

Bioplast Seminar at DTU

Lyngby, February 17, 2009

Polymer Building Blocks From Renewable Resources



Claus Hviid Christensen

Conclusions

- **The transportation sector will minimize its dependence on carbon – the chemical industry cannot.**
- **Biobased chemicals represents the best use of the limited bio-resources, since**
 - **Biobased chemicals give even further reduced CO₂-emissions than those achieved with biofuels**
 - **Biobased chemicals provide products of higher value than biofuels and thus make the biobased technologies more attractive**
- **The Renewable Chemical Industry features an intimate integration of chemical and biological catalytic technologies**
- **Denmark hosts unique scientific, technical and commercial competencies in the relevant fields. They should be explored.**
- **It requires a committed long-term effort, and intelligent subsidies**

Outline

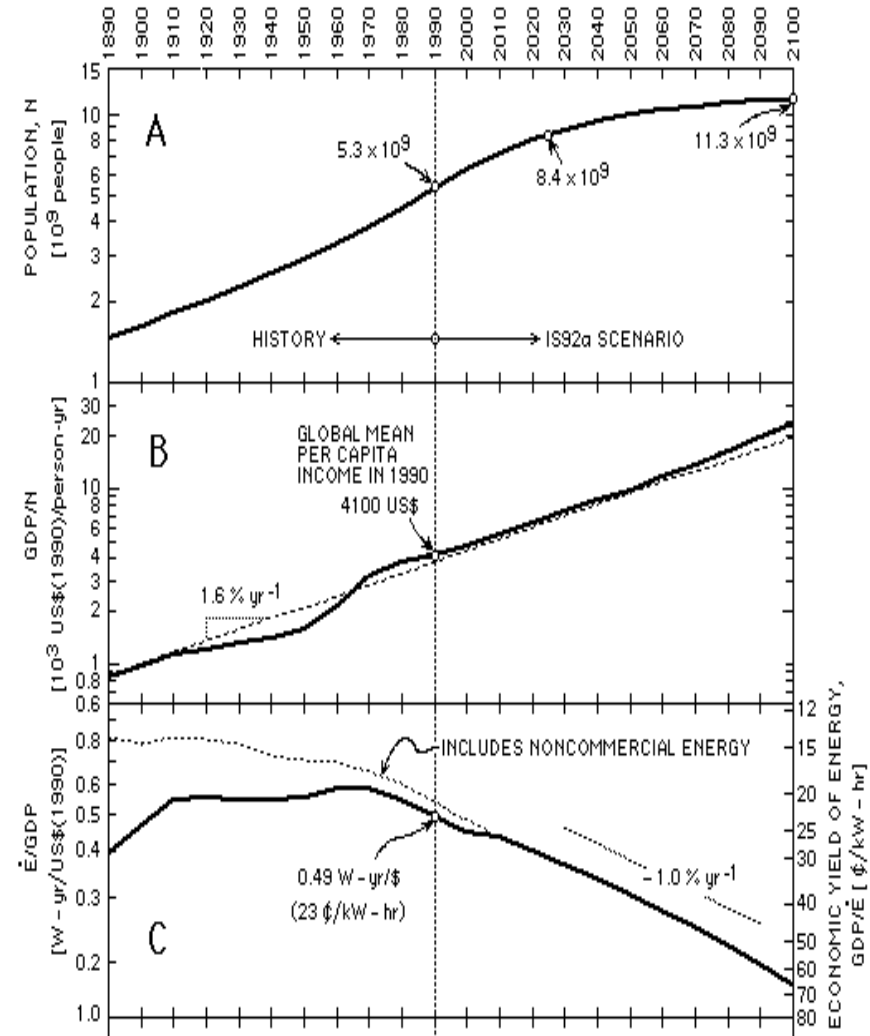
- Drivers for Change
- Sustainable Chemistry
 - C-factors and Value Chains
- The Renewable Chemical Industry
- Polymer Building Blocks from Biomass
- Conclusions

Setting a New Scene

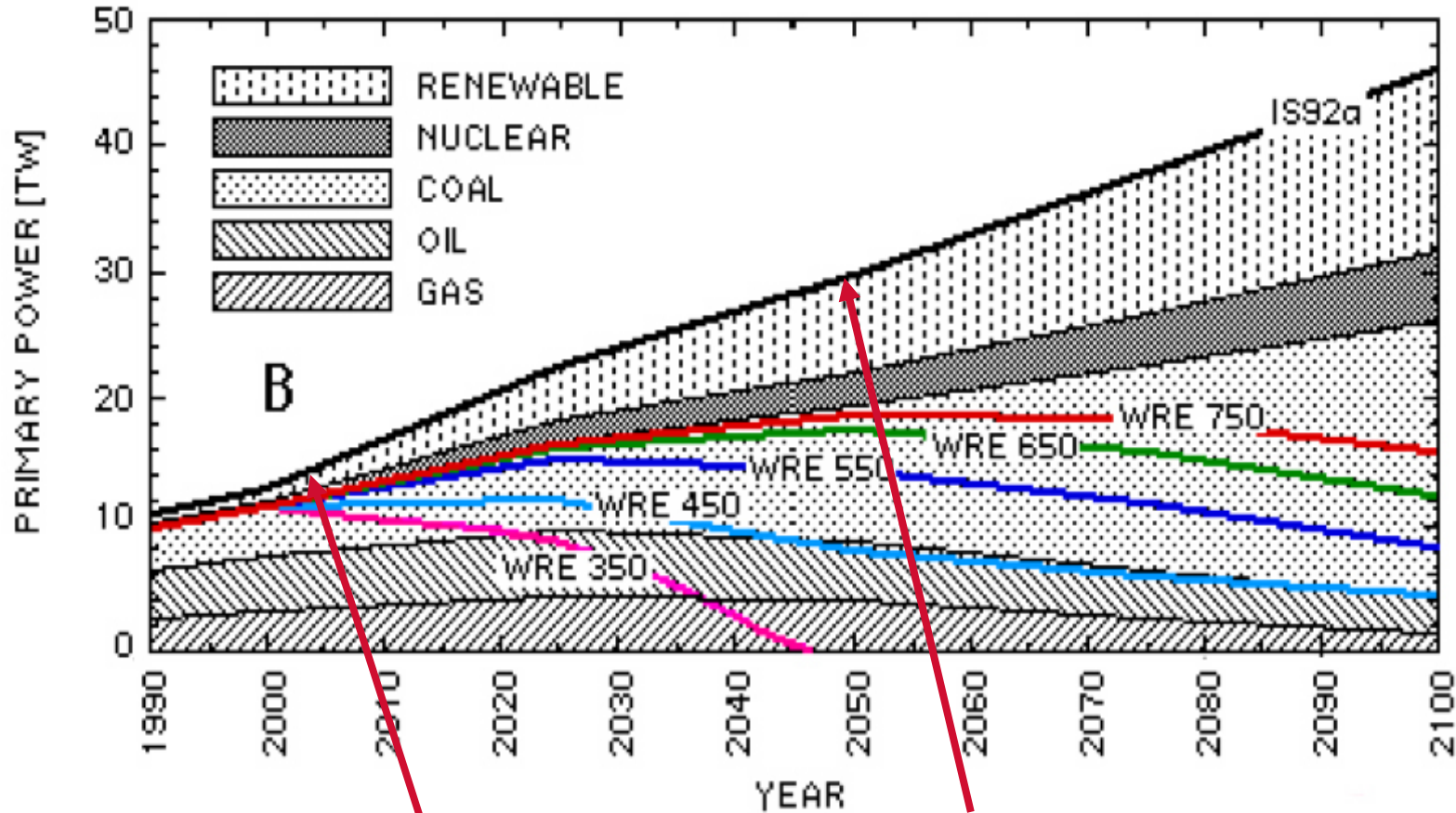
**Population Growth
to 10 - 11 Billion
People in 2050**

