 126 (2019) 795; A. Vikár, Gy. Novodárszki et al., Journal of Catalysis 404 (2021) 67

### **FT-IR spectra of adsorbed pyridine**

![](_page_33_Figure_1.jpeg)

- ▶ 1446/1597 cm<sup>-1</sup> : pyridine coordinating to the silanol group by H-bonding
- > 1450/1608 cm<sup>-1</sup> : pyridine coordinated at Lewis acid (L) sites
- > 1545/1637 cm<sup>-1</sup> : the pyridinium ion formed at the Brönsted acid (B) sites

Gy. Novodárszki et al., Molecules (2023), under review; A. Vikár, Gy. Novodárszki et al., Journal of Catalysis 404 (2021) 67

#### **Catalyst characterisation: Summary**

Catalysts	Metal content <sup>a</sup> wt%	SSA <sup>b</sup> m²/g	<b>Reduction degree</b> <sup>c</sup>	Average Ni <sup>0</sup> diameter <sup>d</sup>	Acidity <sup>e</sup>
SiO <sub>2</sub>	-	385	-	-	-
5Ni/SiO <sub>2</sub>	5.6	252	91	11	$\mathbf{L}_{\mathbf{w}}$
Al <sub>2</sub> O <sub>3</sub>	-	196	-	-	L <sub>s</sub>
<b>5Ni/Al<sub>2</sub>O<sub>3</sub></b>	5.2	192	4.5	<5	$\mathbf{L}_{\mathbf{s}}$
20Ni/Al <sub>2</sub> O <sub>3</sub>	19.9	190	68	11	$\mathbf{L}_{\mathbf{s}}$
$Al_2O_3(P)$	-	167	-	-	$\mathbf{L}_{\mathbf{s}}$
$5Ni/Al_2O_3(P)$	5.1	165	0.5	<5	$\mathbf{L}_{\mathbf{s}}$
$20\mathrm{Ni}/\mathrm{Al}_{2}\mathrm{O}_{3}(\mathrm{P})$	20.1	160	65	14	L <sub>s</sub>
HBETA	-	582	-	-	L <sub>s</sub> /B <sub>s</sub>
Ni/HBETA	5.1	579	70	10	$L_s/B_s$

<sup>a</sup>Determined by the ICP-MS method.

<sup>b</sup>Specific Surface Area (SSA), determined by the Brunauer-Emmett-Teller (BET) method.

<sup>c</sup>Calculated from temperature-programmed H<sub>2</sub>-reduction (H<sub>2</sub>-TPR) curves.

<sup>d</sup>Calculated from the XRPD pattern of the catalysts reduced at 450 °C for 1 h in H<sub>2</sub> flow.

<sup>e</sup>Determined by the FT-IR band of adsorbed pyridine (Py) ( $L_w$ - weak Lewis acid sites;  $L_s$ - strong Lewis acid sites;  $L_s/B_s$ - strong Lewis and Brønsted acid sites).

## **Activity of supports**

![](_page_35_Figure_1.jpeg)

- $\succ$  SiO<sub>2</sub> support is inactive in the conversion of GUA
- $\triangleright$  On Al<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>(P) and HBETA support demethylation (DME) and transalkylation (AL) are the main reactions
  - CAT derivatives are the main products
  - Demethoxylation (DMO) and dehydroxylation (DHO) also takes place
  - PHE derivatives were also formed

#### **Activity and stability**

![](_page_36_Figure_1.jpeg)

300 °C, 10 bar, 1  $g_{cat}/g_{GUA}$ \*h,  $H_2/GUA = 20$ 

- $\succ$  The activity of 5Ni/SiO<sub>2</sub> and 5Ni/Al<sub>2</sub>O<sub>3</sub> catalysts did not change with TOS
  - O-free compounds were mainly formed at 300 °C
- > The activity of 5Ni/HBETA catalyst decrease in function of TOS

### **Effect of temperature**

![](_page_37_Figure_1.jpeg)

- weak Lewis acid sites
- strong Lewis acid sites
- strong Lewis and Brønsted acid sites

#### 10 bar, 1 $g_{cat}/g_{GUA}$ \*h, H<sub>2</sub>/GUA=20

- $\blacktriangleright$  At 225 °C cyclohexanols were the main products on 5Ni/SiO<sub>2</sub> and 5Ni/Al<sub>2</sub>O<sub>3</sub> catalysts
  - With temperature the yield of benzenes increased
- > The amount of PHE derivatives increased with temperature on 5Ni/HBETA

## Activity and stability of Al<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub>(P) supported catalysts

![](_page_38_Figure_1.jpeg)

### Activity and stability of Al<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub>(P) supported catalysts

![](_page_39_Figure_1.jpeg)

FT-IR spectra of phenol adsorbed on Al<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> support

![](_page_40_Figure_1.jpeg)

Gy. Novodárszki et al., Molecules (2023), under review

## **Conclusions of GUA hydroconversion**

- > The sequential steps of GUA hydroconversion can be controlled by modifying the alumina support.
- > Demethylation of GUA on  $Al_2O_3$ ,  $Al_2O_3(P)$  and HBETA supports leads to catechol formation.
- ➢ Ni/SiO₂ and Ni/Al₂O₃ catalyzed hydroconversion of GUA to O-free compounds like cyclohexane.
- > At lower temperature and space time cyclohexanols were formed in large amounts.
- > With temperature the yield of benzenes increased.
- Ni/Al<sub>2</sub>O<sub>3</sub>(P) catalysts are selective to aromatics. These catalysts remain active in demethylation and demethoxylation, but lose their ability to hydrogenate the aromatic ring. Weak interaction of phenol intermediate was observed on the Al<sub>2</sub>O<sub>3</sub>(P) support.
- > The HBETA zeolite supported Ni catalyst activity decrease due to strong Lewis and Brønsted acidity.

![](_page_42_Picture_0.jpeg)

Nemzeti Kutatási, Fejlesztési És Innovációs Hivatal

## Thank you for your kind attention!

![](_page_42_Picture_3.jpeg)

![](_page_42_Picture_4.jpeg)

The Earth has enough resources to meet the needs of all but not enough to satisfy the greed of even one person.

- Mahatma Gandhi-

#### Acknowledgement

- Ministry of Innovation and Technology for its support from the National Research, Development and Innovation Fund within the framework of the 2019-2.1.13-TÉT\_IN program (Project No.: 2019-2.1.13-TÉT\_IN-2020-00043)
- Supported by the ÚNKP-23-4 New National Excellence Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund."

![](_page_42_Picture_10.jpeg)

![](_page_42_Picture_11.jpeg)

![](_page_42_Picture_12.jpeg)

![](_page_42_Picture_13.jpeg)