

# *The role of bioenergy and green gas technologies in energy systems decarbonisation strategies*

**Gabin MANTULET,  
Adrien BIDAUD, Silvana MIMA**

# Plan

I – Energy context

II – Green gas process

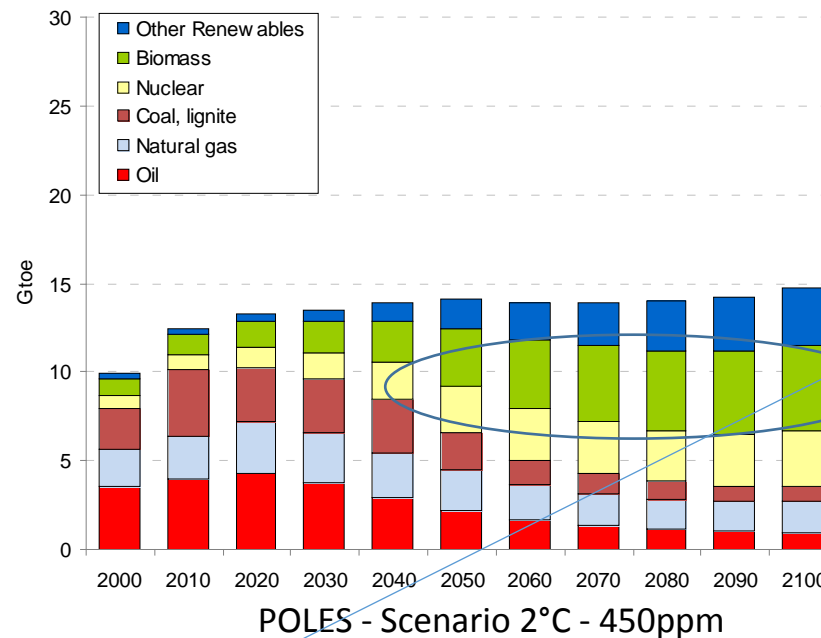
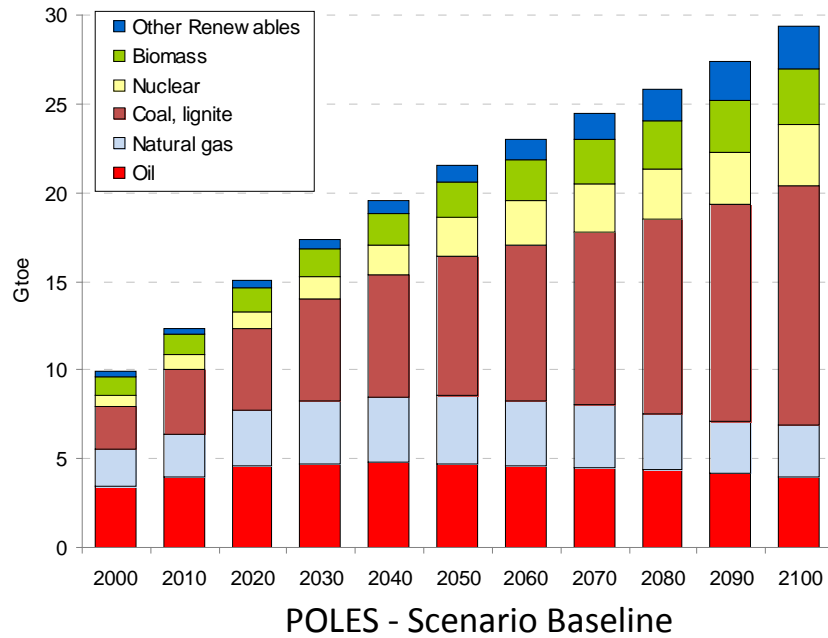
III – Methodology

IV – Modelling results

V – Conclusions and perspectives

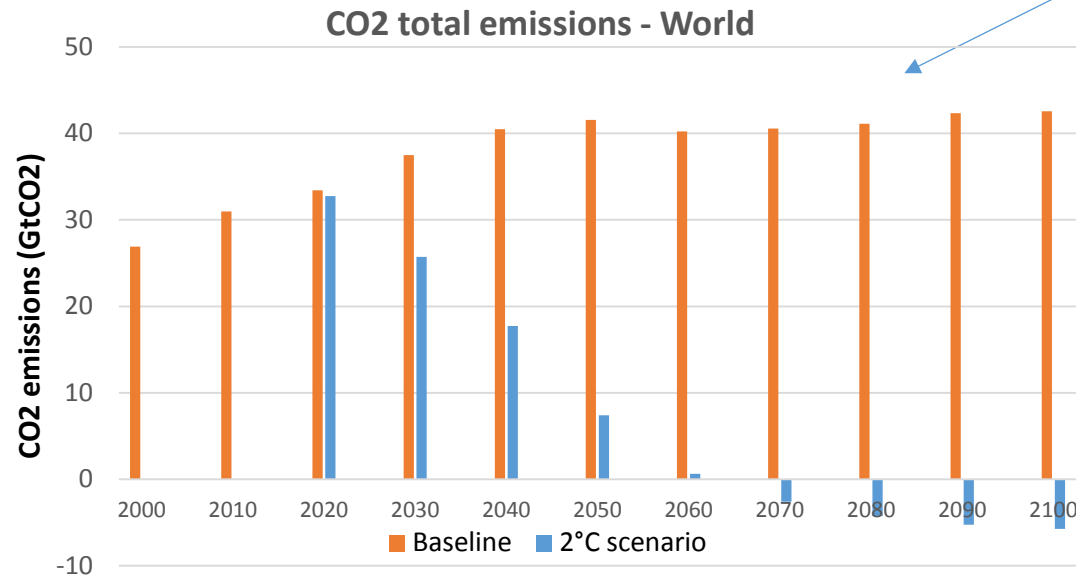
# I – Energy context: need of energy system decarbonisation

## World primary consumption



Importance of biomass

- Renewable energy
- Various energetic or chemical valorization
- Negative CO2 emissions



- The interactions of bioenergy deployment and emission reductions have been analyzed in a number of studies : **prominent role of biomass with climate policies**
  - Combustion: heat and electricity
  - Biofuels
  - Biogas
- This study : more detailed analysis on the availability of bioenergy technologies and their role in emission limitations.

# Plan

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**II – Green gas process**

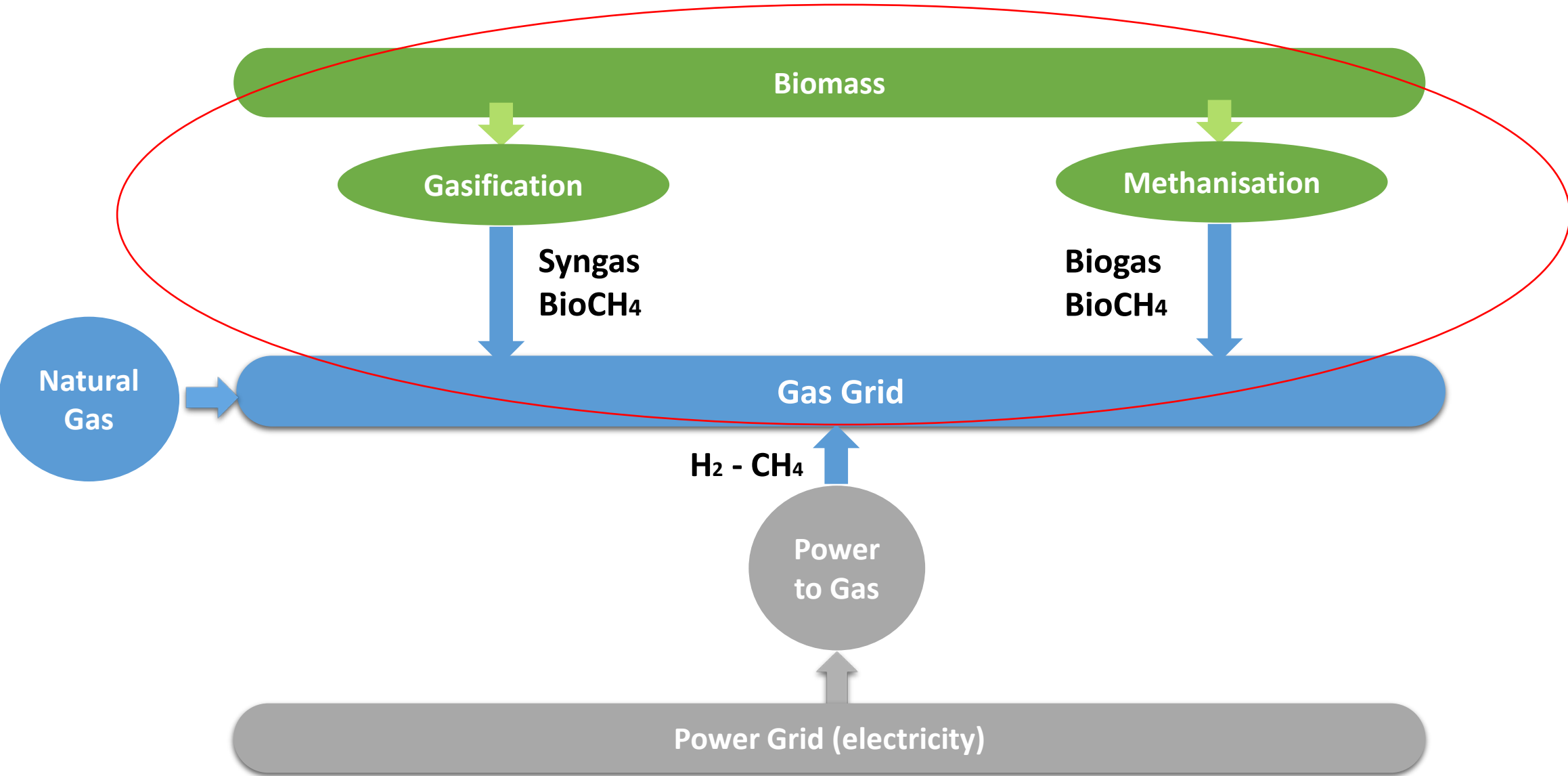
III – Methodology

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# II – Green gas processes

The study : the role of new utilizations of biomass linked with **green gas** vector: **gasification** and **methanisation**