**Per Capita GDP
Growth at 1.6% yr⁻¹**

**Energy consumption
per Unit of GDP
declines at 1.0% yr⁻¹**



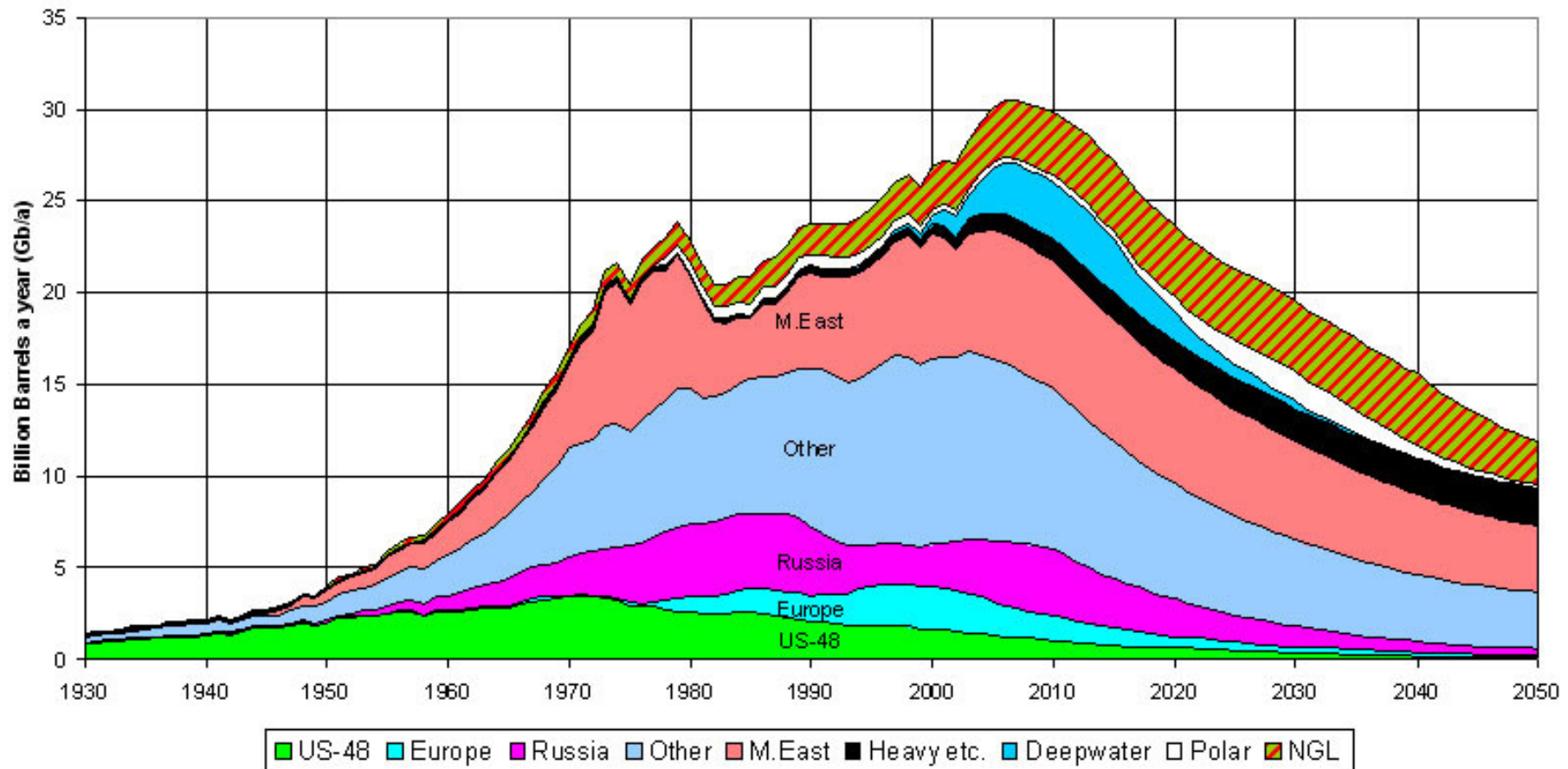
The Resource Challenges



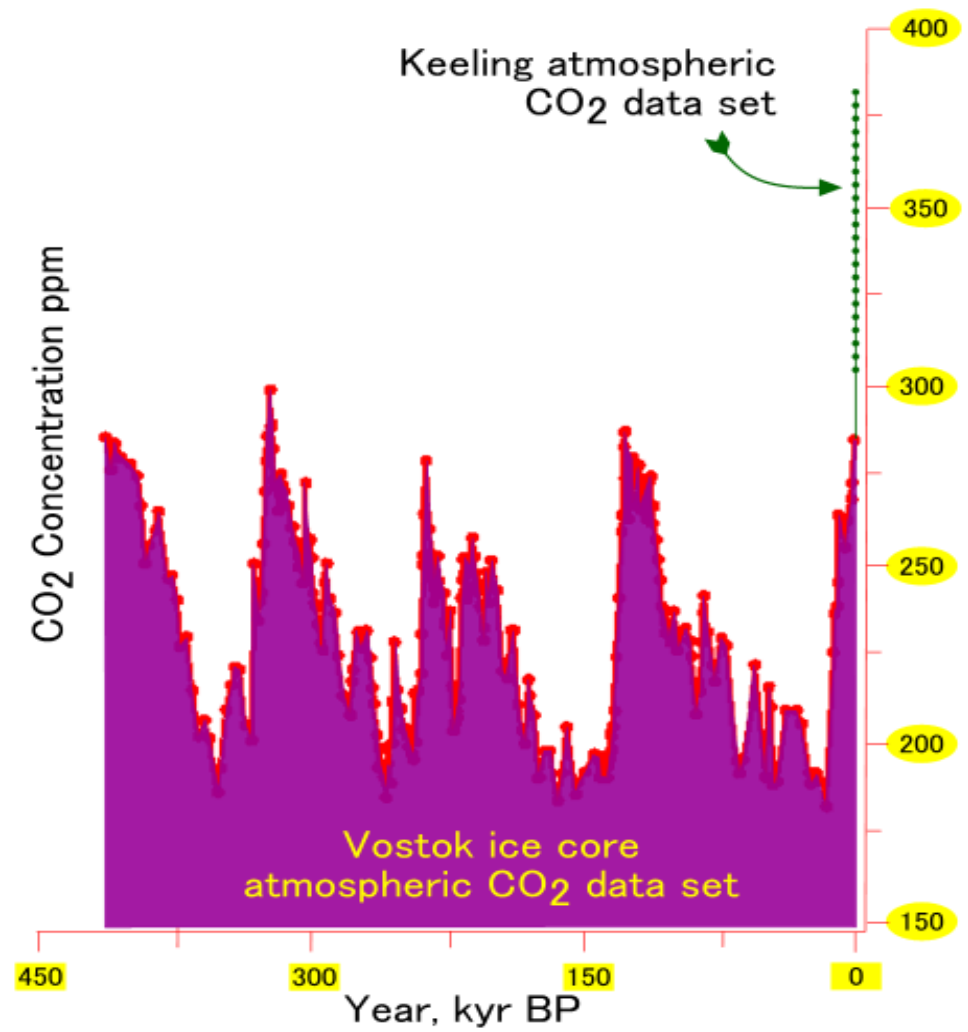
2005: 14 TW 2050: 28 TW

Future of Oil Resources

OIL AND GAS LIQUIDS 2004 Scenario



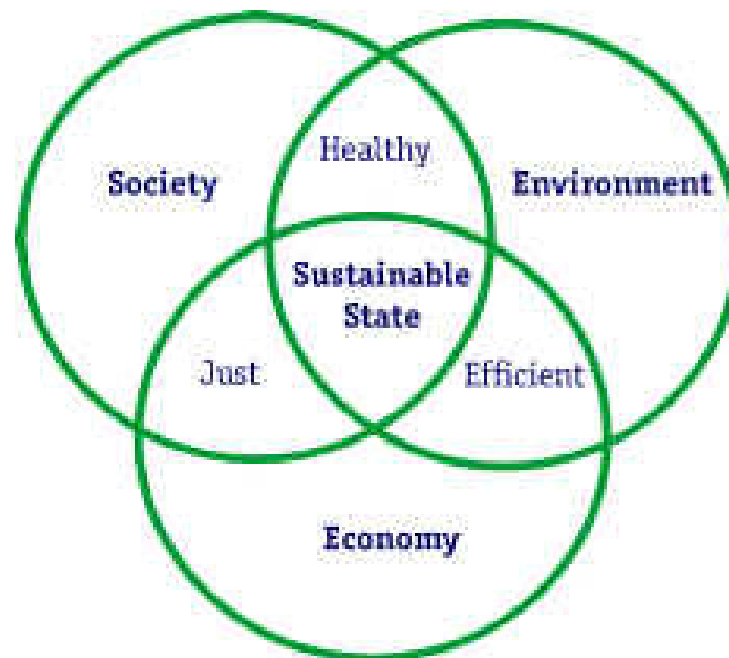
The Climate Challenge



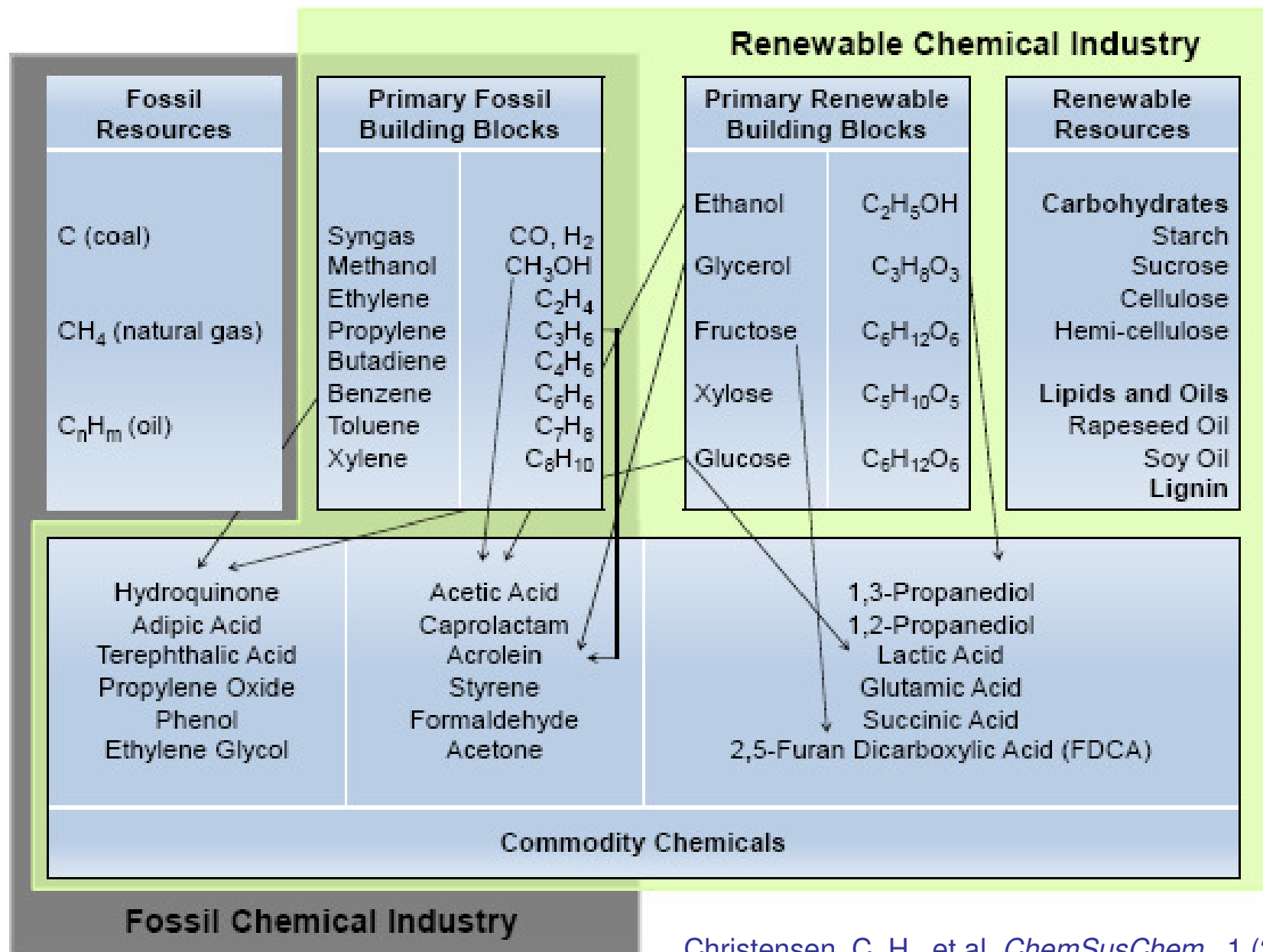
Sustainable Chemistry

- What is it?

“Chemistry that contributes to meeting the needs of the present without compromising the ability of future generations to meet their own needs.”



Christensen, C. H., *Top. Catal.* (2009) in press

