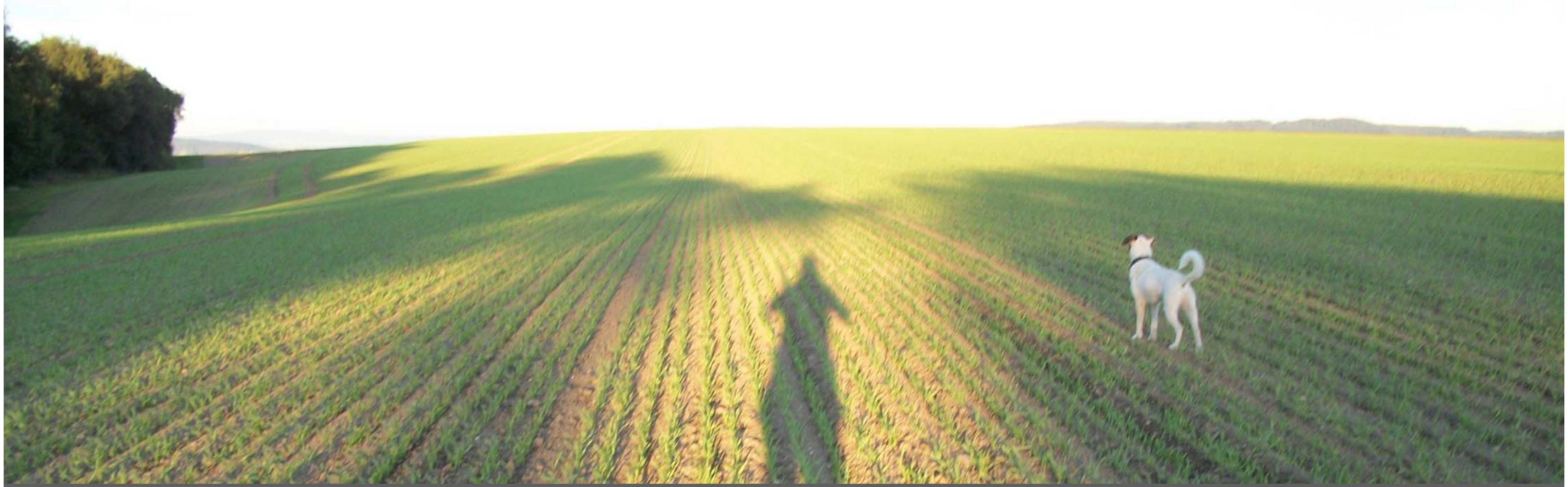
ICCA/IEA/DECHEMA Roadmap Catalysis

Disclaimer

- ☐ This presentation contains preliminary results from an ongoing project.
- ☐ This data is still subject to revision and correction.
- ☐ The final results will be published in a joint roadmap.



Petrochemical Industry Energy & GHG Savings via Catalysis –Still a Large Opportunity

Russel Mills, Dow Chemicals

Catalysis Roadmap Partners:

International Energy Agency

INTERNATIONAL
COUNCIL OF
CHEMICAL
ASSOCIATIONS

DECHEMA
Gesellschaft für Chemische Technik
und Biotechnologie e.V.

ICCA/IEA/DECHEMA Roadmap Catalysis

High Level Objectives

- ☐ Provide credible information on the potential of reducing energy & GHG emissions by applying catalysis
- ☐ Identify key technology breakthroughs, paths to achieve them
- ☐ Give responsible advice for policy makers on how enable this impact

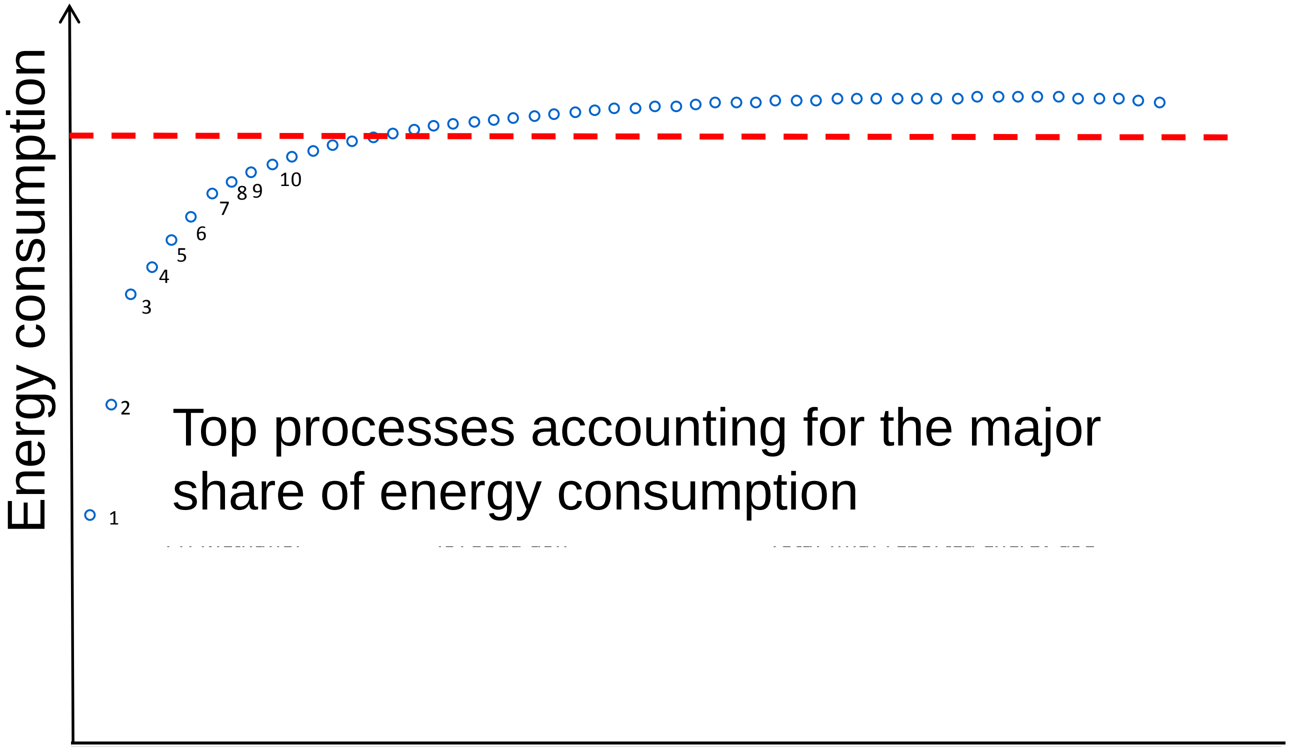
Approach

Assumptions:

- ❑ Large processes also have the largest saving potential (even if relative improvement potential seems low)
- ❑ The large number of small/medium-sized processes can be disregarded (even if relative improvement potential seems high)

Approach

- ❑ Identify ~40 top energy consuming processes
- ❑ Cut-off at top 10-20 for detailed analysis



Top processes accounting for the major share of energy consumption

Methodology I

Bottom up data compilation by survey

Industrial manufacturers survey

- Top energy consuming chemical processes
- Specific energy consumption and direct GHG emissions (1990 – 2020)
- Catalysis impact, future potential, hurdles

Catalyst manufacturers survey

- Chemical processes, refinery processes, other catalysis areas
- Catalysis impact, future potential, hurdles

Catalyst experts

- New catalytic processes
- Expected breakthroughs, feedstock change
- Historical examples

Methodology II

Top down data compilation

SRI Consulting and Chemical Manufacturing Associates Inc. (CMAI)

- Production volumes with regional and country distribution
- Energy Consumptions and allocation to fuels, steam, electricity etc.
- GHG estimates

Other sources

- Available benchmark studies and technical reports
- GHG inventory reports
- Special literature

⇒ **Synthesis of top down with bottom up data**

Selection of Subset: Top Energy Consuming Processes

World Total Energy Consumption
Chemical & Petrochemical Sector (IEA 2009):
14,9 EJ excl. feedstock (36,2 EJ incl. feedstock)

Preselection: 40 major products manufactured by energy intensive processes (catalytic or with potential to run catalytically)

Selection of 18 top products, representing:

9,5 EJ (64% of energy consumption of world total chemical production)