Source: GRTgaz, projet Jupiter 1000, dec 2016

# Plan

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II – Green gas process

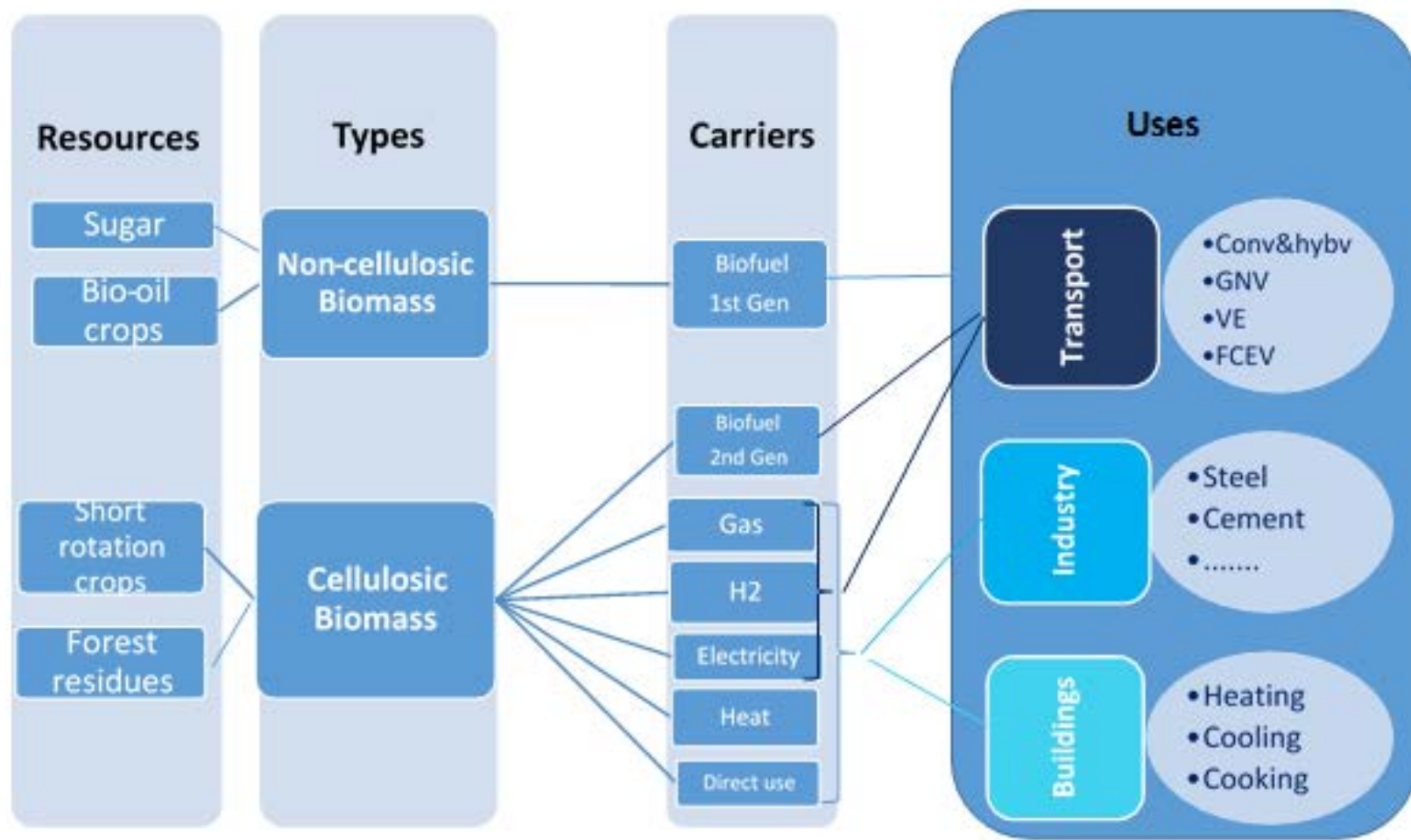
**III – Methodology**

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# III – Methodology: biomass modelling in the POLES model



- Several biomass generations with different energetic valorization
- Each bio-energy feedstock is represented by a maximum potential and a marginal cost curve  
→ informations comes from specialist models: GLOBIOM (from IIASA, by default), Green-X, etc.

# III – Methodology: biomass in climate constraint scenarios

## 1) 3 scenarios

- **Baseline** = business as usual
  - Stabilization of GES emission up to 50GtCO<sub>2eq</sub>/year until 2100
  - 2010 – 2100 carbon budget : **4500 GtCO<sub>2eq</sub>**
- **2°C scenario** = presence of climate policies in order to reduce CO<sub>2</sub> emissions
  - 2010 – 2100 carbon budget : **900 GtCO<sub>2eq</sub>**
    - One scenario with the possibility of implementing **CCS technologies** to have **negative emissions** in the second part of the century
    - An another **without**, considering actual uncertainties about CCS future.

## 2) Output declined as

- **Perimeter** (World and several countries: France, China, Brazil and USA)
- **Type of biomass** (1<sup>st</sup> and 2<sup>nd</sup> generation of biomass)
- **Final use** (electricity, heat, gas, biofuel)
- **Technologies** (gasification and methanisation)

## 3) Comparisons with other output from models

- International Energy Agency
- World Energy Council



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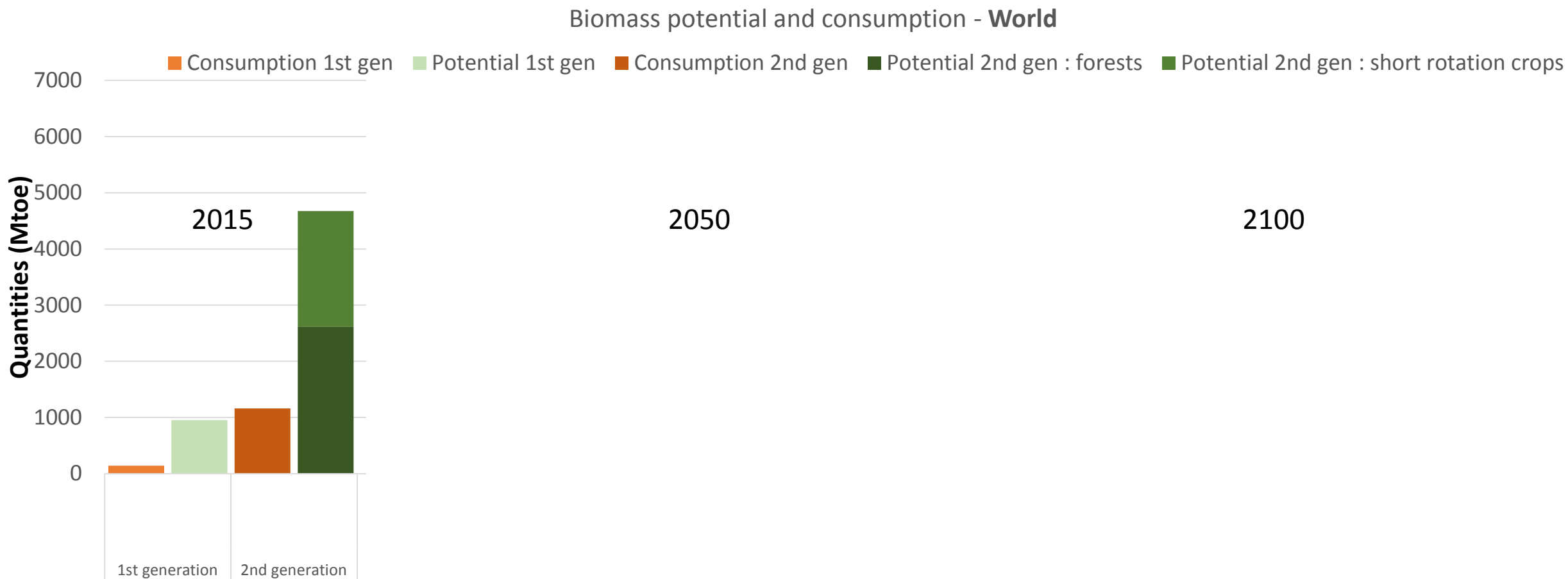
III – Methodology

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# IV – Modelling results : growth of biomass potential and consumption worldwide



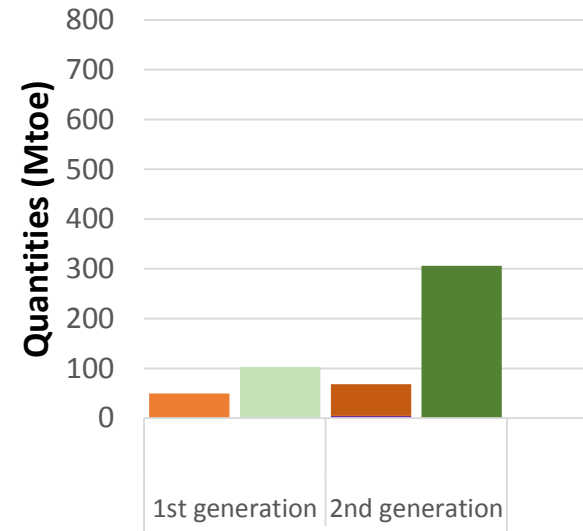
Levels and repartitions of bioenergy consumption and use depend on **climate objectives** and **policies implemented**

# IV – Modelling results: growth of biomass potential and consumption - countries

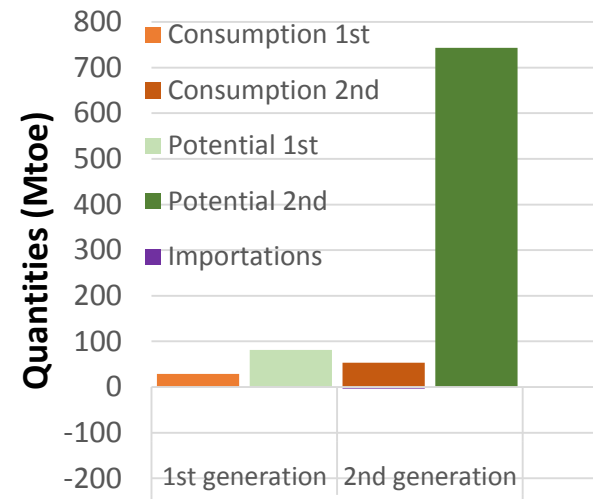
Potential and  
imports + consumption

2015

### The USA

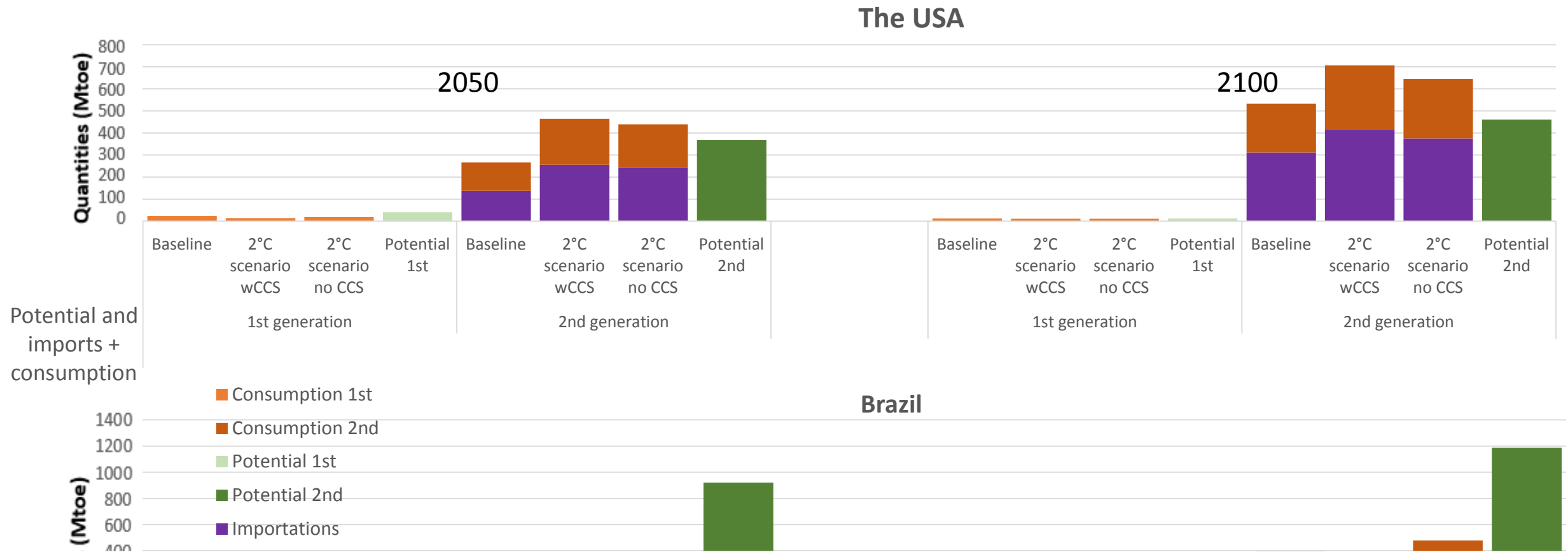


### Brazil



- A large potential is not exploited
- Consumption
  - 1<sup>st</sup> generation for biofuels
  - 2<sup>nd</sup> generation in majority woody biomass, in a traditional valorization
- Few quantities are traded
  - 4 Mtoe importations for the USA
  - 6 Mtoe exportations for Brazil