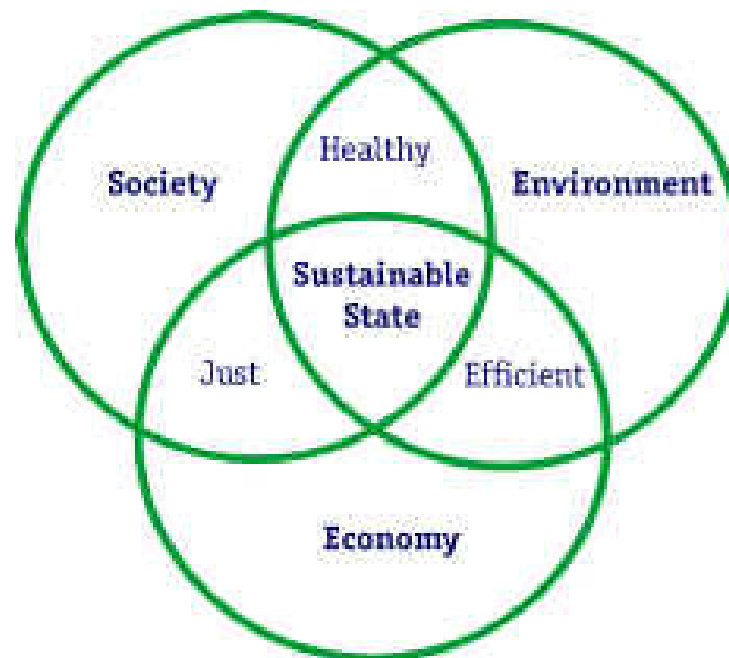


Christensen, C. H., et al. *ChemSusChem*, 1 (2008) 283

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C-factors in Chemical Industry

- The C-factor expresses the amount of CO₂ produced per amount of desired product.
- Current C-factors for some chemicals derived from fossil resources:

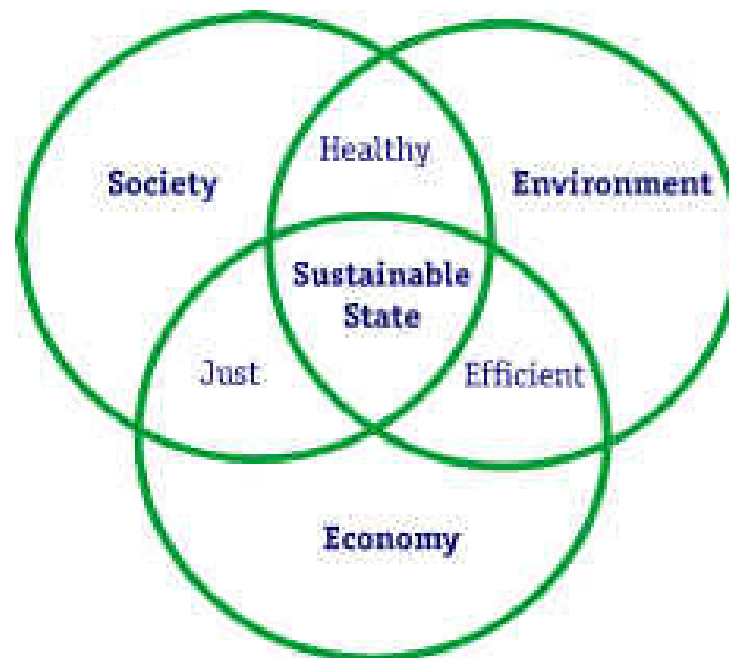
<i>PRODUCT</i>	<i>kg CO₂/kg product</i>
Ammonia	1.2
Ethylene	0.9
Acetic Acid	0.5
Fischer-Tropsch diesel	1.2

Christensen, C. H., Egeblad, K., Rass-Hansen, J, Taarning, E., Marsden, C. *ChemSusChem*, 1 (2008) 283

Sustainable Chemistry

- What is it?