Top energy consuming processes

- Ammonia
- Ethylene
- Propylene
- Methanol
- BTX
- Terephthalic Acid (TPA)
- Polyethylene
- Styrene
- Ethylene Oxide
- Vinyl Chloride Monomer (VCM)
- Polypropylene
- Propylene Oxide
- Ethylene Glycol
- Phenol
- Acrylonitrile
- Caprolactam
- Cumene
- Ethylene Dichloride (EDC)
- Ethylbenzene
- Polyvinyl Chloride (PVC)
- Phthalic Anhydride
- Acetone
- Butadiene
- Acetic Acid
- Vinyl Acetate (VAM)
- Methyl tert-Butyl Ether (MTBE)
- Nitric Acid
- Formaldehyde

Top 18 chemicals: ~130 processes

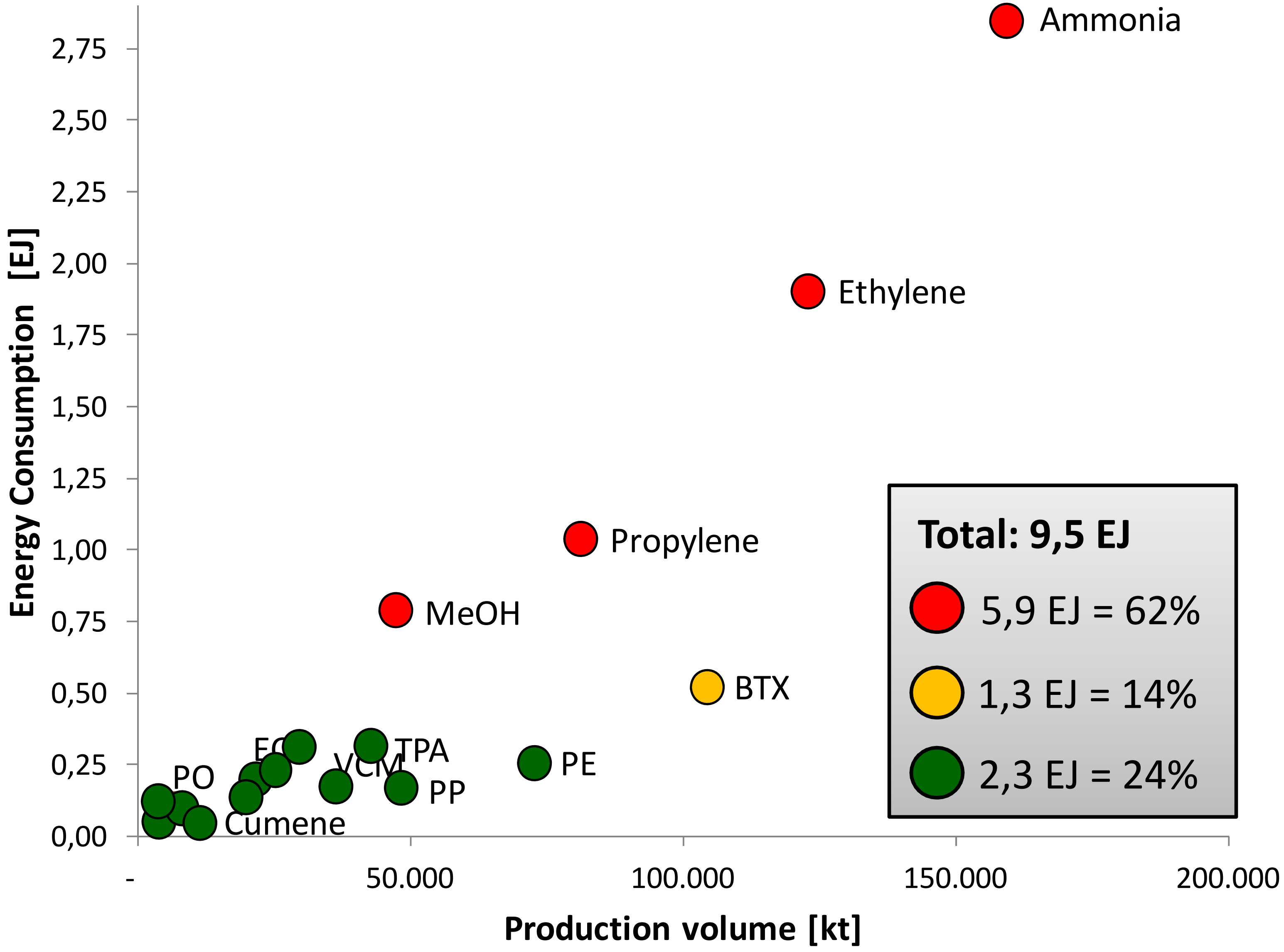
Acrylonitrile from acetylene
Acrylonitrile from propane
Acrylonitrile from propylene
Ammonia from coal (partial oxidation)
Ammonia from heavy fuel oil (partial oxidation)
Ammonia from naphtha (steam reforming)
Ammonia from natural gas (steam reforming)
Benzene from catalytic reformate
Benzene from coal tar
Benzene from coke oven light oil
Benzene from mixed xylenes via toluene disproportionation (MSTDP
Benzene from mixed xylenes via toluene disproportionation (MTPX)
Benzene from propane/butanes (Cyclar)
Benzene from pyrolysis gasoline
Benzene from toluene dealkylation
Benzene from toluene disproportionation
Benzene from toluene/xylenes
Benzene from unspecified raw materials
Caprolactam from cyclohexane (via cyclohexanone)
Caprolactam from cyclohexanone (phenol or cyclohexane-based)
Caprolactam from phenol (via cyclohexanone)
Caprolactam from toluene
Cumene from propylene and benzene
Cumene from recovered
Ethylene from butane
Ethylene from condensate
Ethylene from deep catalytic cracking of VGO
Ethylene from ethane
Ethylene from ethane/propane
Ethylene from ethyl alcohol
Ethylene from gas oil
Ethylene from LPG (propane/butane)
Ethylene from mixed feedstocks
Ethylene from naphtha
Ethylene from naphtha with BZ
Ethylene from propane
Ethylene from refinery off-gases
Ethylene from selected gas streams from coal-to-oil
Ethylene from Superflex technology
Ethylene Glycol from ethylene (ethylene glycol)
Ethylene Glycol from ethylene oxide (hydration)
Ethylene Glycol from unspecified raw materials
Ethylene Oxide from ethylene (chlorohydrin process)
Ethylene Oxide from ethylene (direct oxidation)
Ethylene Oxide from unspecified raw materials
HDPE Gas Phase
HDPE Slurry
HDPE Solution
HDPE Unidentified
LDPE Autoclave
LDPE Tubular
LLDPE Autoclave
LLDPE Gas Phase
LLDPE Slurry
LLDPE Solution
LLDPE Tubular
LLDPE Unidentified
LLDPE/HDPE Gas Phase