# IV – Modelling results: growth of biomass potential and consumption - countries



Levels and repartitions of bioenergy consumption and use depend on climate objectives, **local biomass patterns**

# IV – Modelling results: different biomass use pattern - world

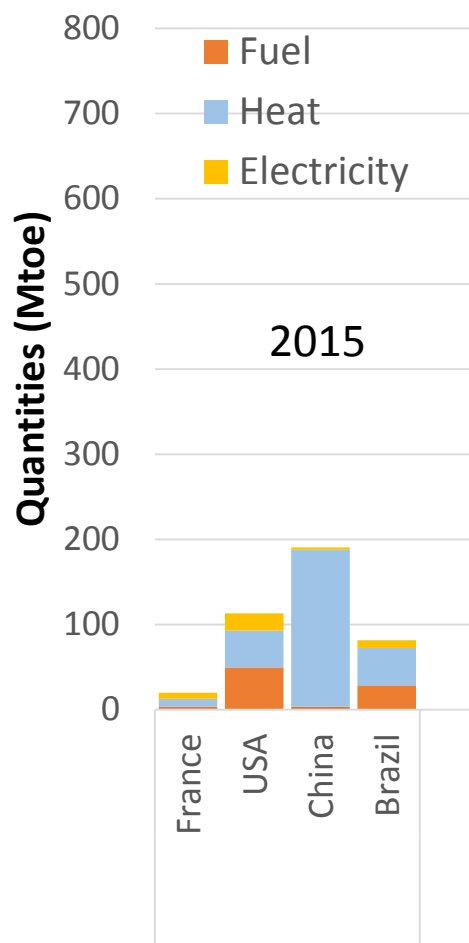


Level and repartition of bioenergy consumption and use depend on climate objectives, local biomass patterns, **energy needs**



# IV – Country use and consumption

Domestic consumption and uses



Levels and repartitions of bioenergy consumption and use depend on climate objectives, local biomass patterns, energy needs, **local energy specifications**



# IV – Modelling results: different technologies penetration rate

Installed power : gasification and methanisation technologies

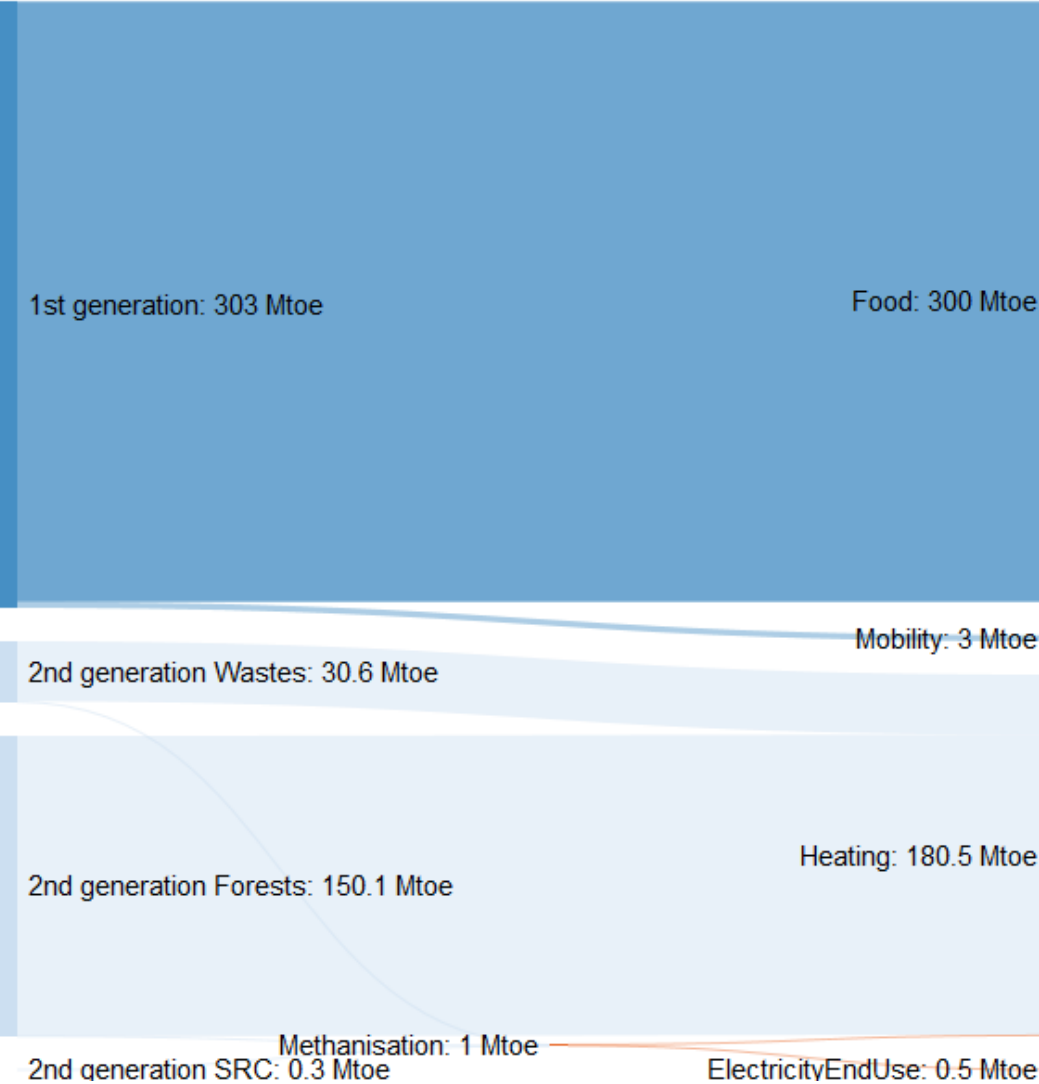


Levels and repartitions of bioenergy consumption and use depend on climate objectives, local biomass patterns, energy needs, local energy specifications, **technologies policies prioritizations and technologies development rates.**

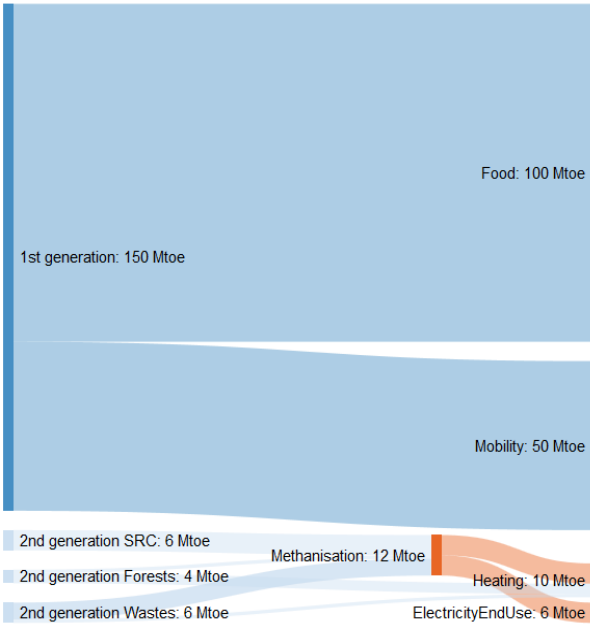
# IV – Sankey Diagram summary for resource consumption

## 2015, countries patterns

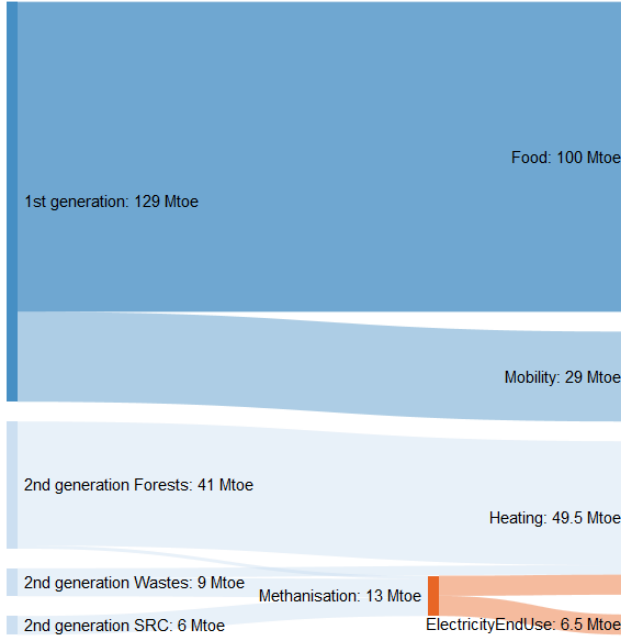
China



The USA



Brazil



### Different patterns in biomass energetic valorization

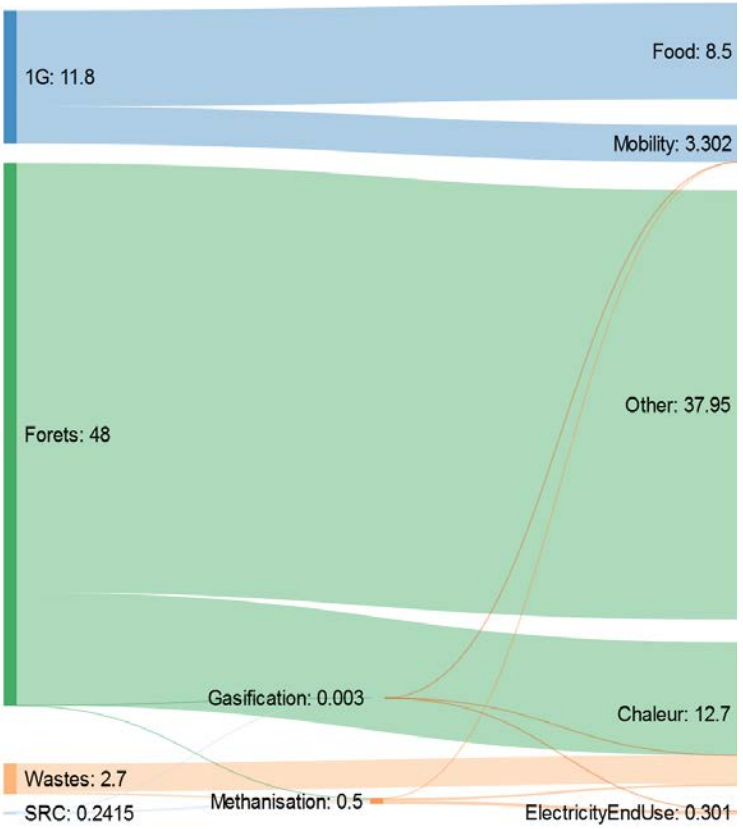
- Several trends, several end-use depending on population needs (food), level of country development, and local resource
- Some methanisation projects in exploitation, with heat+electricity valorization in majority, but remain limited in 2015