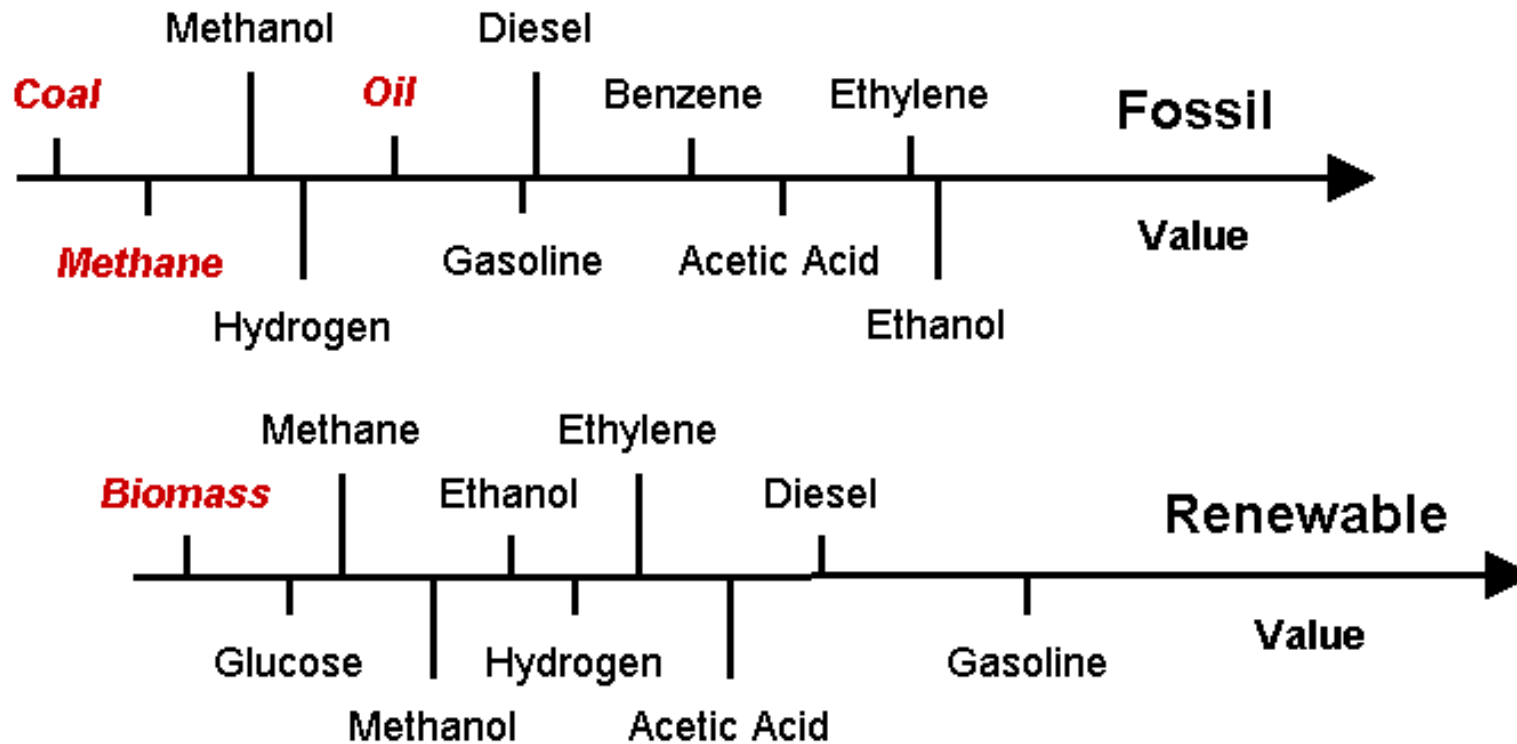
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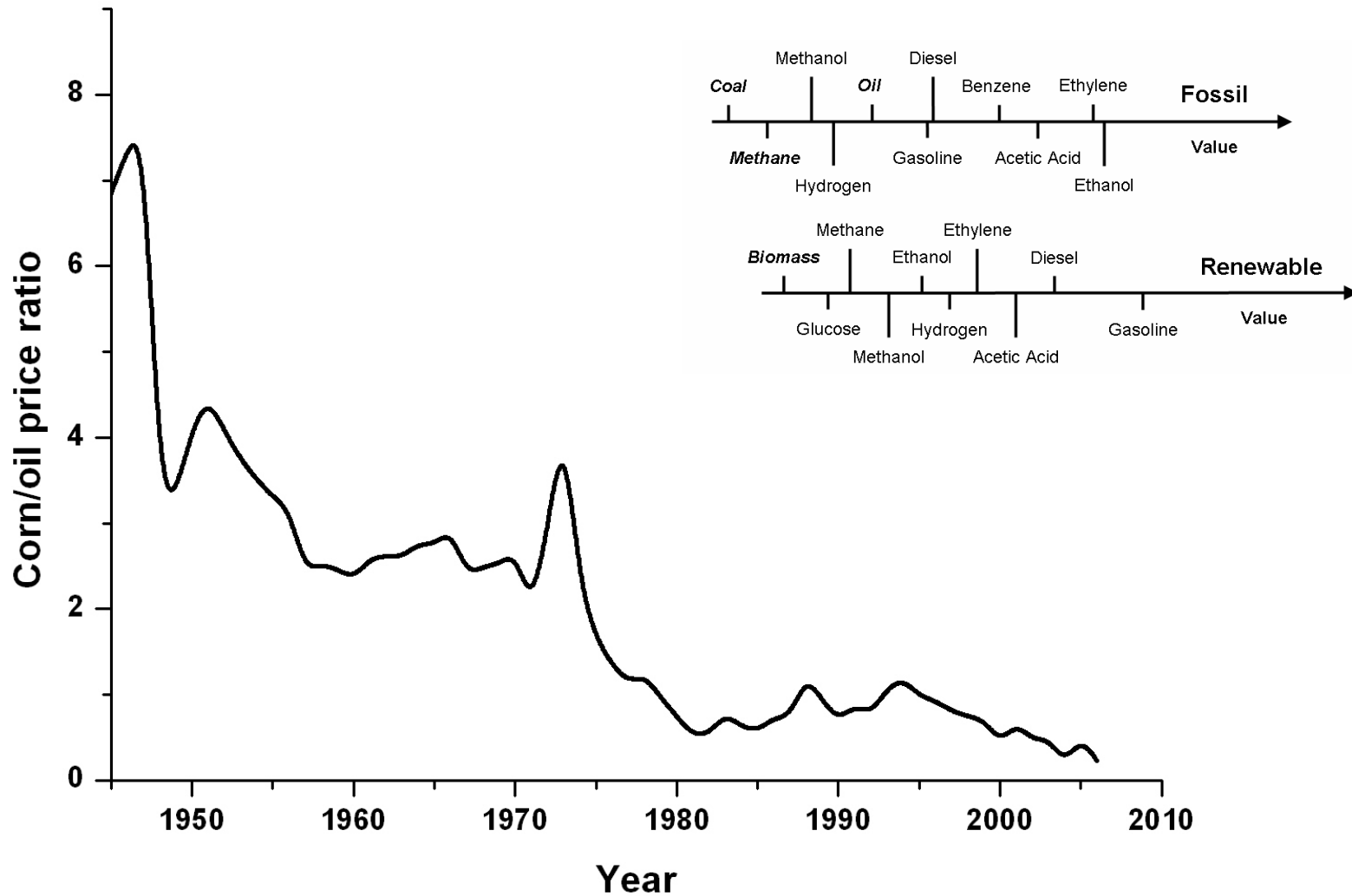
Value Chains in Chemical Industry

The value of a bulk chemical is largely determined by the cost of the feedstock and the efficiency of the involved catalytic processes.



Rass-Hansen, Falsig, Jørgensen, Christensen, *J. Chem. Technol. Biotechnol.* 2007, 82, 329.