Boundary conditions

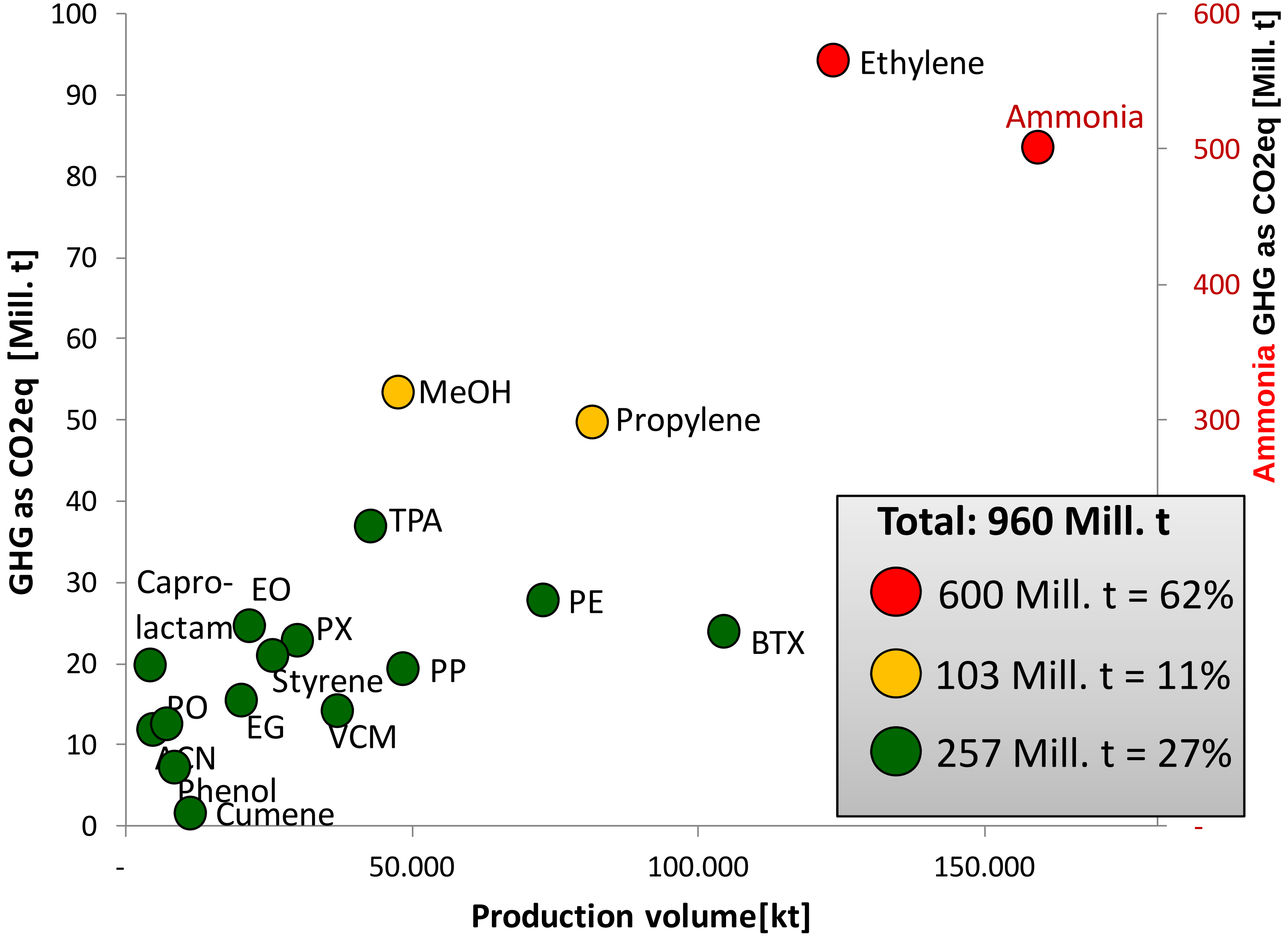
- Process system boundaries:
  - fence to fence (e.g. for EO: ethylene as feedstock, ethylene production not included)
- Specific Energy Consumption (SEC) includes:
  - direct energy (fuel, steam)
  - Indirect energy (electricity)
  - Energy equivalent of feedstock is <u>not</u> included
- GHG emissions
  - Direct process emissions as CO_2 equivalents
  - Direct utilities emissions (fuel)
  - Indirect emissions (electricity) MWh/t -> tCO_2/t*

* based on an average energy mix in the U.S (0,584 MT/MWh (electricity) and 0,05598 MT/GJ (heat + fuel))

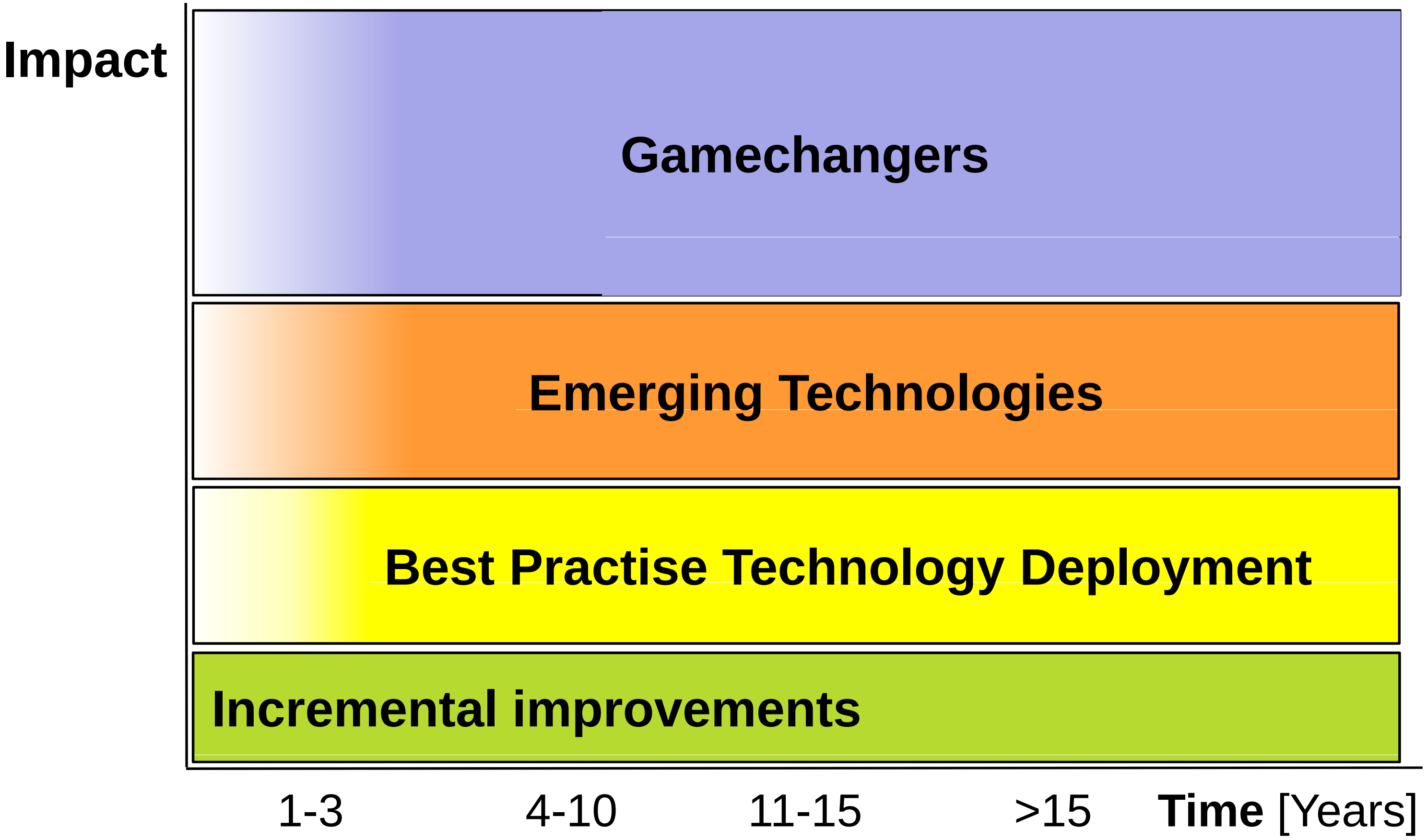
Energy consumption top 18 chemical products