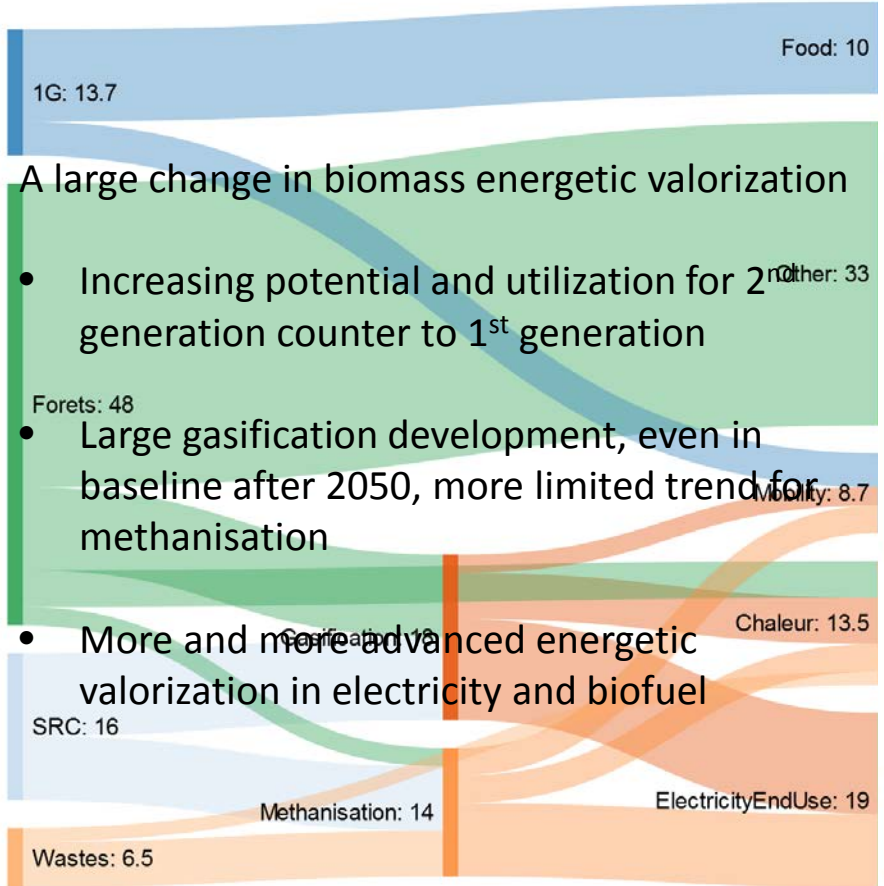
# IV – Sankey Diagram summary for resource consumption

## France – baseline evolution through XXIth century

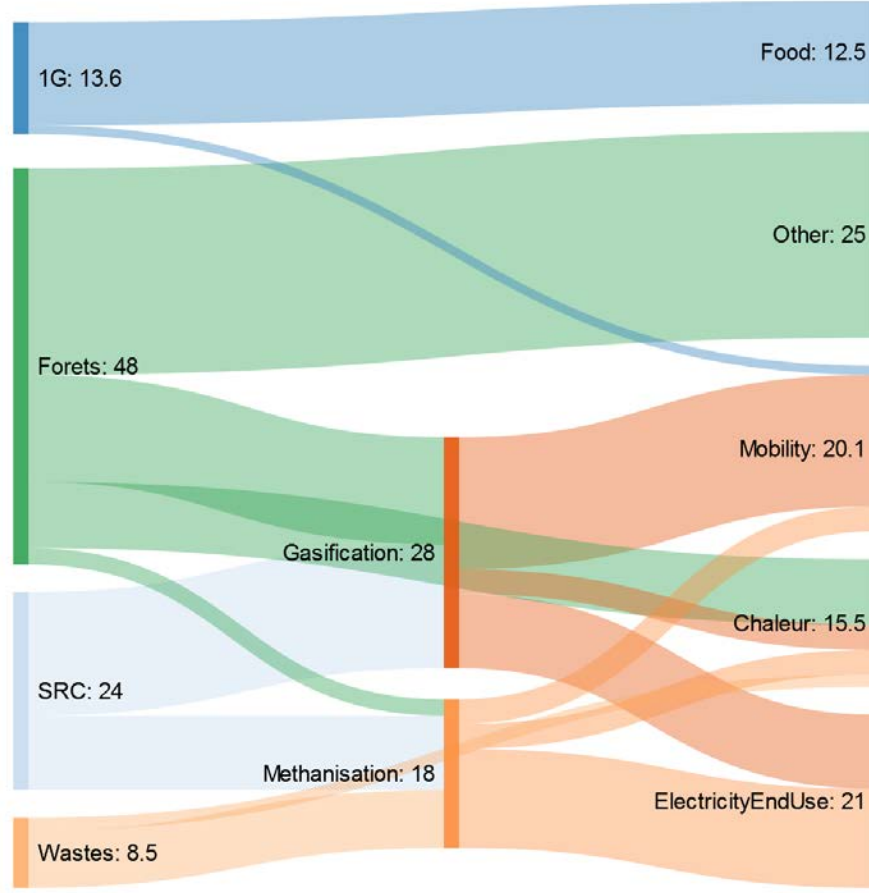
France – 2015



France – 2050 – baseline



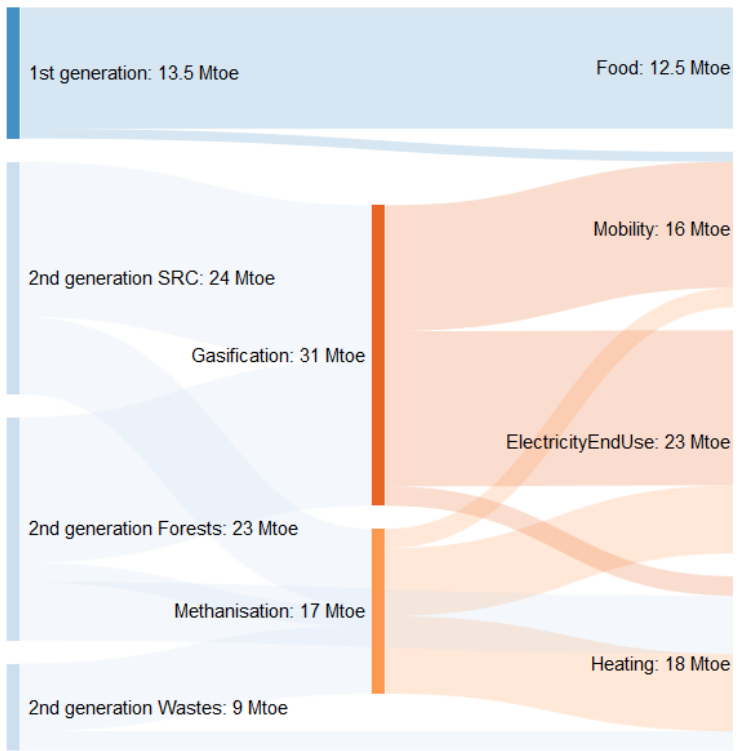
France – 2100 – baseline



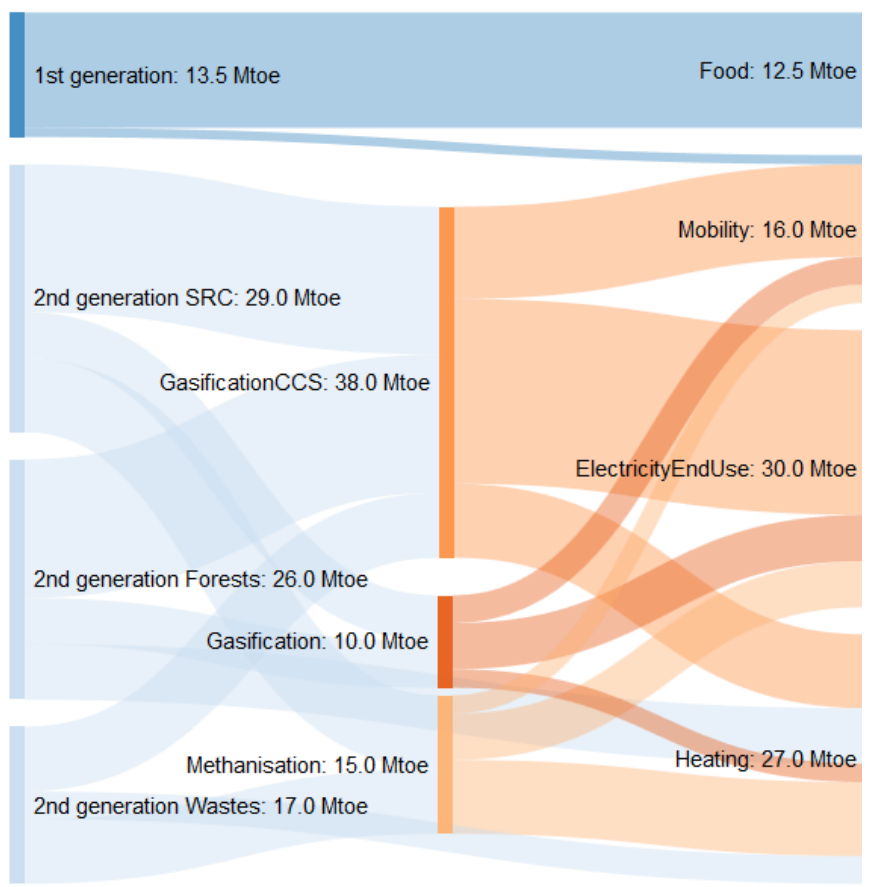
# IV – Sankey Diagram summary for resource consumption