Towards Renewable Feedstocks

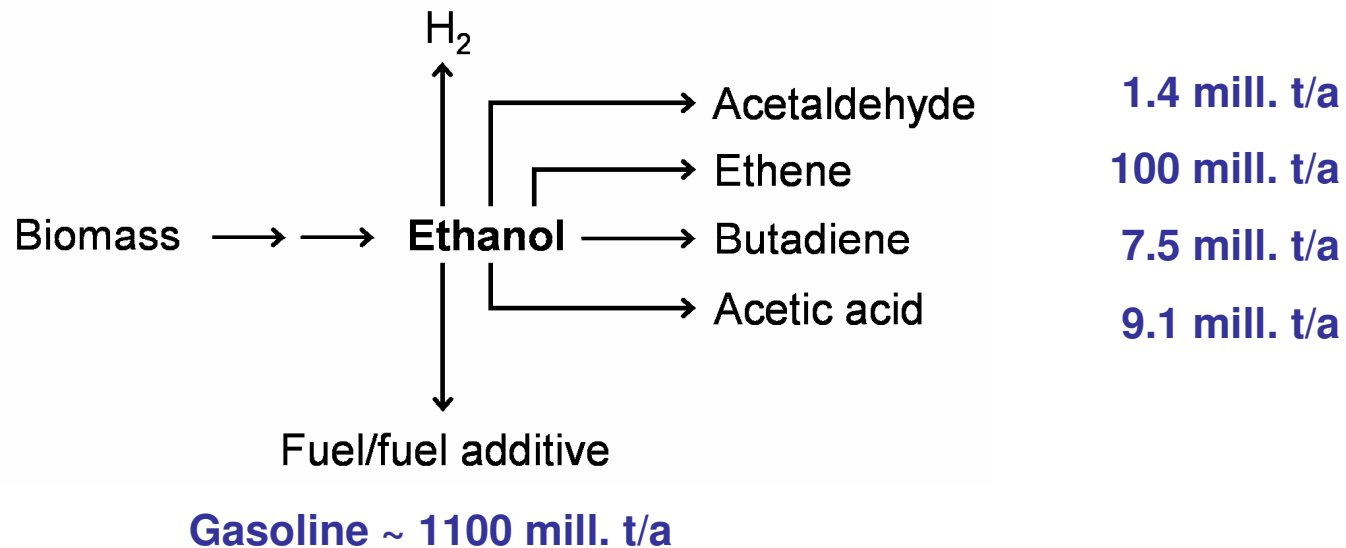


Rass-Hansen, Falsig, Jørgensen, Christensen, *J. Chem. Technol. Biotechnol.* 2007, 82, 329.

Bioethanol: Fuel or Feedstock?

Annual bioethanol production

~ 55 mill. ton



Christensen *et al.*, *Angew.Chem. Int. Ed.* 2006, 45, 4648.

Ethanol is Cost Competitive in Some Areas

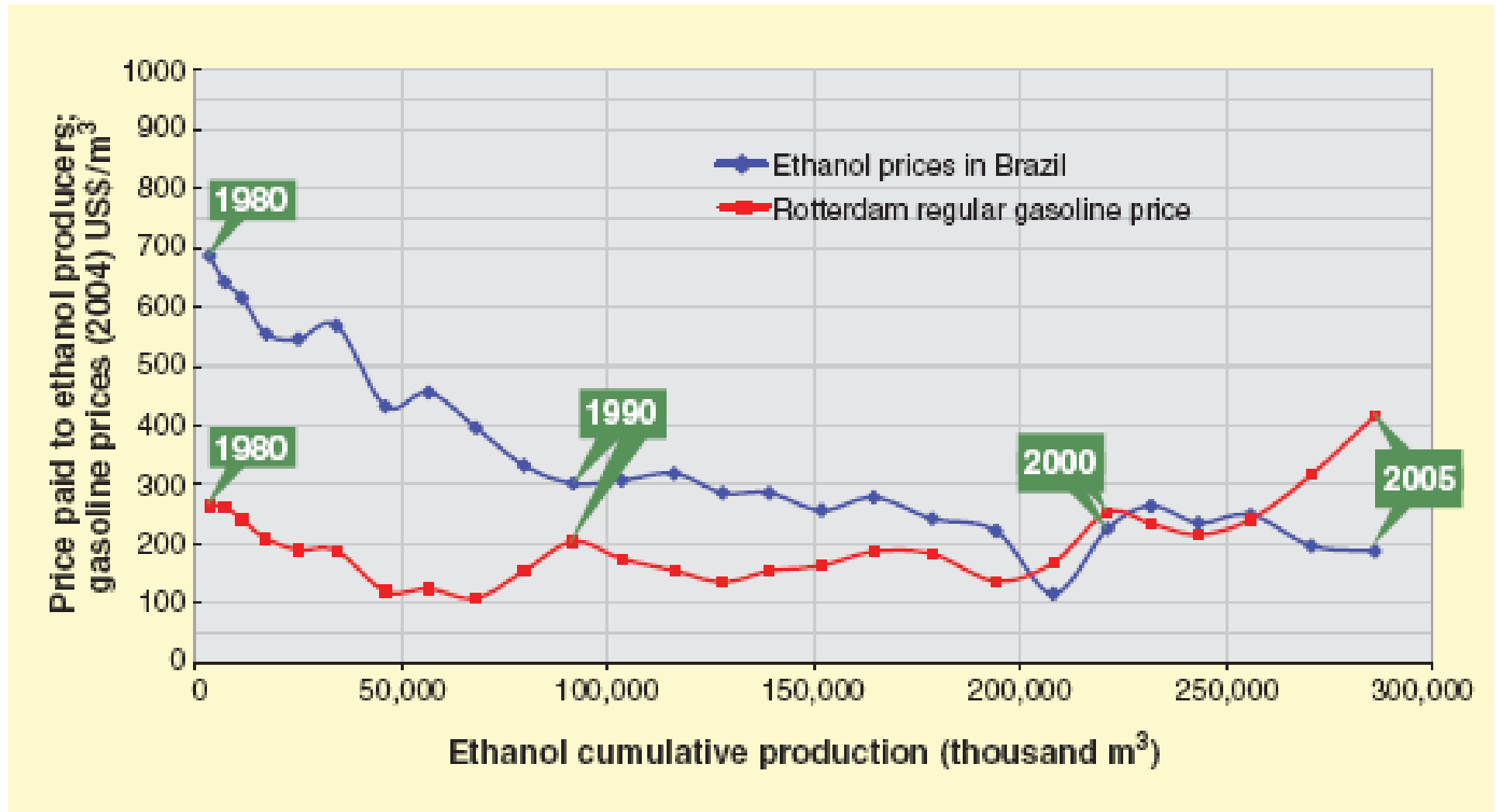
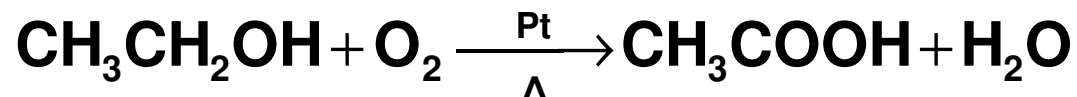


Fig. 2. Ethanol learning curve in volume, comparing the price paid to ethanol producers in Brazil with the price of gasoline in the international market of Rotterdam (6).

Selective Catalytic Oxidation of Ethanol

- 1820 E. Davy
- 1822 J.W. Döbereiner



- Palladium and platinum classical catalysts for oxidation of ethanol

Döbereiner, *Ann. Phys.* **1822**, 72, 193.