Process related GHG emissions top 18 chemical products



Potential energy reduction options



Reduction options

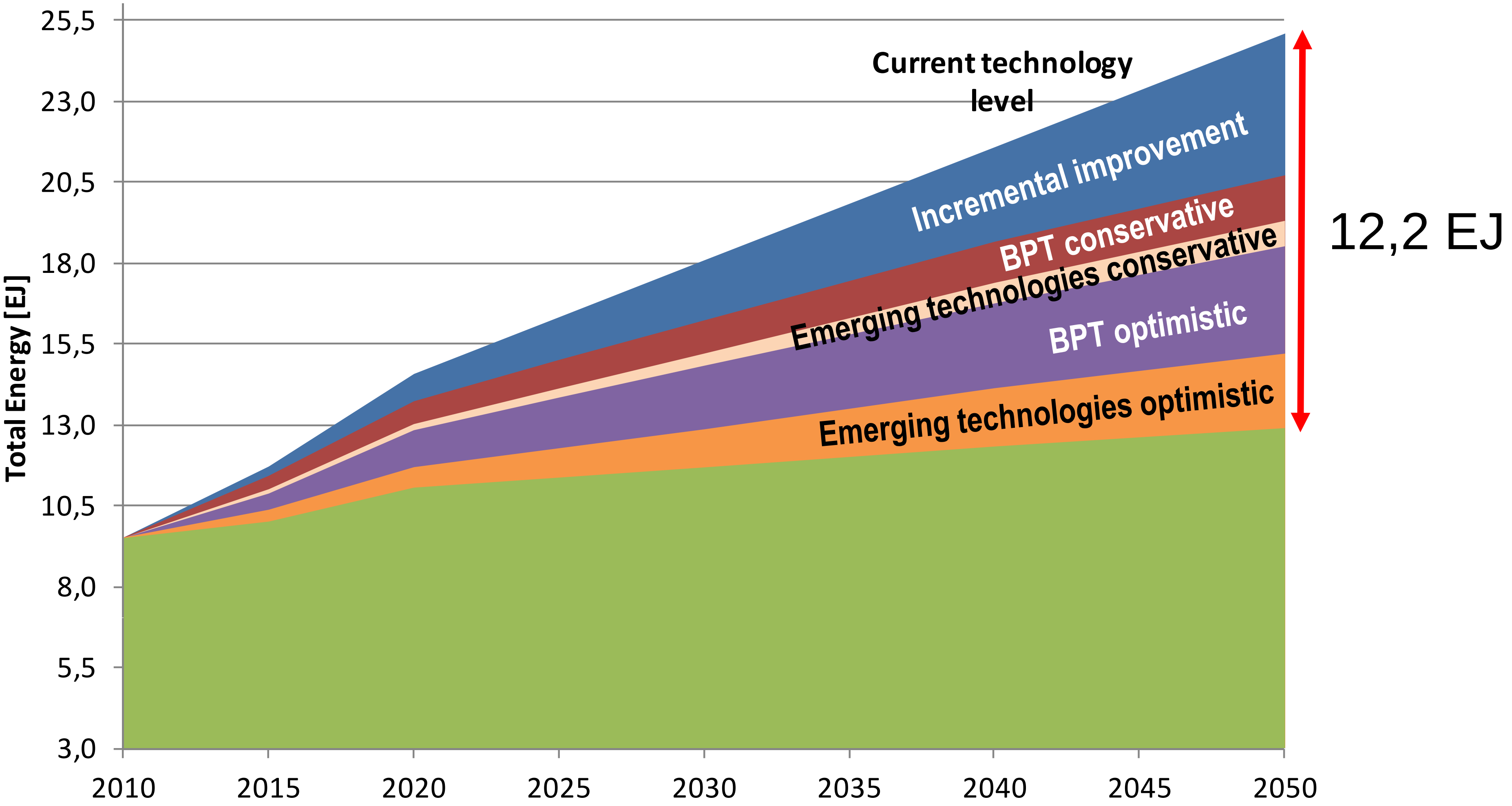
- **Incremental improvements**
  - small, continuous technological advances
  - retrofits to already existing plants
- **Best practise technology (BPT) implementation**
  - Most energy-efficient process configurations
  - established technologies in existing plants or new facilities
- **Emerging technologies**
  - step-change advances via application of new technology
  - currently in demonstration or later R&D stages
  - Here: catalytic olefin technologies, MTO
- **Gamechangers**
  - significant change of process; direct routes, alternative feedstocks
  - far from commercialization, high economic and technical hurdles, relatively high risk
  - Here: renewable hydrogen for NH_3 and MeOH and biomass

Compared scenarios

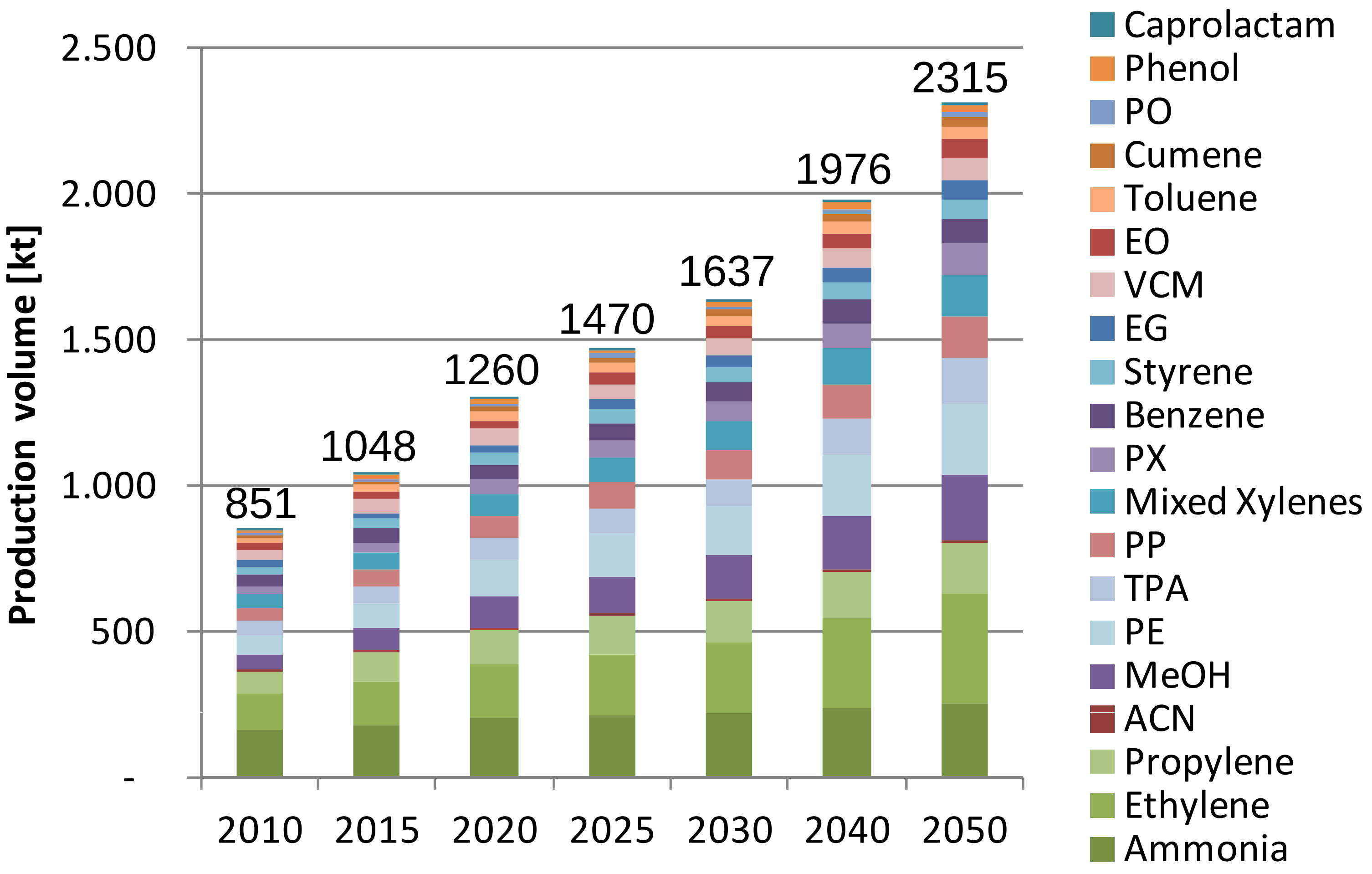
- **Optimistic scenario**
  - All new and retrofitted plants with energy efficiency at the new technology level

- **Conservative scenario**
  - 50% of new plants at new technology level
  - 30% of retrofitted plants at new technology level, 70% at average energy consumption