## France – scenarios comparison in 2100

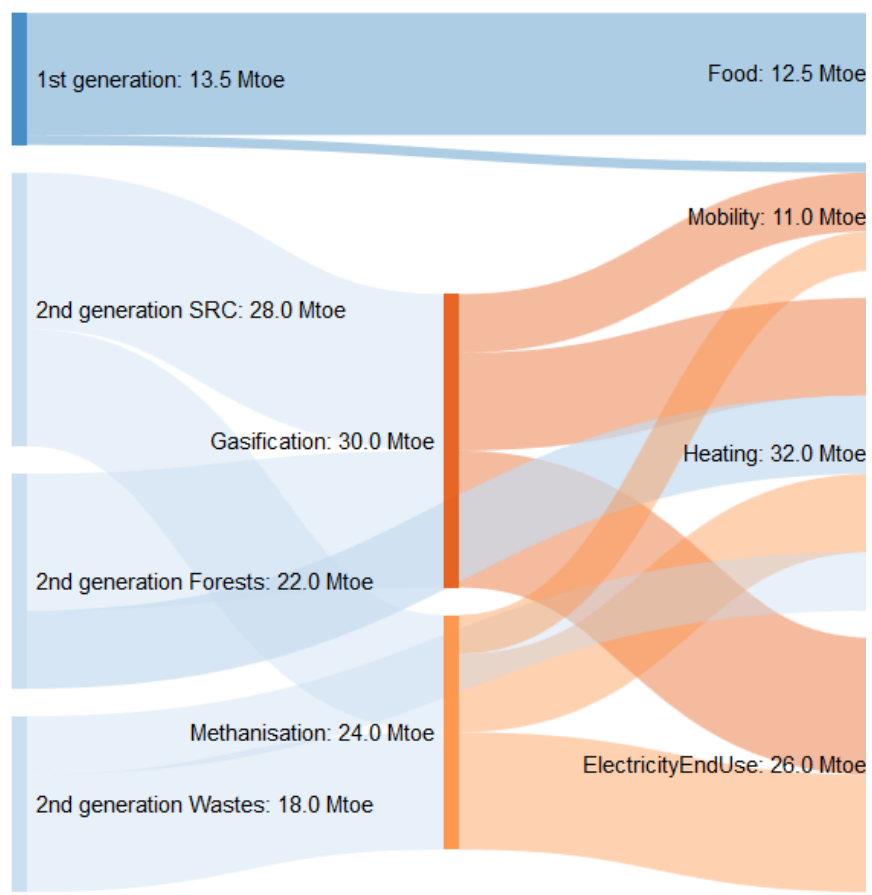
France – 2100 – baseline



France – 2100 – 2°C



France – 2100 – 2°C no CCS



A large change in biomass energetic valorization

- Larger use in climate policies scenarios, in particular for heating and electricity
- The highest use in 2°C with CCS with dedicated cultures : short rotation crops
- More methanisation in the absence of CCS

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# V – Conclusions and perspectives

## Conclusion

- Bioenergies technologies will develop by 57 to 93% (according to the scenario) from 2015 to 2050 and the **bioenergy** could be **multiplied by 5 from 2015 to 2100**.
- **2<sup>ND</sup> generation biomass** will be used widely in presence of **climate policies**, notably in **electric system**
- Generally, **electricity and heat** are prominent in **northern countries**, **biofuels** in **developing countries**
- Penetration speeds and rates depends on potential, technology maturities and cost effectiveness
  - Methanisation develops earlier (from now) than gasification (after 2030) ...
  - ... but gasification will be used widely in the second part of the century
- The future of CCS is a key factor that will decide what will be the main conversion routes for biomass
  - More electricity and heat with, **centralised** use
  - More biofuel without, **decentralised** use

## Perspectives

- 1) Consider a larger perimeter in the modelling
  - Adding **power to gas** to complete the full green gas chain and **gas mobility** (Natural Gas Vehicle) in final use
  - Consider other biomass valorization through **co-products** (oil chemistry and oil base product replacement)
- 2) The contribution in the structure of a decarbonised energy system
  - Consider the role of bioenergy and green gas technologies as **flexibility options** and in **capacity markets**
  - Consider the **trade of biomass** and **innovation** in **advanced bioenergy technologies**

## V – Conclusions and perspectives

Levels and repartitions of bioenergy consumption and use depend on **climate objectives, local biomass patterns, energy needs, local energy specifications, technologies policies prioritizations and technologies development rates.**

# Thank you for your attention

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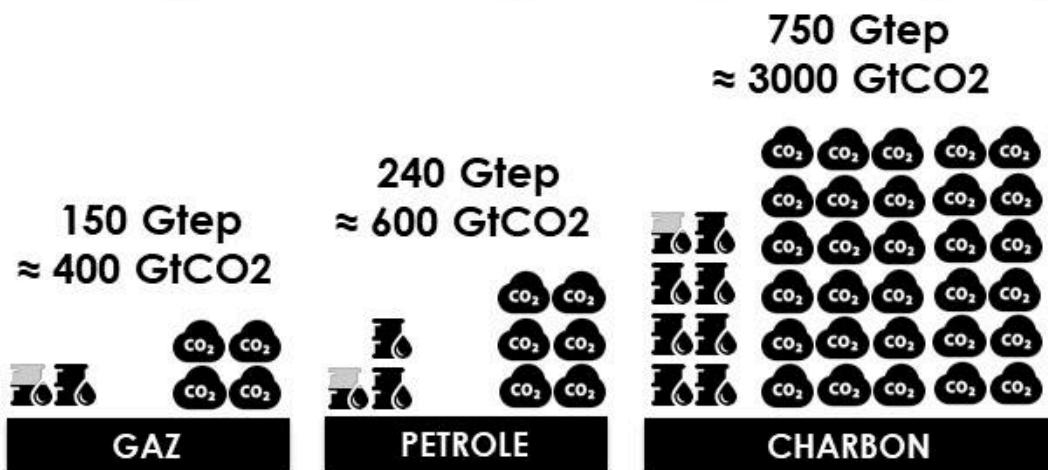
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# I – Energy context: decarbonisation of energetic system



Ce qu'il nous reste (réserves prouvées) :



**TOTAL : ≈ 4000 GtCO<sub>2</sub>**

Gaz à effet de serre équivalents (100 GtCO<sub>2</sub>eq)

Énergie équivalente (100 Gtep)

## BUDGÉTISONS LE CARBONE

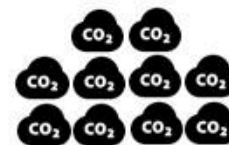
TIC, TAC...



Emissions GES actuelles

≈ 50 GtCO<sub>2</sub>/an

Ce que nous pouvons encore émettre :



≈ entre 800 et 1000 GtCO<sub>2</sub>

À répartir sur les différentes énergies !

**Notre budget 2°C  
(66% de chance de rester sous 2°C)**

**Entre 20% et 25% des réserves prouvées**

**Entre 1% et 2% des ressources**

**Temps restant à émissions constantes :**

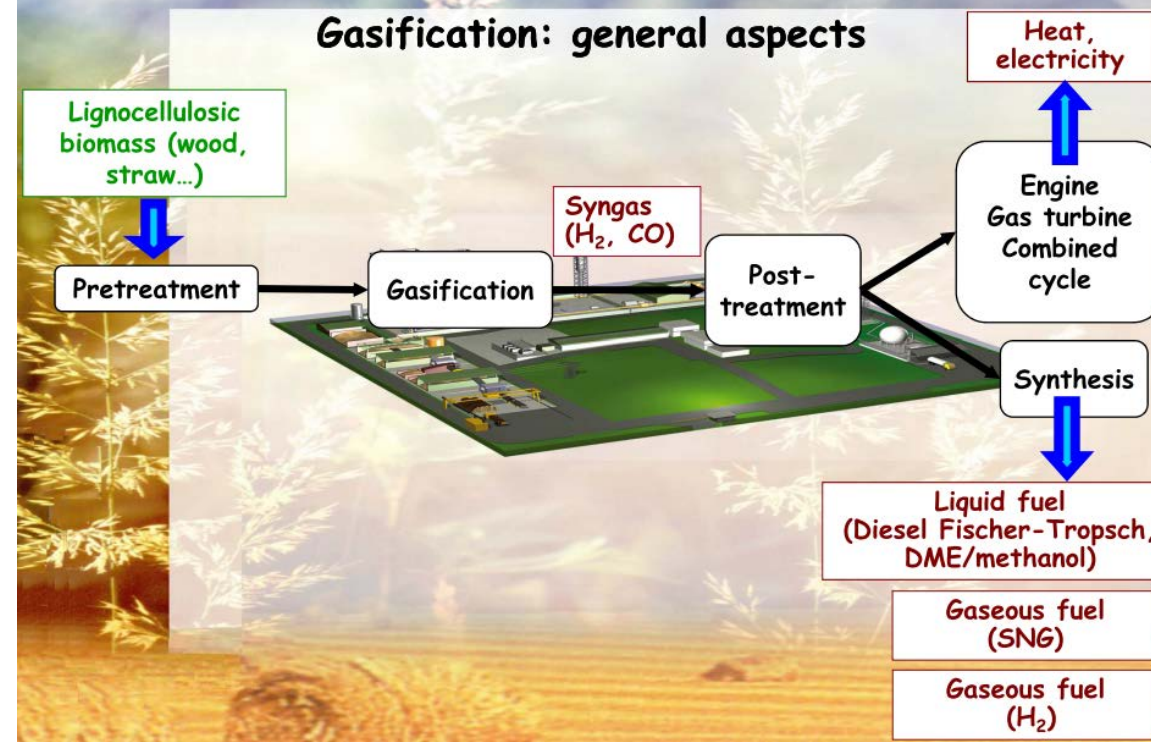
**20 ans**



Source : Avenir Climatique, IPCC AR5 WG3, BP Statistical Review 2016

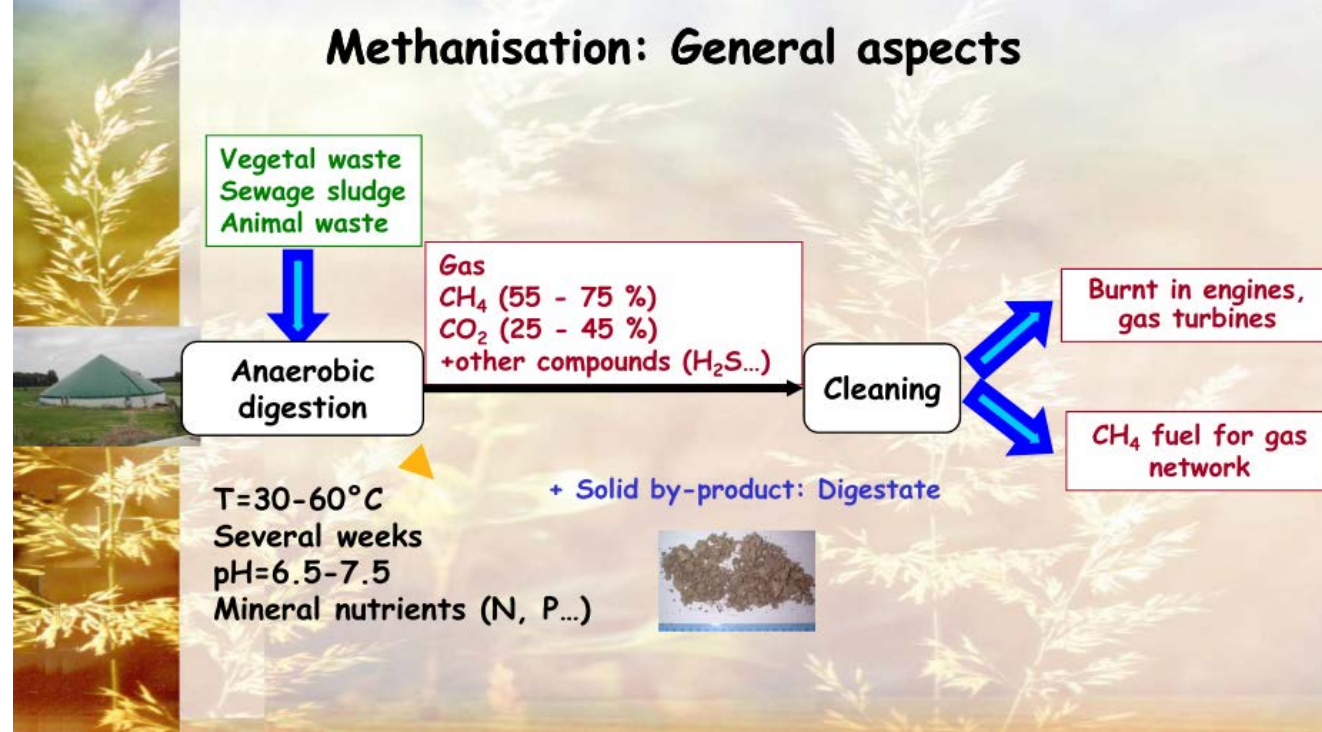


# II – Gasification



| <b>Advantages</b>  | <b>Drawbacks</b>   |
|--|--|
| Able to convert lignocellulosic biomass and solid recovered fuels: <b>2nd generation biomass</b>           | <b>High costs</b> for the resource   |
| <b>Recovery of local resources</b> (local lignocellulosic resource such as wood residues)                  | Suitable only for <b>medium to large scale applications</b>  |
| <b>Various final products</b> , including fuels that are mixable with conventional fossil fuels            | Field <b>not very organised</b> yet. Still <b>R&amp;D issues</b>   |
| The bioenergy technology with the <b>best energy index</b> = energy in fuel / total fossil energy consumed | <b>High competition with other use</b> for 2 <sup>nd</sup> generation of biomass such as direct heating and building timber. |