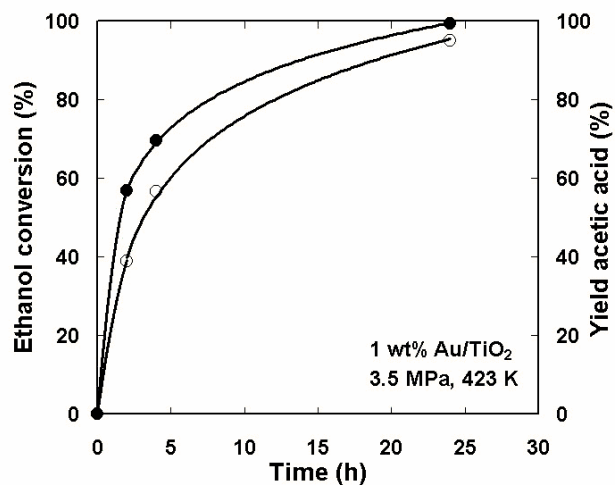
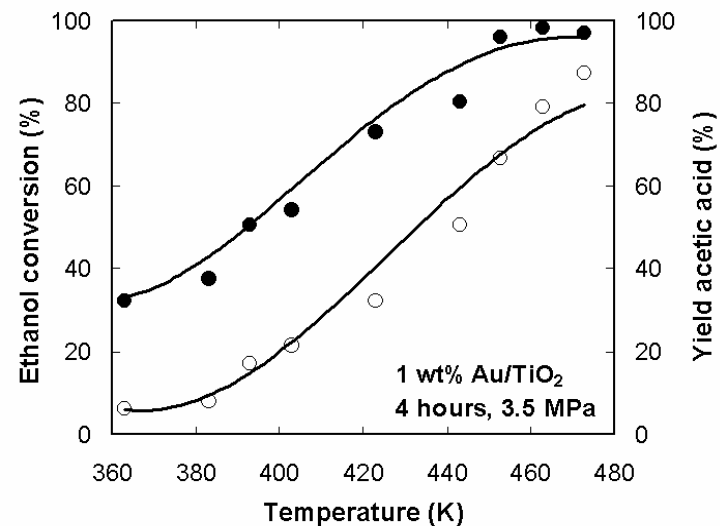
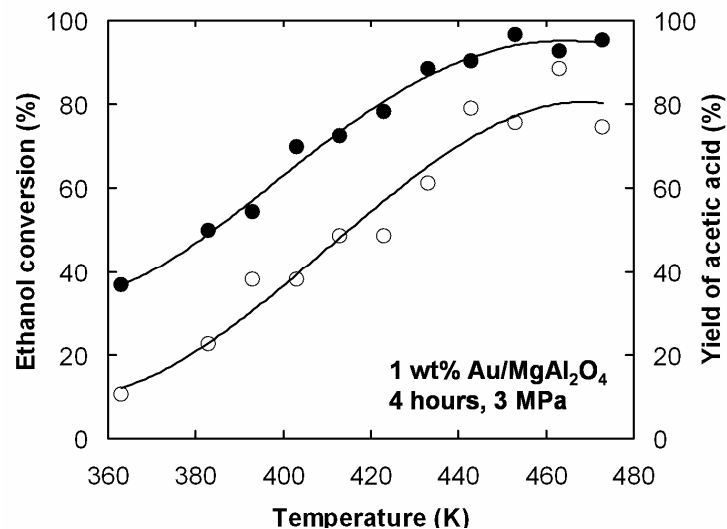
Gold-catalyzed Oxidation of Ethanol

Batch reactions in a stirred autoclave

- 5 wt% ethanol in water
- 1% Au on MgAl_2O_4 and TiO_2
- 3.0-4.5 MPa of air
- 90-200 °C
- 4-30 h

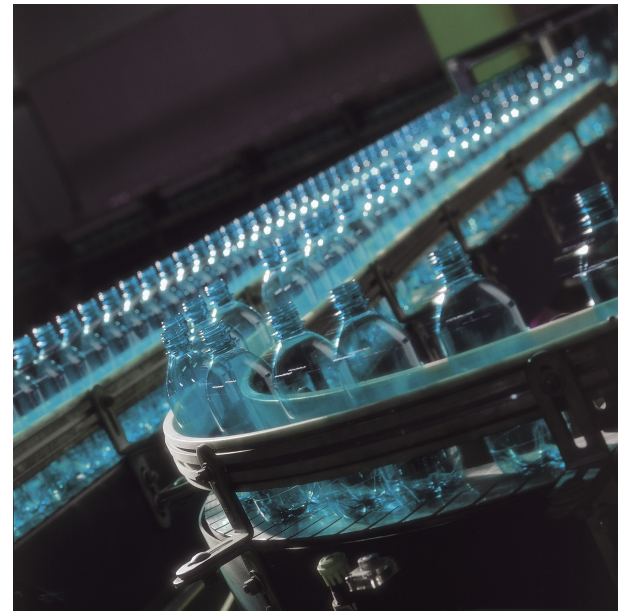
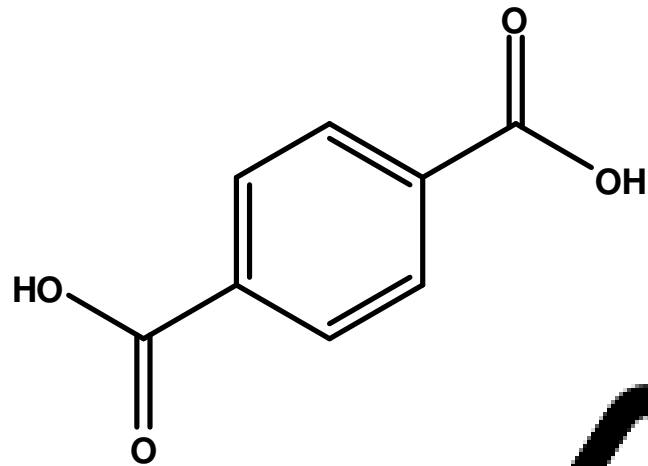
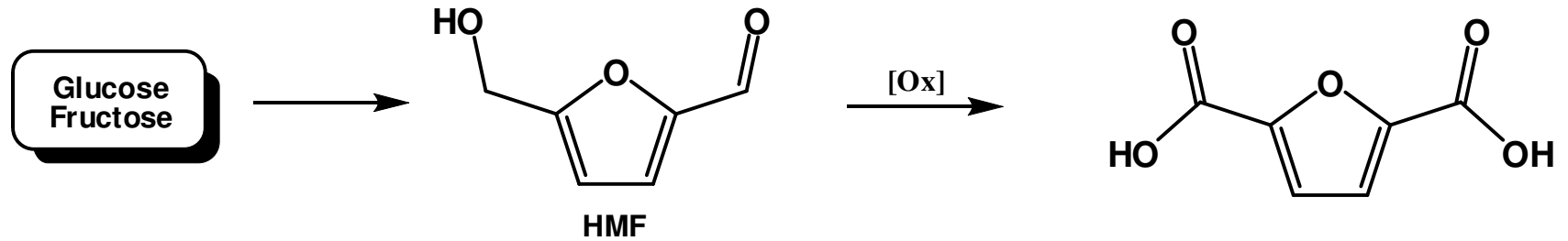


Sustainable Acetic Acid



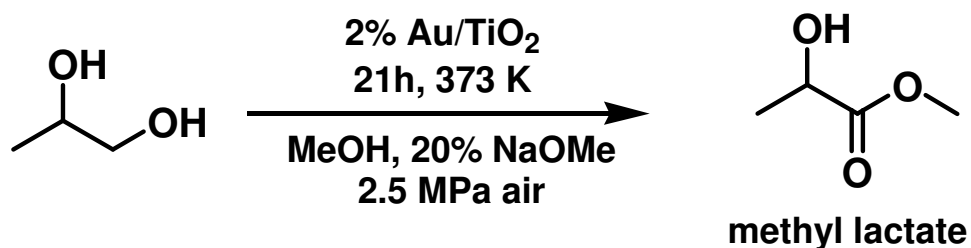
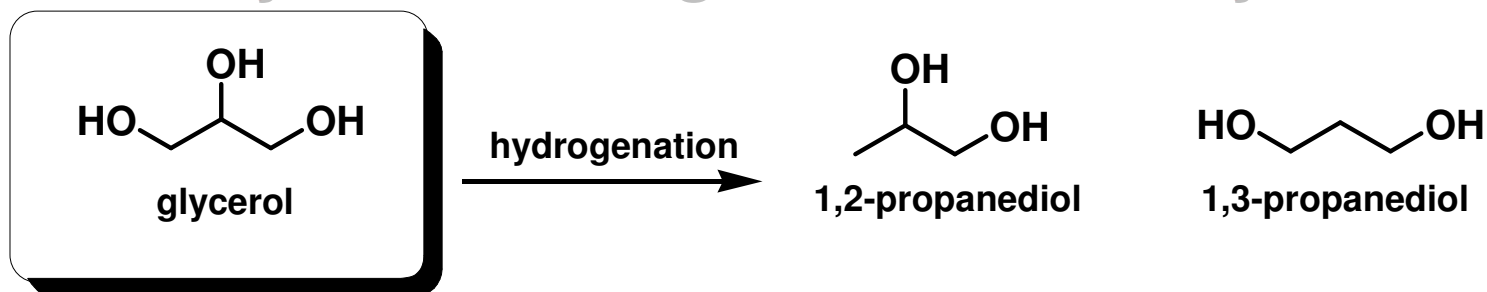
Christensen *et al.*, *Angew.Chem. Int. Ed.* 2006, 45, 4648.