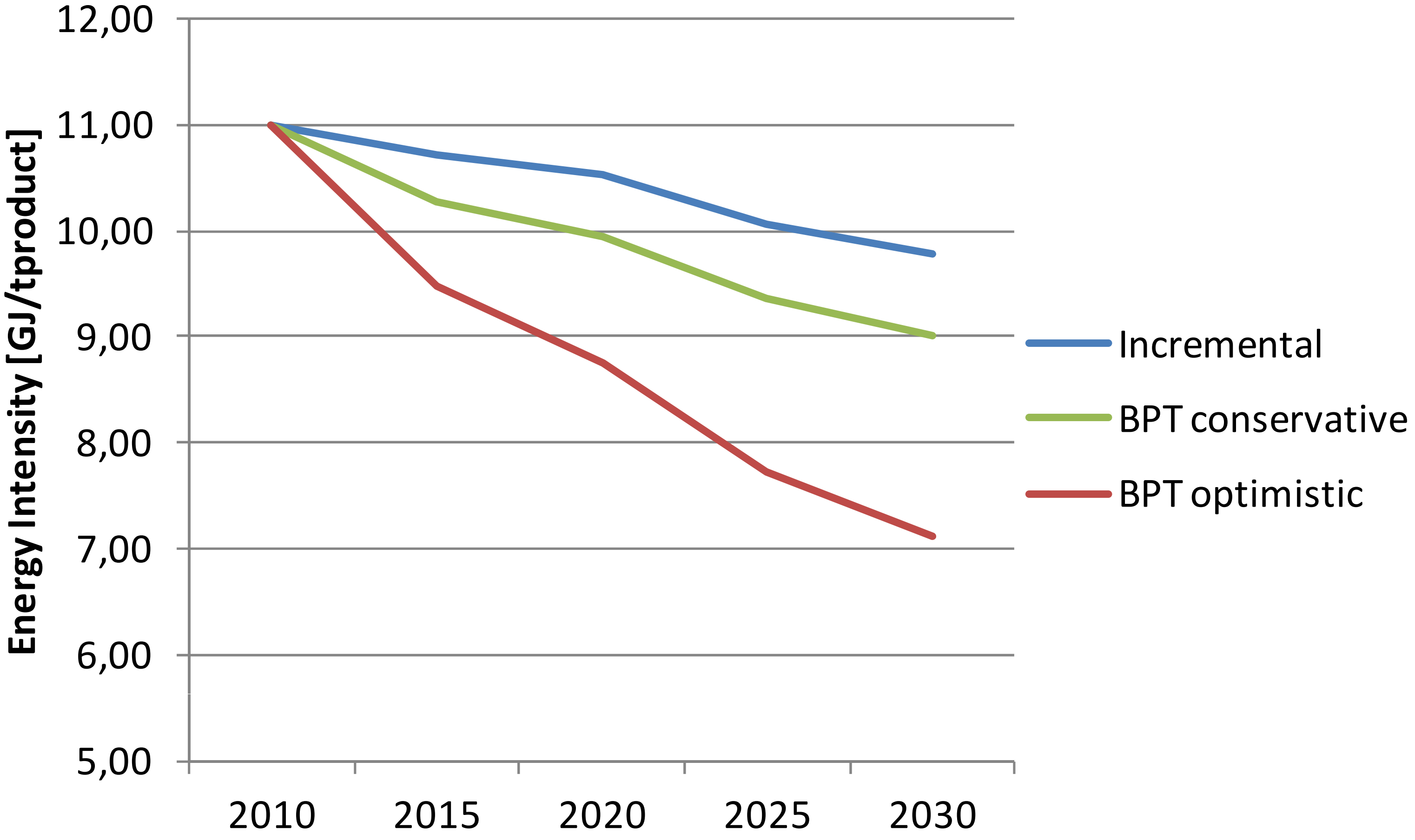
Potential energy reduction options



Expected production volumes



Avrg. Energy Intensity



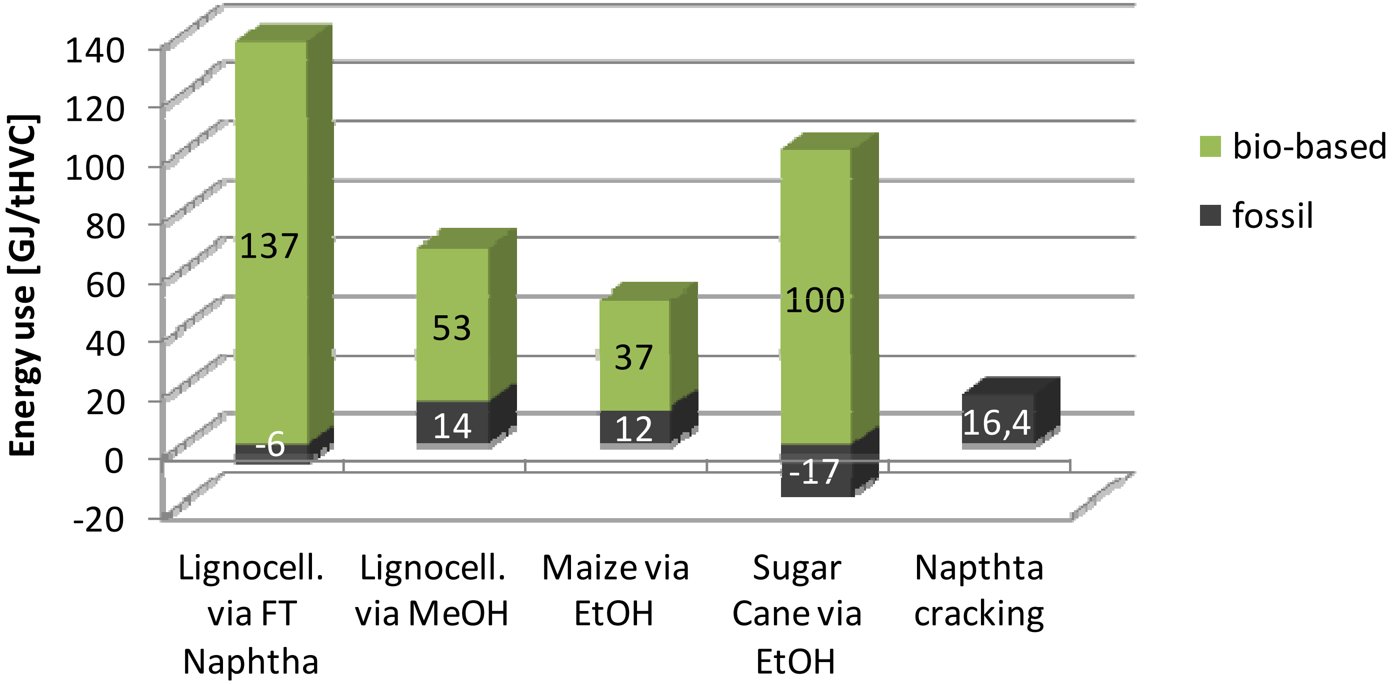
Impact of gamechangers

Discussed options

- Biomass as feedstock for olefins (ethylene, propylene)
- Hydrogen as feedstock for chemical processes available from renewable energy sources

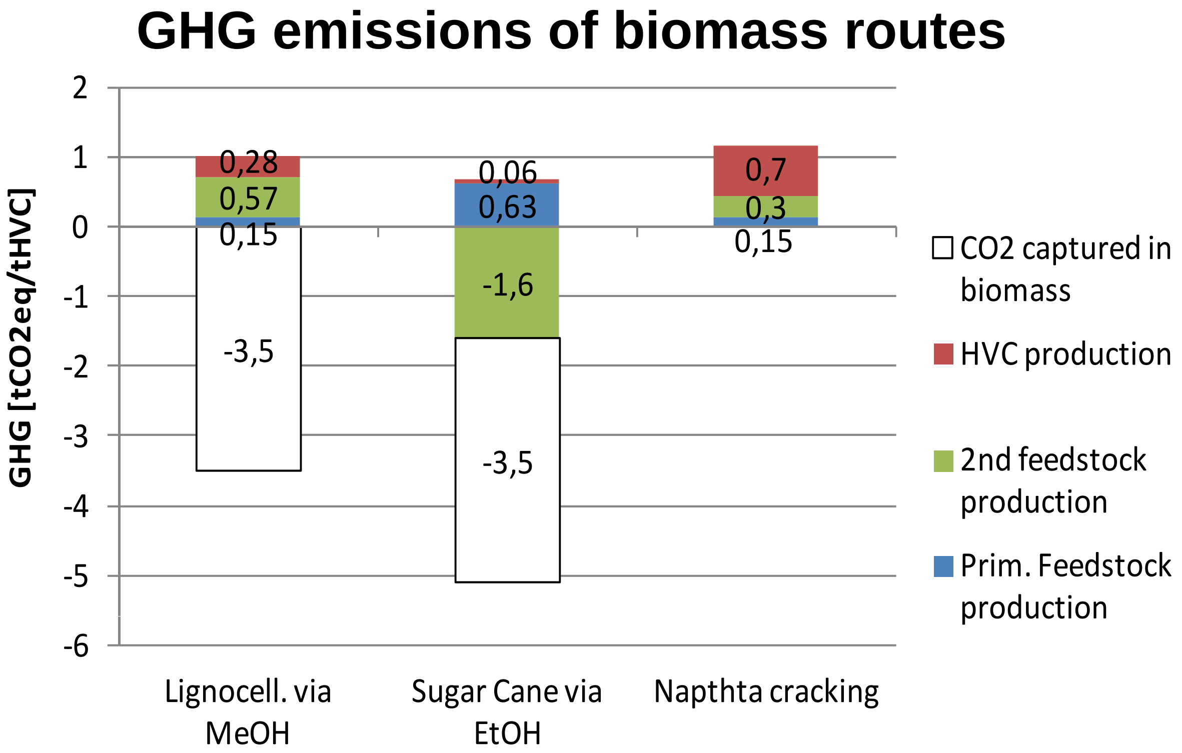
Biobased ethylene and propylene

Biomass and fossil energy use of biomass routes



- ❑ Substantial **biomass-derived** energy consumption
- ❑ Reduced **fossil** energy consumption