# II – Methanisation



### Advantages

### Drawbacks

**Robust and simple technology** due to low temperature and pressure needed

Very **low reaction rate** (up to several weeks)

**Recovery of local resources** (wastes, agricultural by-products for farmers)

**Not** suitable for exclusive **2<sup>nd</sup> generation biomass** valorization (lignocellulosic)

Suitable for **wet biomass and liquids**

**Bacteria poisoning** with some biomass

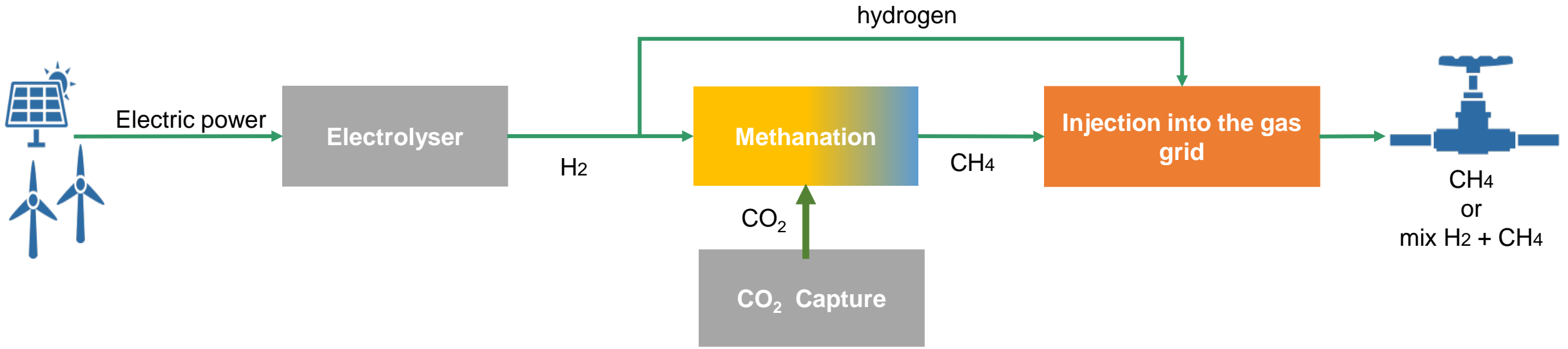
Production of **CH<sub>4</sub>** for use in **the existing pipeline**

**Severe gas cleaning mandatory** for fuel application

Recovery for by-products (the digestate can be used as soil **fertilizer**)

Suitable for **small scale units**

# II – Power to gas

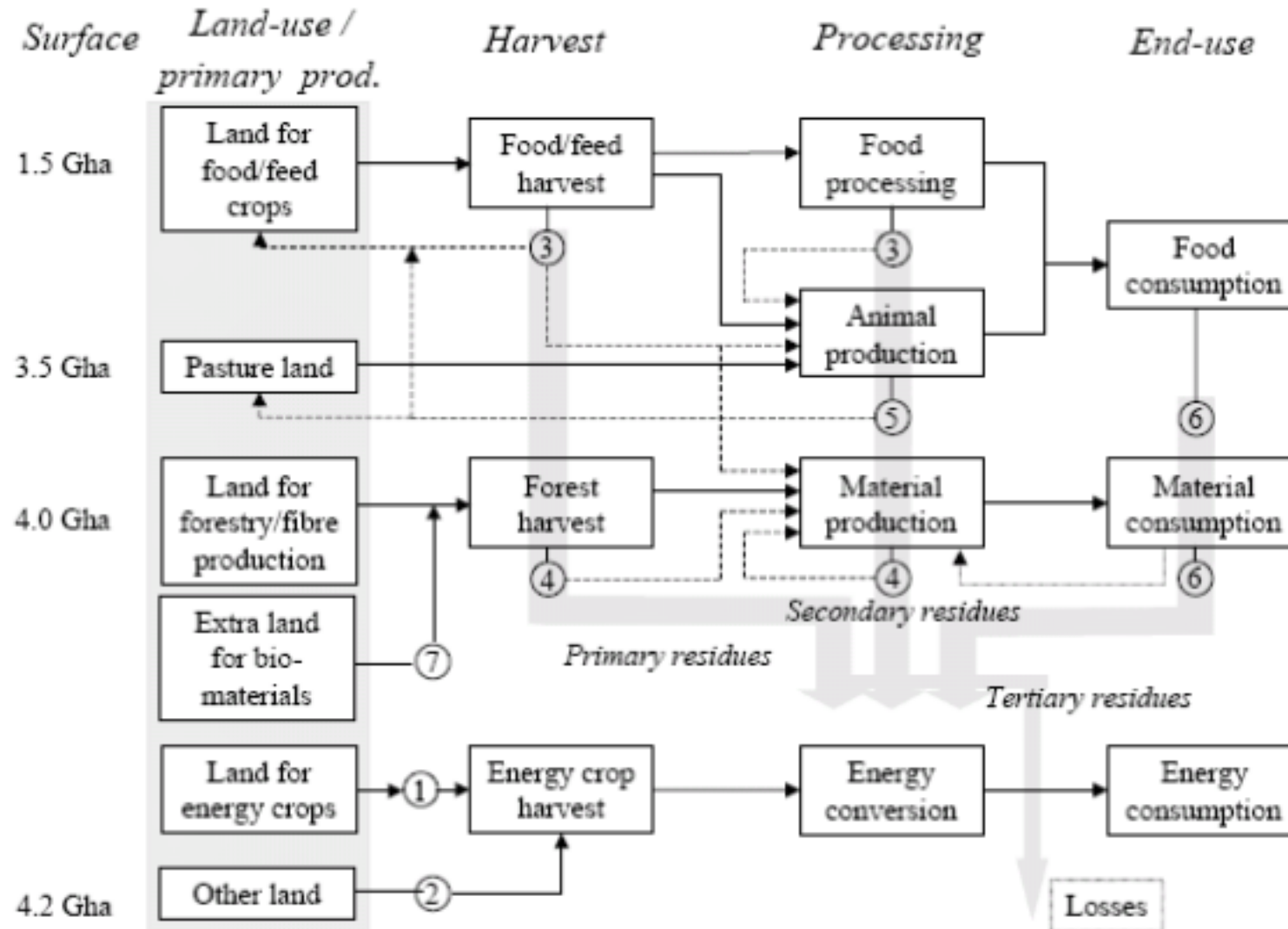


| Advantages  | Drawbacks                           |
|---|-------------------------------------|
| Valorization of <b>electricity surplus</b> produced by VRE  | <b>Yields</b> to be improved        |
| <b>Large scale storage</b> system   | Yet <b>expensive</b> technology     |
| <b>Various valorization products</b> , including electricity (gas to power), direct gas consumption, heat | Only at a <b>early R&amp;D step</b> |
| <b>CO<sub>2</sub></b> valorization (Carbon Capture and Use)   |                                     |

# II – Bioenergies

## End use competition for biomass resource

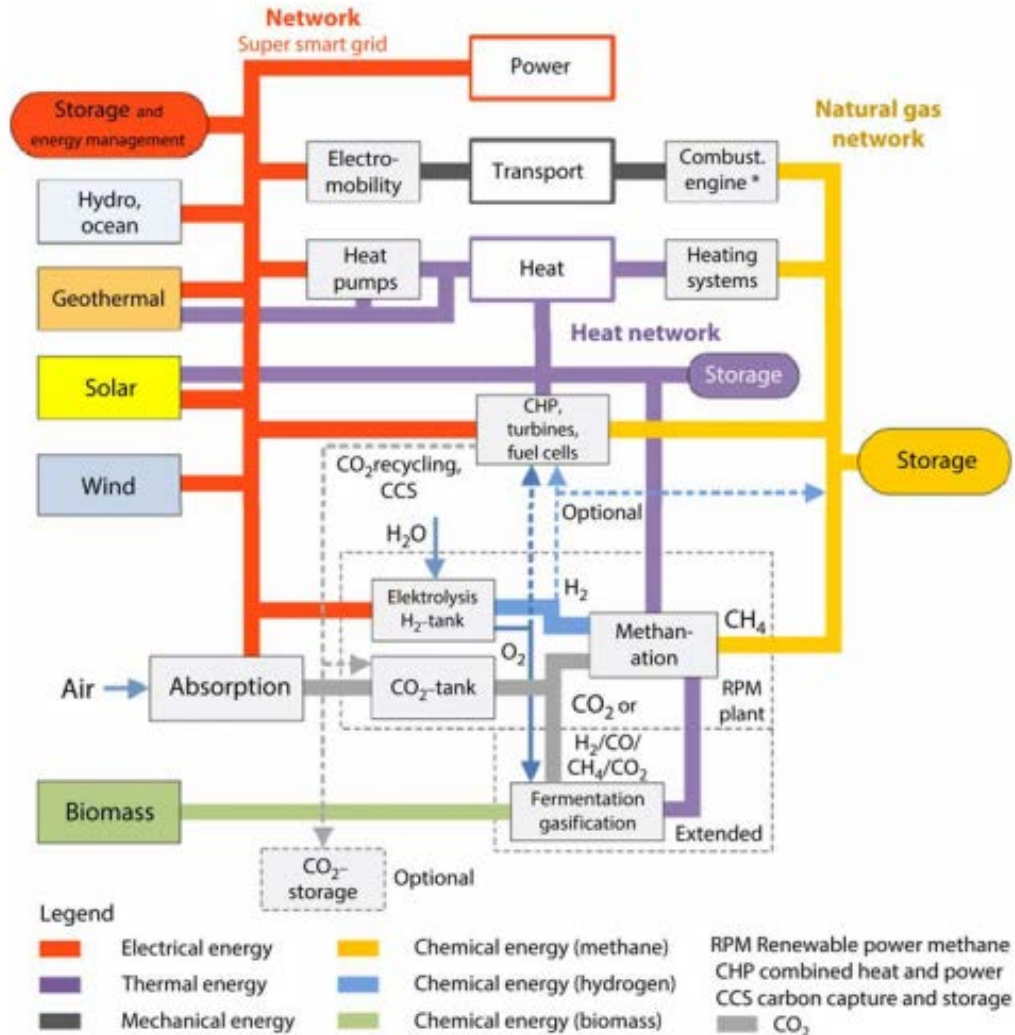
Figure 32: Overview of the biomass flows and the global land surface (Source: Hoogwijk, 2003)