Value-added Chemicals from Biomass

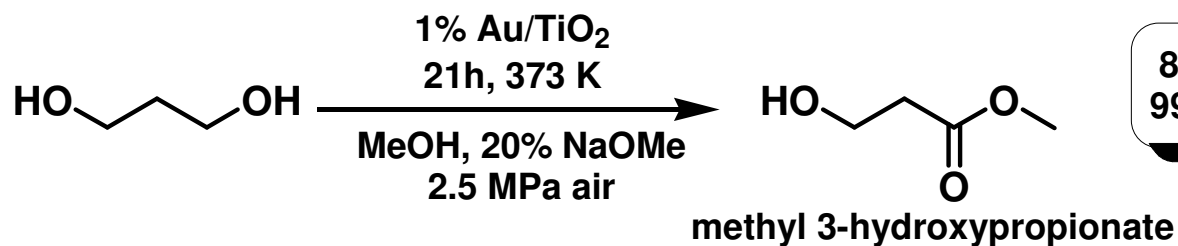


Bottles made of
Polyethylene *tere*-phthalate (PET)

Polymer Building Blocks from Glycerol



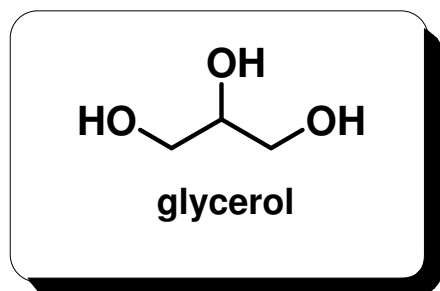
71% selectivity
99% conversion



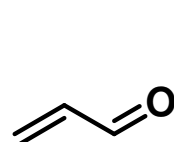
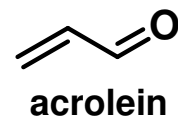
85% selectivity
99% conversion

Taarning, Madsen, Marchetti, Egeblad, Christensen, *Green Chem.*, 10 (2008) 408

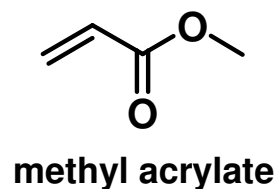
Polymer Building Blocks from Glycerol



dehydration



1% Au/TiO₂
21h, room temp.
MeOH, 20% NaOMe
atm. pressure of air

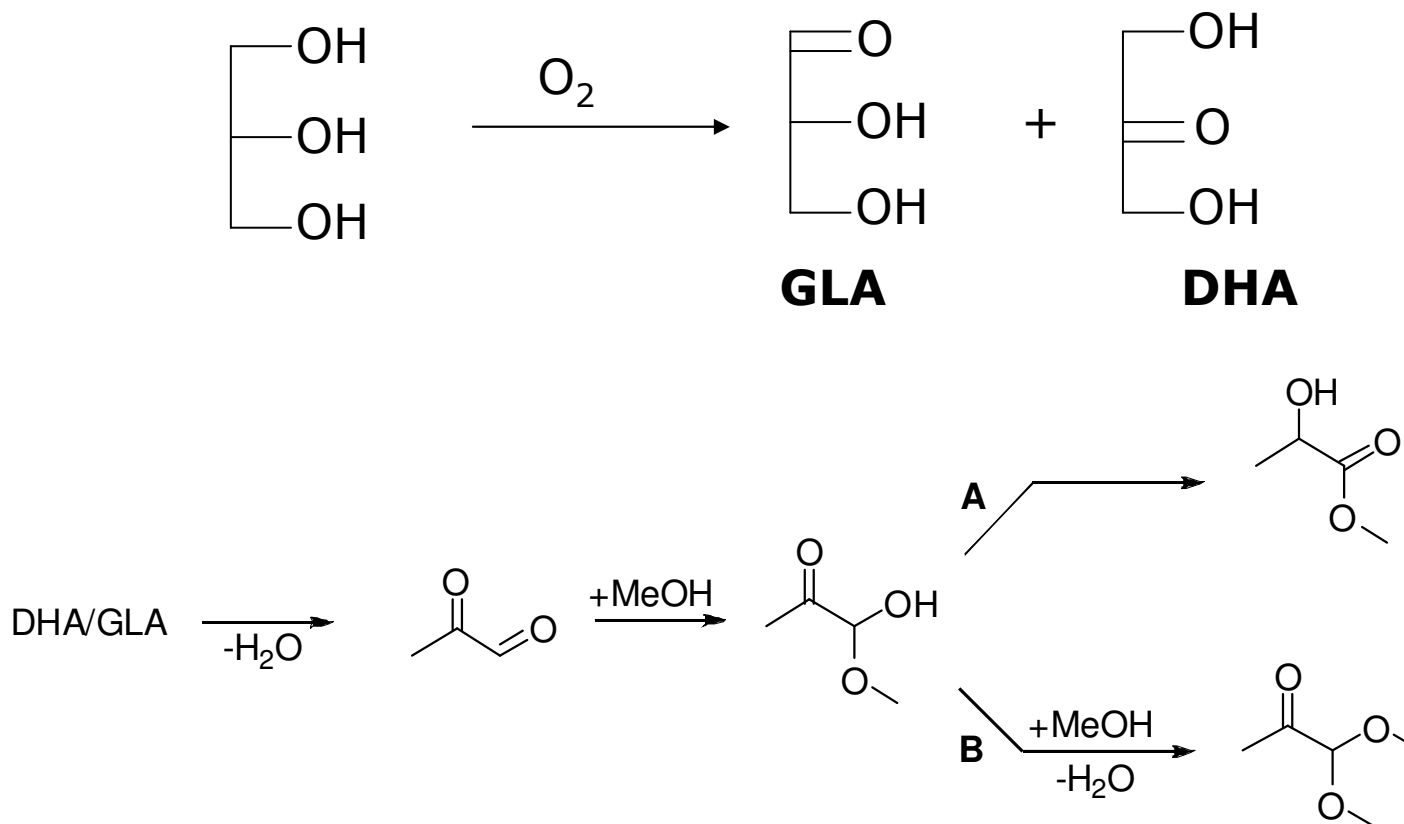


87% selectivity
97% conversion

Marsden, Taarning, Hansen, Johansen, Klitgaard, Egeblad, Christensen, *Green Chem.* 10 (2008) 168