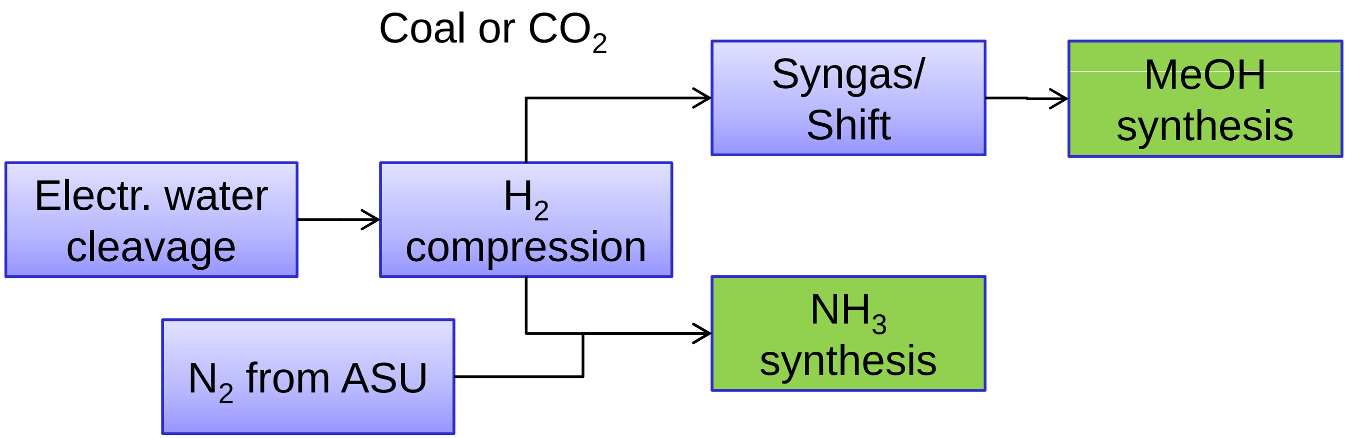
Biobased ethylene and propylene



- ❑ Reduced GHG emissions due to carbon captured in biomass and sequestered in MeOH/HVCs
- ❑ Process related GHG emissions comparable to fossil routes, in some cases lower*

*depending on process configuration,
e.g. co-generation of electricity

Hydrogen option



Coal or CO_2

Electr. water cleavage

H_2 compression

N$_2$ from ASU

Syngas/ Shift

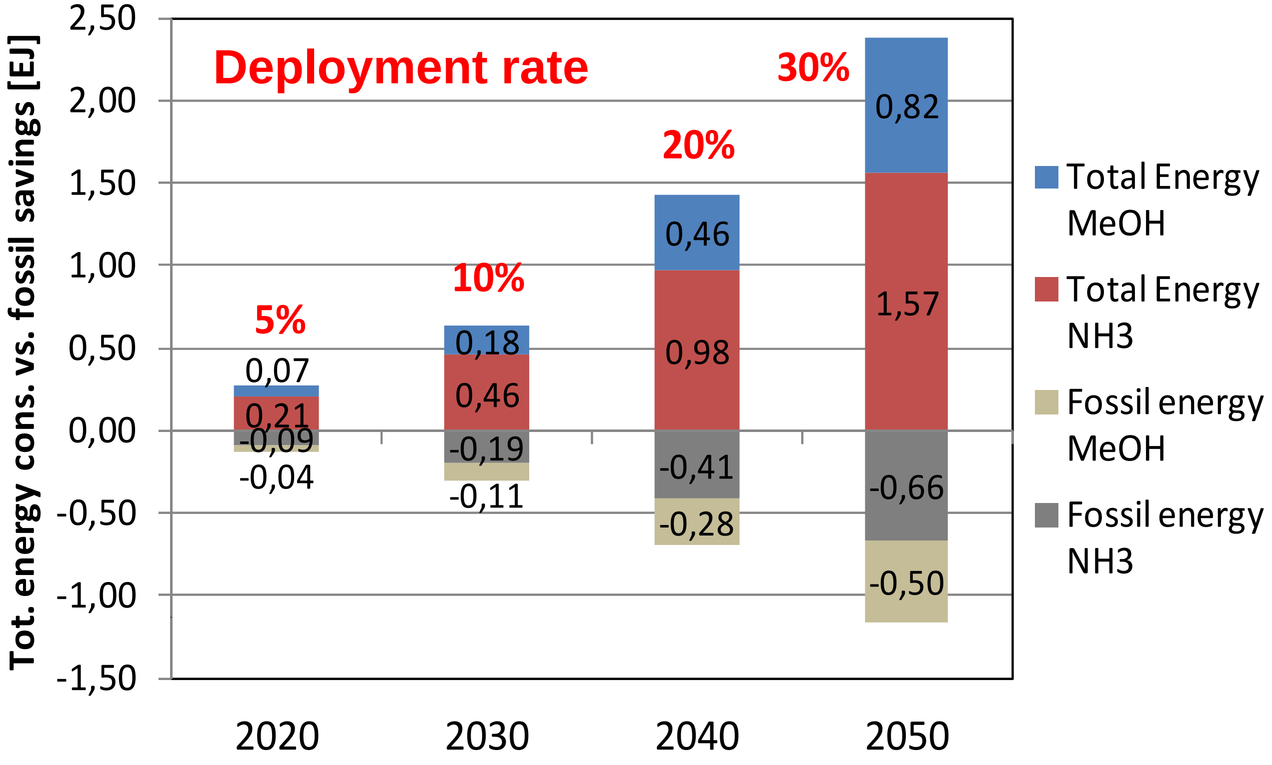
MeOH synthesis

NH_3 synthesis

	SEC H_2 route [GJ/t]	SEC BPT (gas) [GJ/t]	GHG reduction
Ammonia	37,3	7,2-9,0	1,2 t/tNH_3
MeOH from coal	27,8*	9,0-10,0	-0,52 t/tMeOH
MeOH from CO_2	43,7**		-1,84 t/tMeOH