# II – Bioenergies

## Biogas production from biomass: multiples synergies and competitions with the other sources of energy



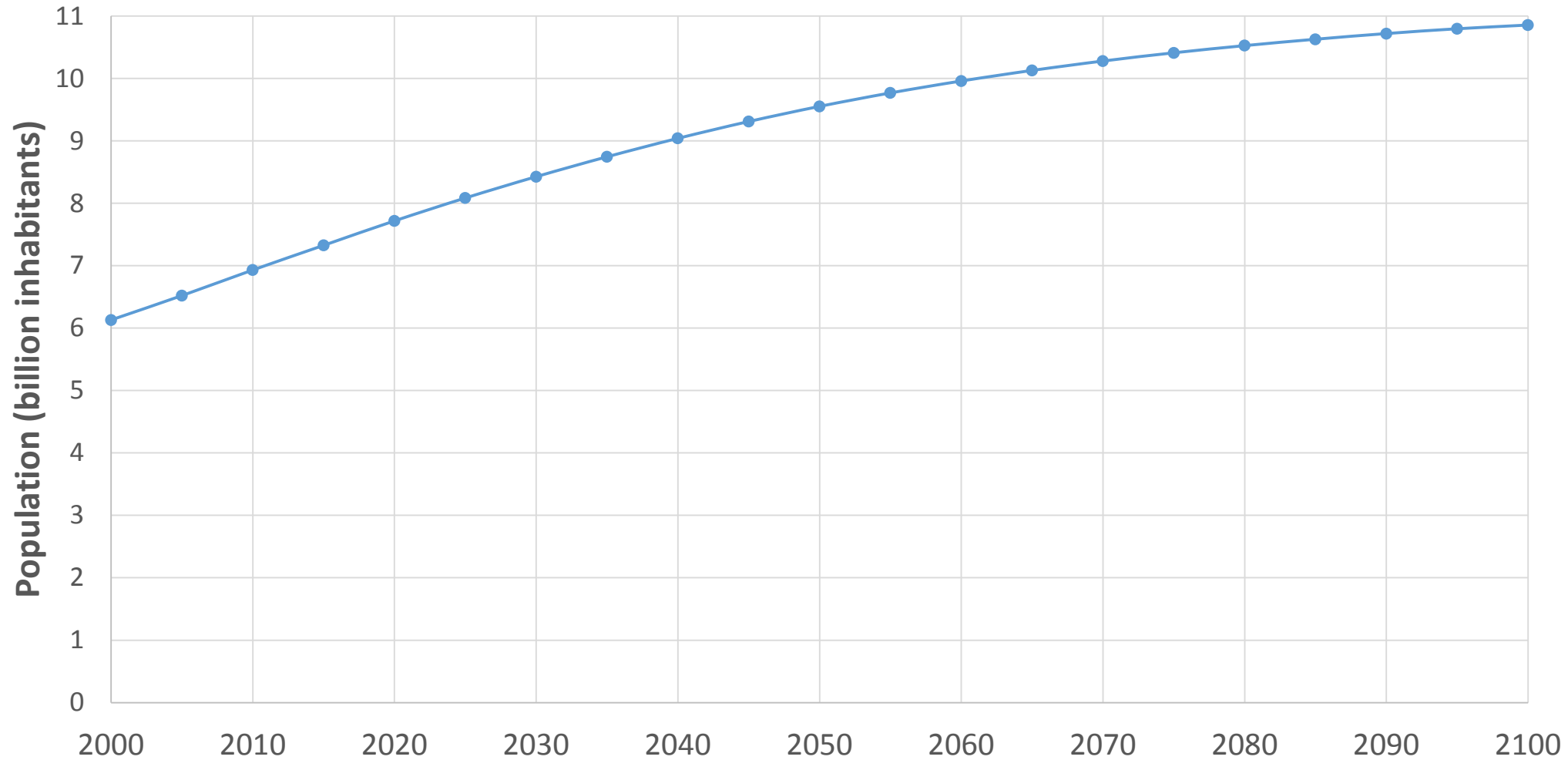
Europe's Energy Transition, Insights for Policy Making

Conceivable design of an integrated energy network system. From Sterner, Bioenergy and renewable power methane in integrated 100% renewable energy systems, Dissertation, University of Kassel, 2009 [38]; L. Brodecki, J. Tomaschek, U. Fahl, Synergies in the integration of energy networks for electricity, gas, heating and cooling. INSIGHT\_E Rapid Response Energy Brief, 2014 [39].

# III – Methodology

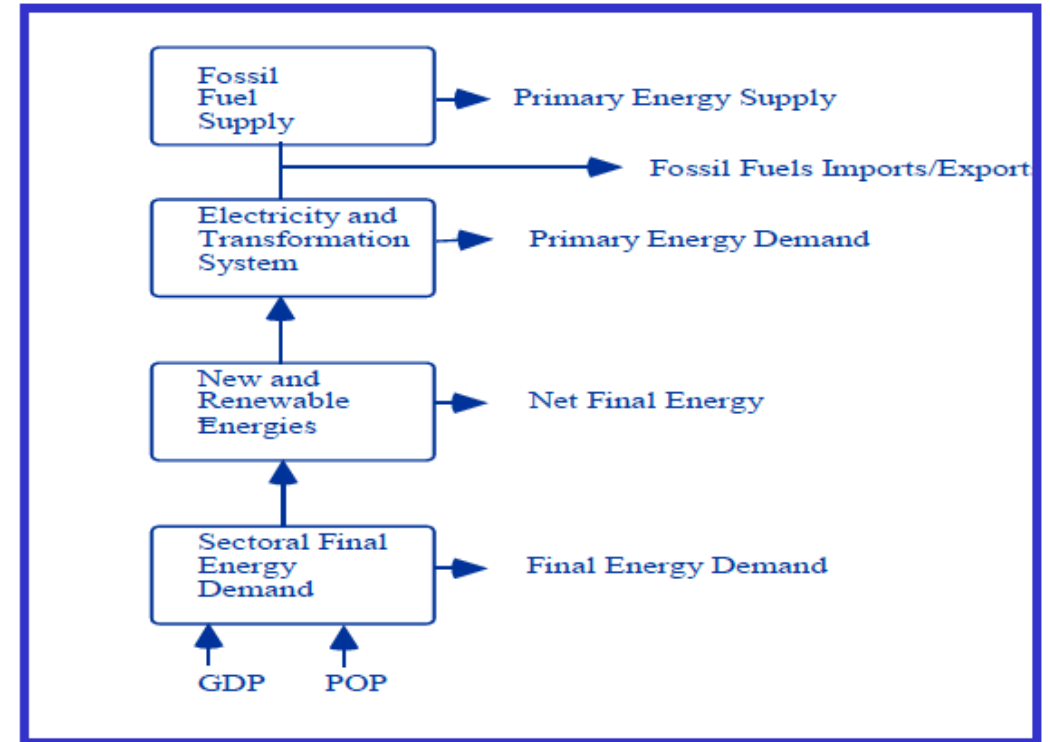
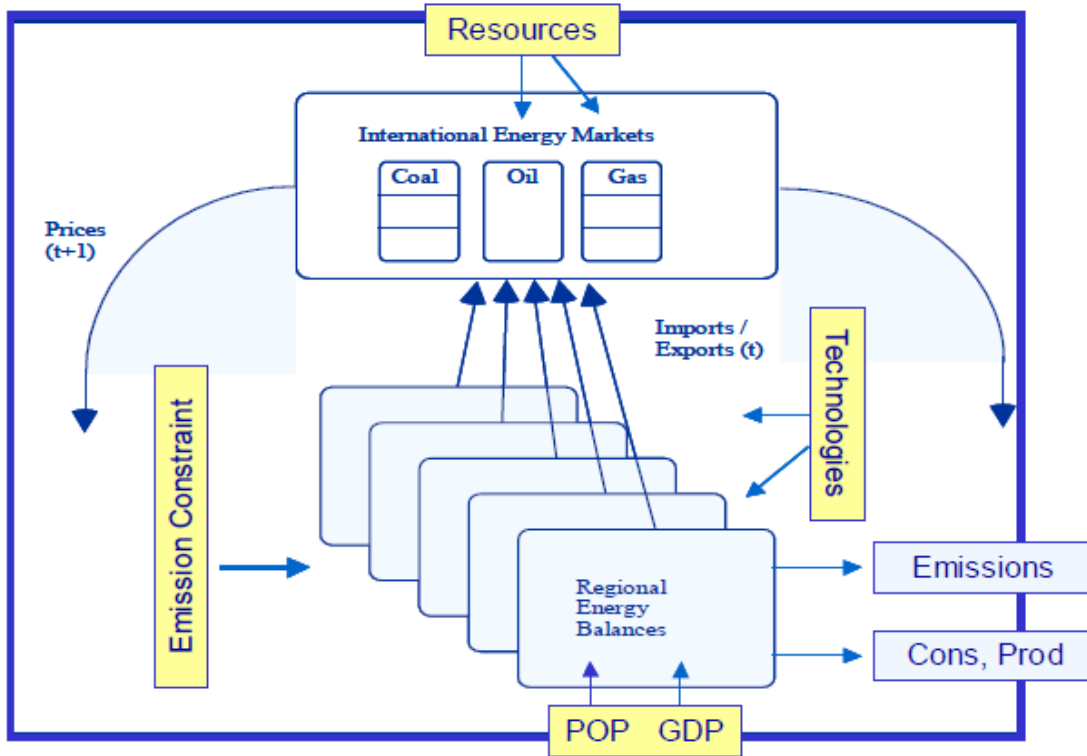
## Modelisation hypothesis

### World population



# III – Methodology

## POLES, a long term energy prospective Bottom-Up modelling tool



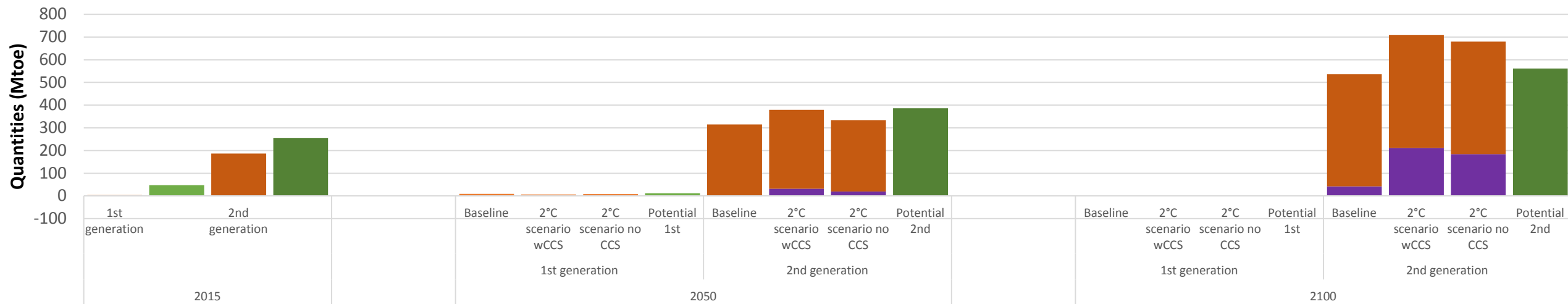
The POLES model is a global sectoral model for the world energy system. It has been developed in the framework of a hierarchical structure of interconnected sub-models at the international, regional, national level. The dynamics of the model is based

on a recursive (year by year) simulation process of energy demand and supply, with lagged adjustments to prices and a feedback loop through international energy prices.