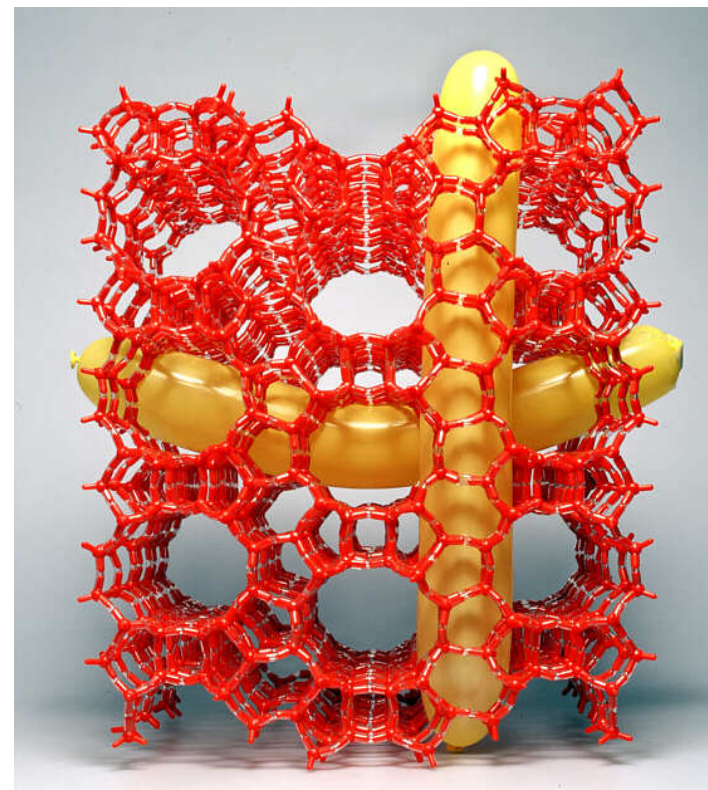
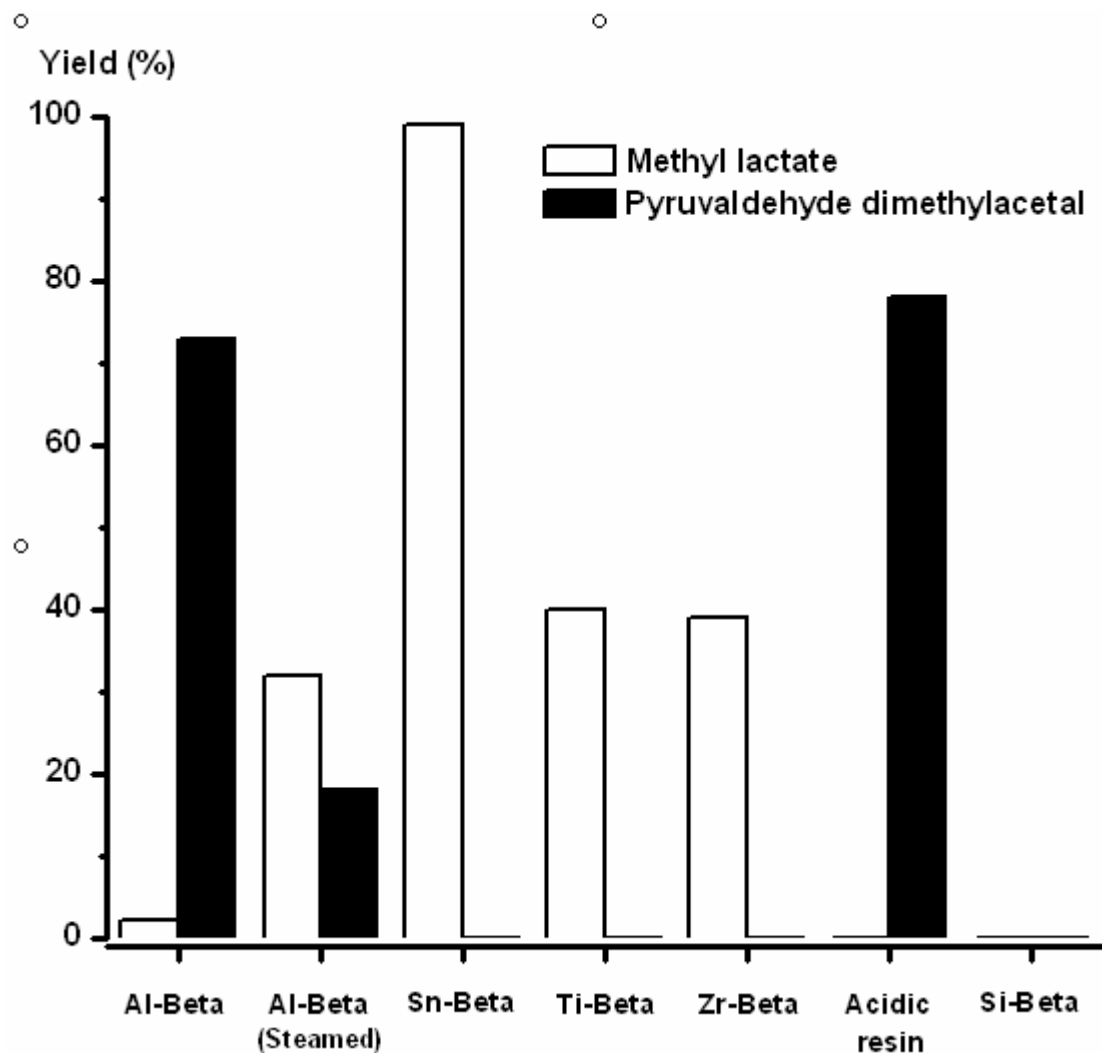
Methyl Lactate from Glycerol using Zeolite Catalysts

- Aerobic oxidation of glycerol using either heterogeneous catalyst or enzyme



Taarning, Saravanamurugan, Holm, Xiong, West, Christensen, submitted (2008)

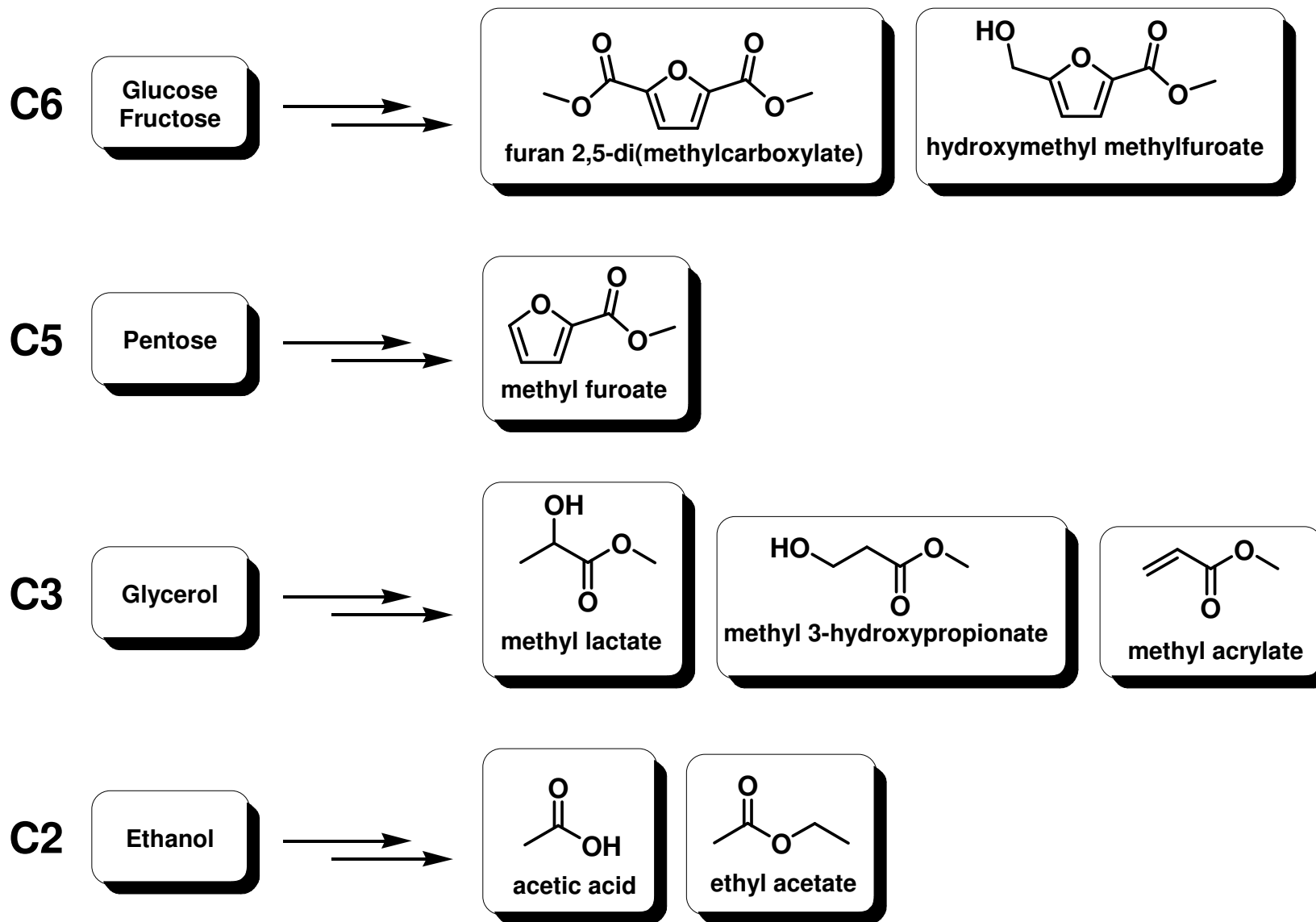
Methyl Lactate from Glycerol using Zeolites



Conditions: DHA (1.25 mmol), methanol (4 g) and catalyst (80 mg) was stirred at 115 °C for 24 hours.

Taarning, Saravanamurugan, Holm, Xiong, West, Christensen, accepted (2009)

Summary



Conclusions

- **The transportation sector will minimize its dependence on carbon – the chemical industry cannot.**
- **Biobased chemicals represents the best use of the limited bio-resources, since**
 - **Biobased chemicals give even further reduced CO₂-emissions than those achieved with biofuels**
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Acknowledgements



Danish National Research Foundation's



Center for Sustainable and Green Chemistry

THANK YOU FOR YOUR ATTENTION !