Hydrogen option

Energy impact of hydrogen based ammonia and methanol production

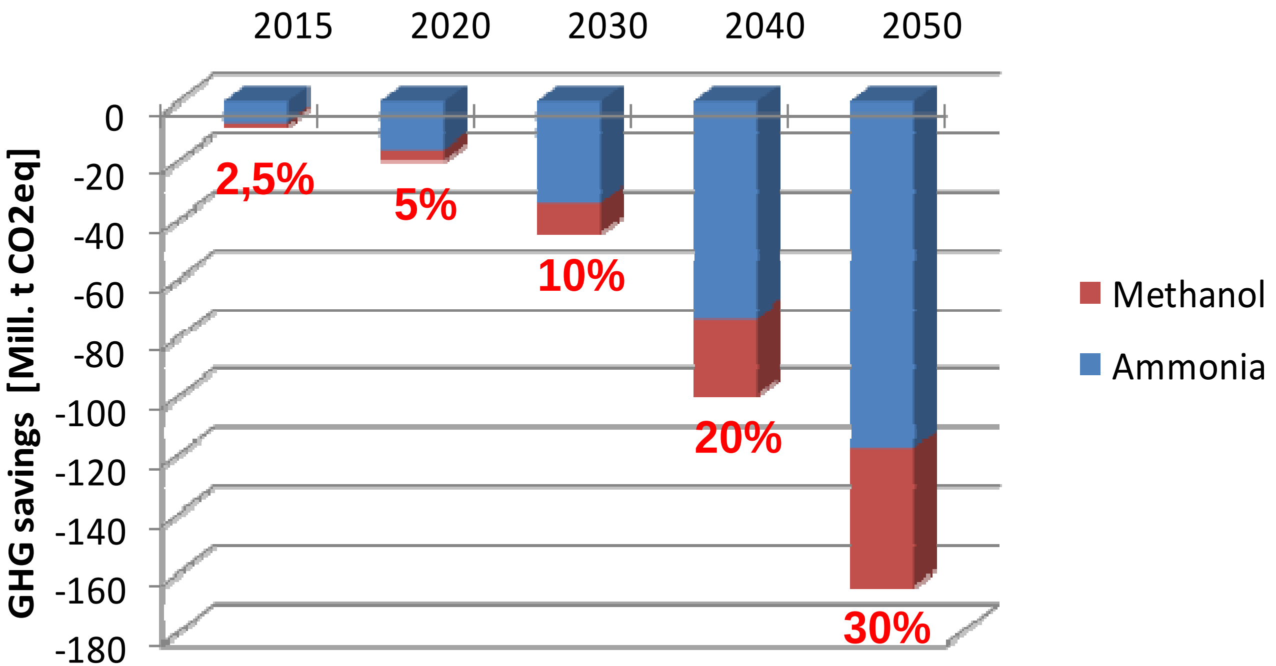


Example:

- ❑ 30% deployment in 2050:
- ▪ 1,4 EJ more energy
- ▪ 1,15 EJ less fossil energy

Hydrogen option

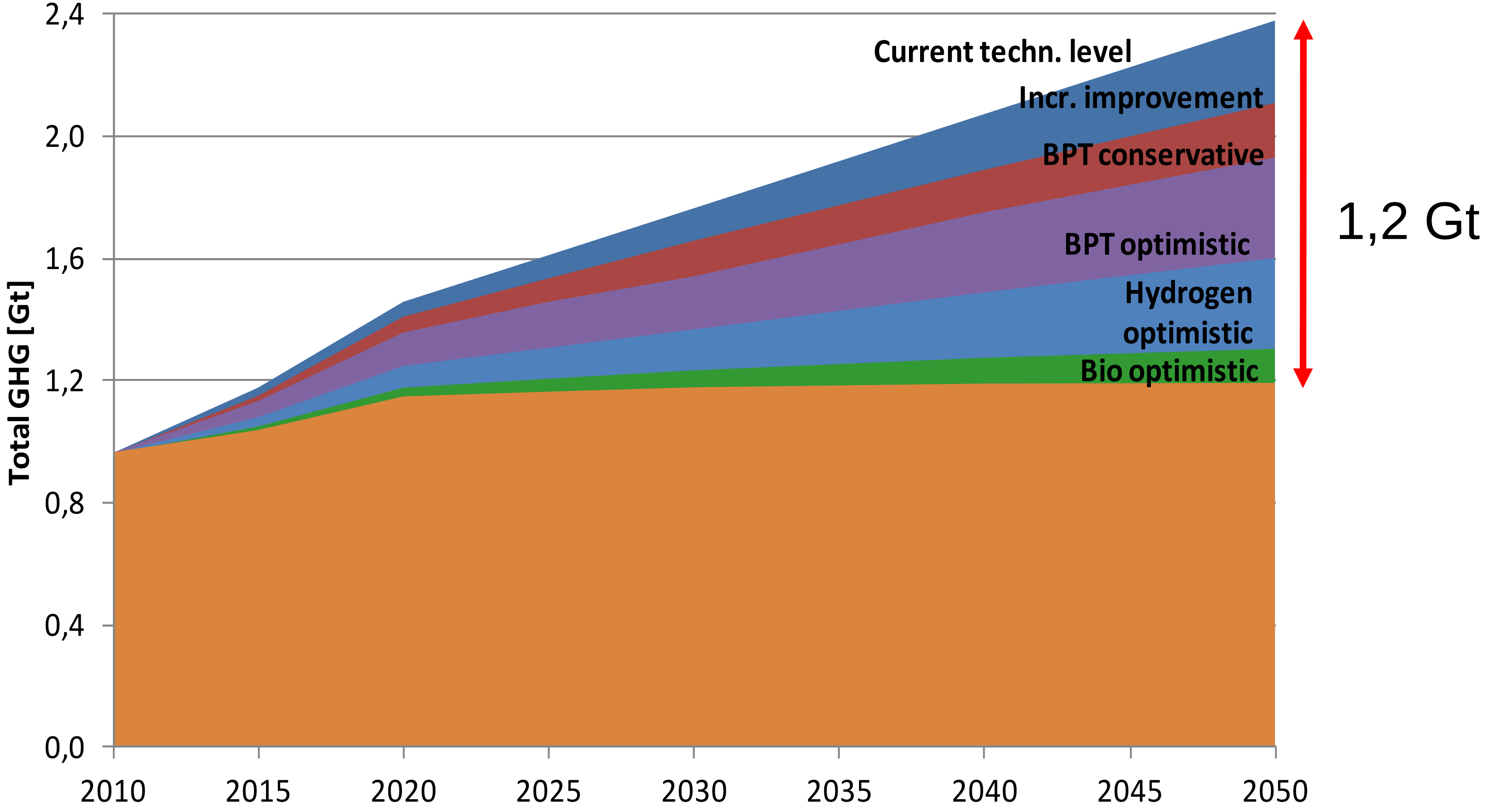
GHG impact of hydrogen based ammonia and methanol production



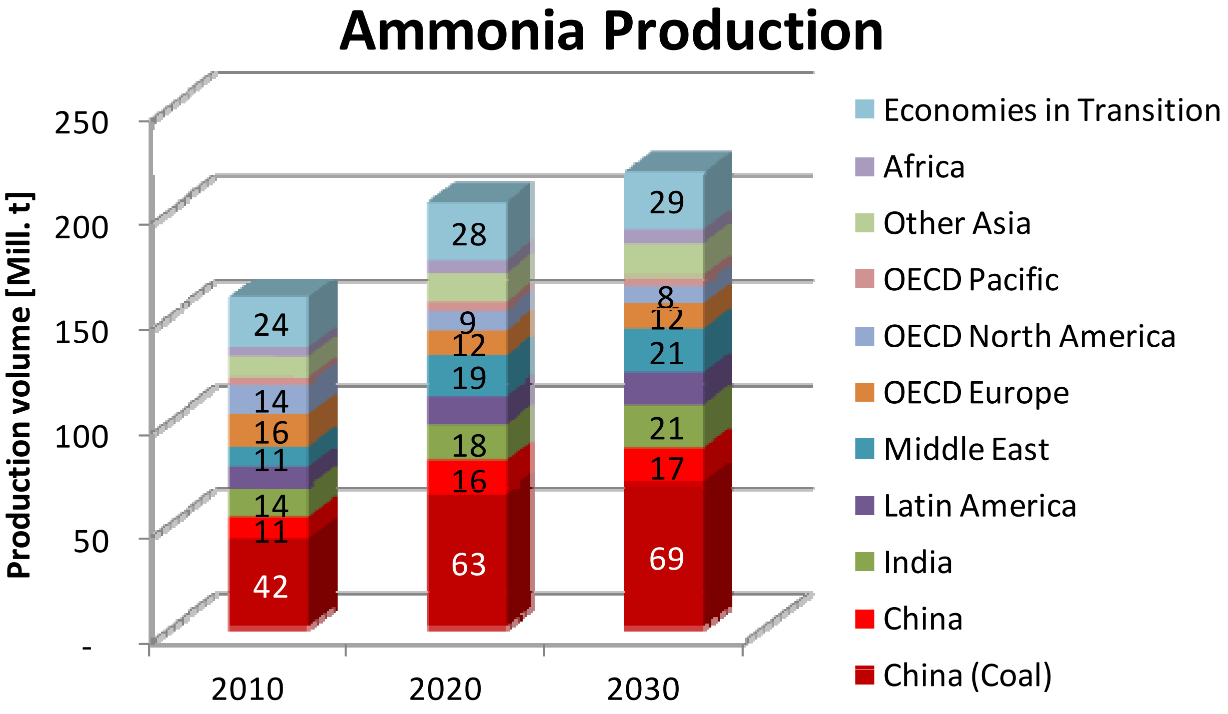
Example:

- ❑ 30% deployment in 2050:
- ▪ GHG reductions of 170 Mill t CO2eq.

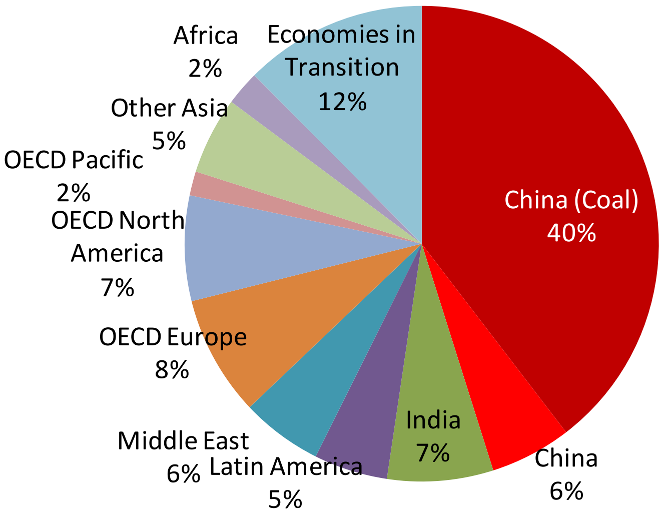
Potential GHG reduction options



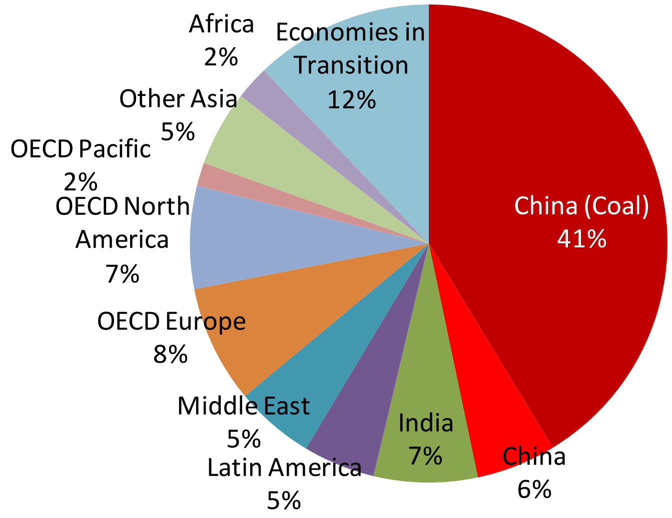
Regional impact: example ammonia



Ammonia Production



Energy consumption



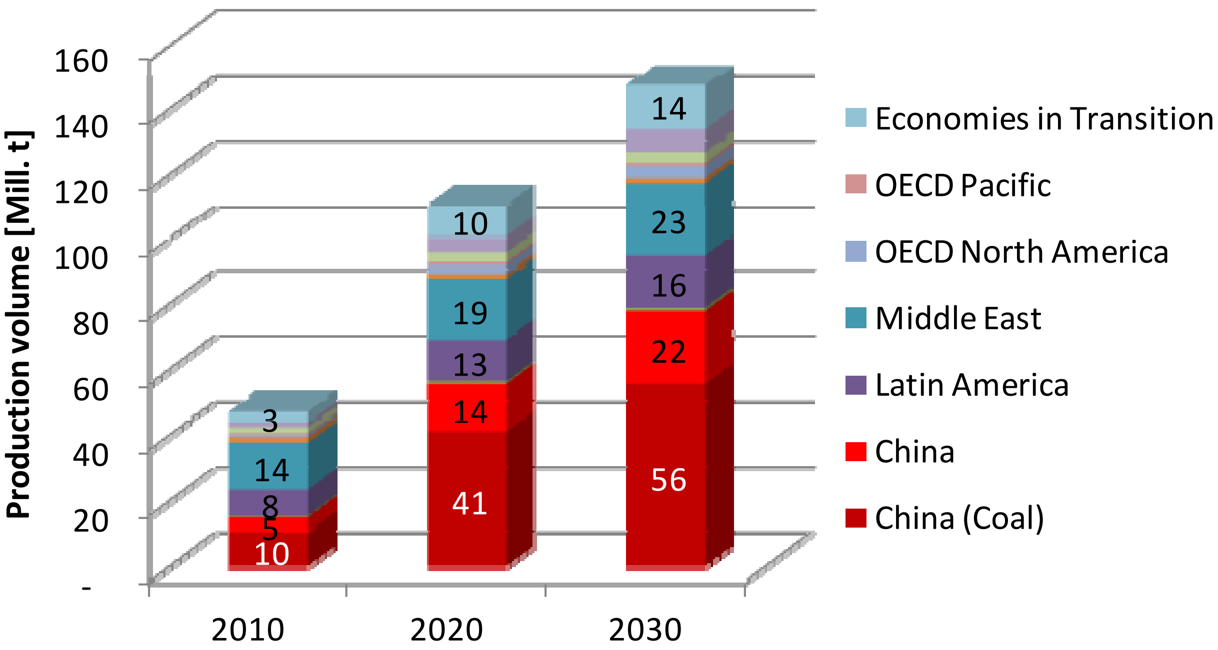
GHG emissions

Primary feedstock for ammonia and methanol in China: Coal

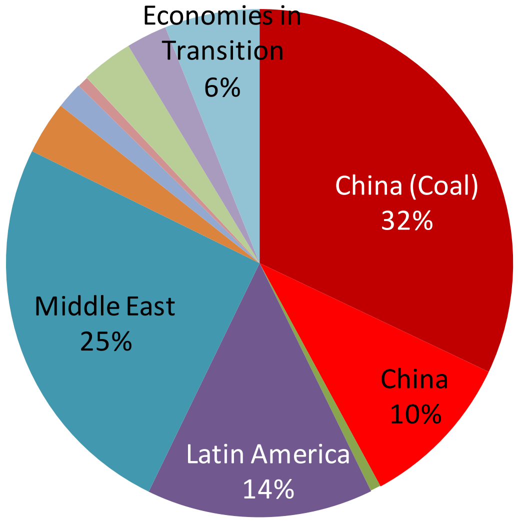
- 1.7 x higher energy consumption compared to gas
- 2.3 x higher CO_2 emissions compared to gas

Regional impact: example methanol

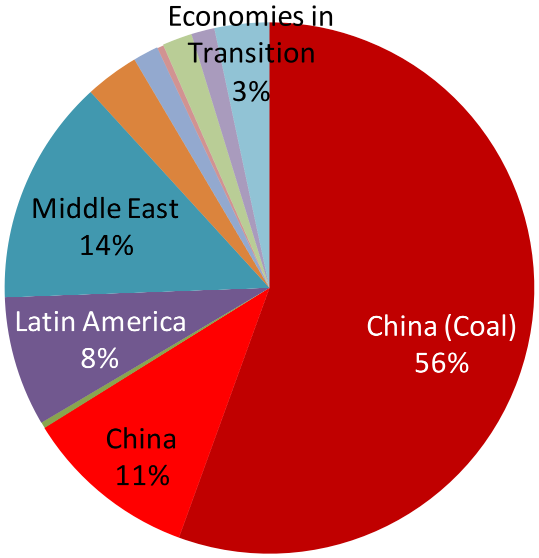
Methanol Production



Energy consumption



GHG emissions



Primary feedstock for ammonia and methanol in China: Coal

- 1.7 x higher energy consumption compared to gas
- 2.3 x higher CO_2 emissions compared to gas

Conclusions

- Potential energy & emissions savings via catalysis in the chemical segment vs. a “do nothing” case of 12 EJ/yr and 0.86 Gt CO2/yr by 2050 (incremental + BPT scenarios)
- Full implementation of Best Practice Technology could improve energy intensity per ton of product by as much as 40% by 2050.
- While these energy savings are sizeable on an absolute scale, expected production increases globally will likely outpace these savings and overall energy and GHGs will likely increase
- Reducing energy use or GHG emissions by half or more by 2030 or 2050 does not seem realistic even in developed regions with lower growth such as Europe .
- Gamechangers could yield additional reductions in GHGs, but would increase energy use and require huge investments to develop / lower operational costs