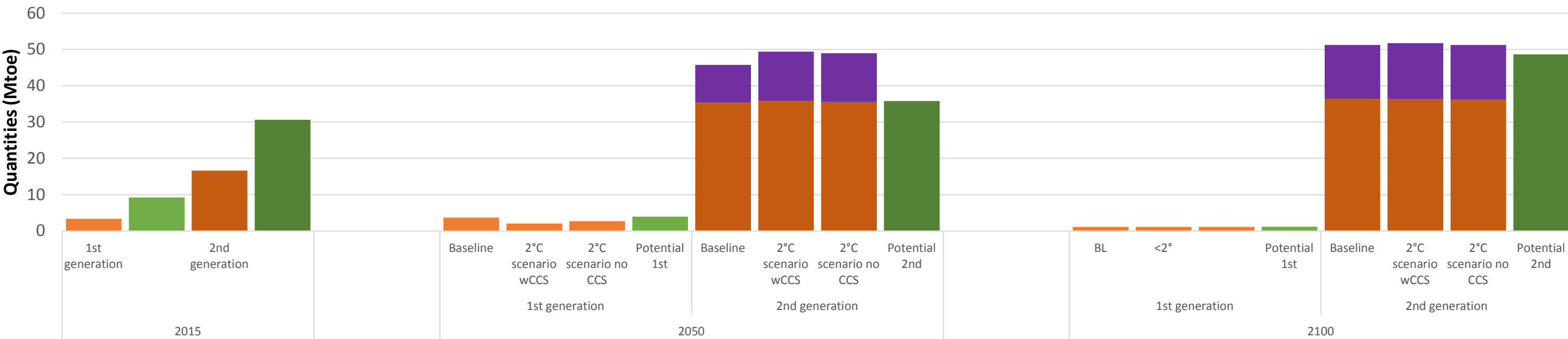
Allocation of resources by merit order (cost)

# IV – Modelling results: growth of biomass potential and consumption - countries

## Potential+imports and consumption - China



## Potential+imports and consumption - France



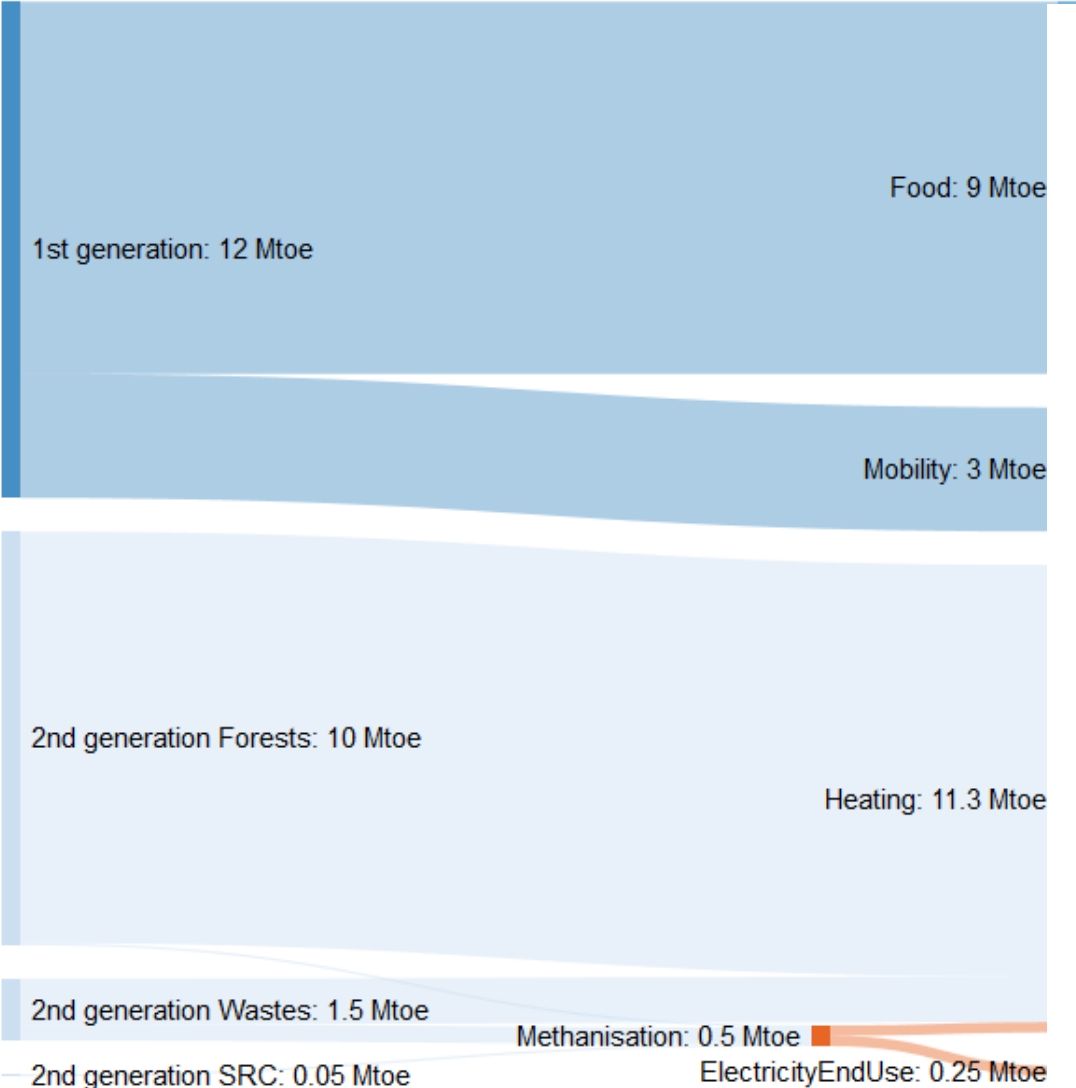
■ Consumption 1st  
 ■ Consumption 2nd  
 ■ Potential 1st  
 ■ Potential 2nd  
 ■ Importation



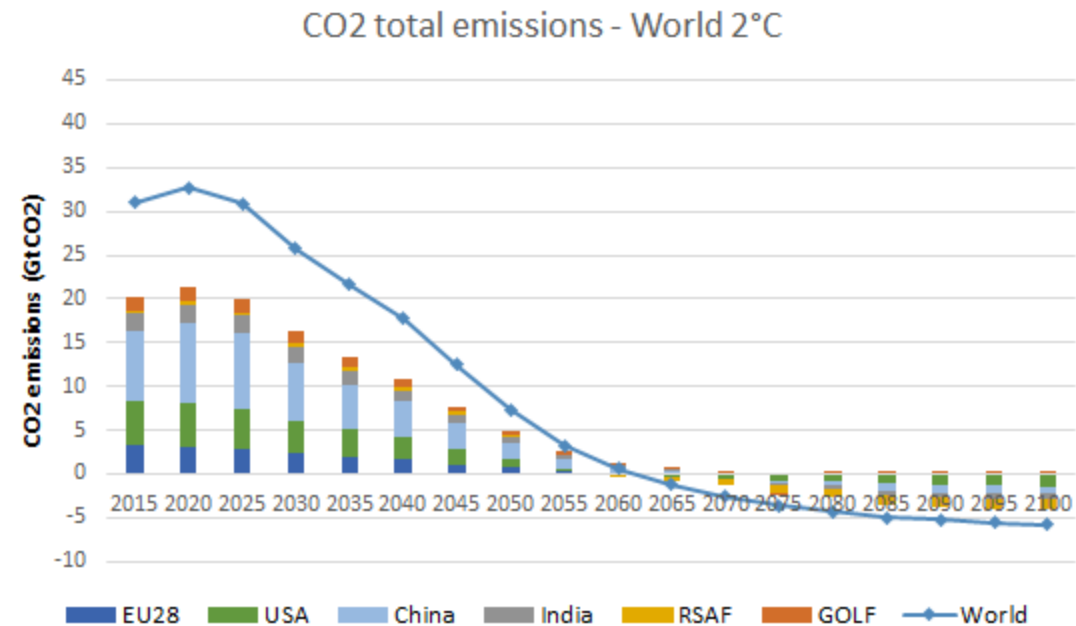
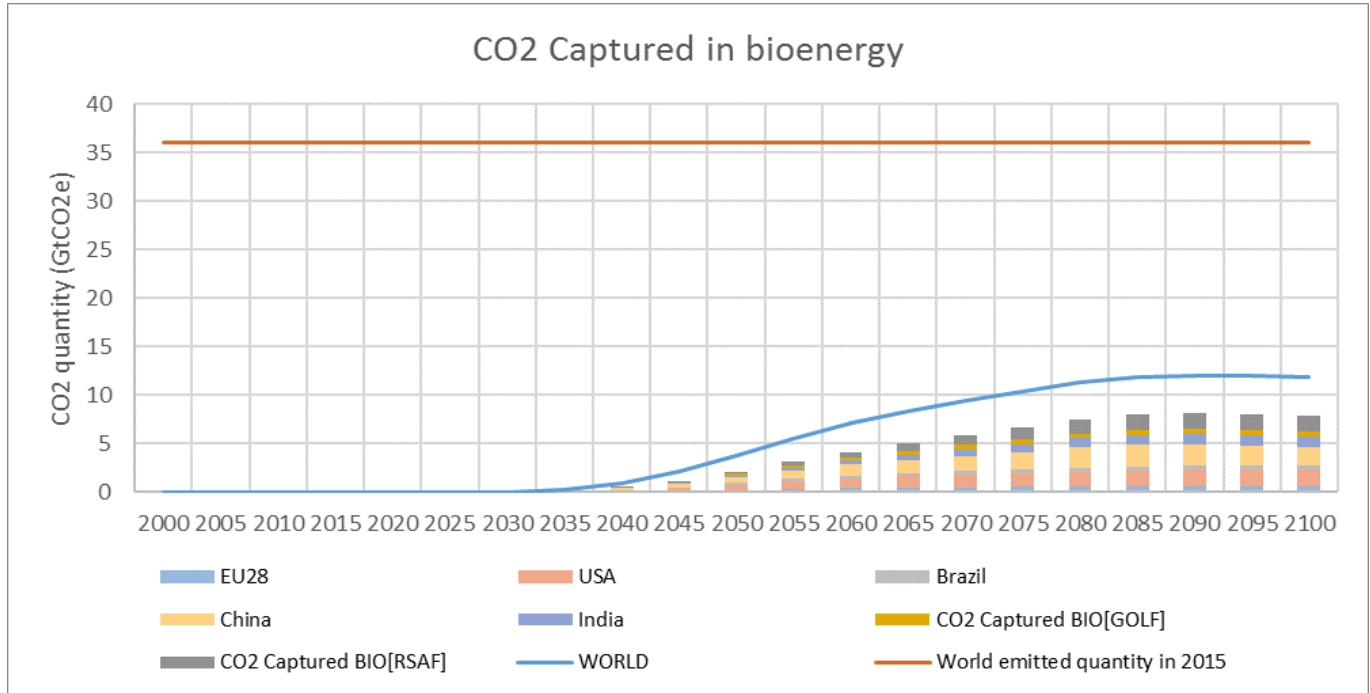
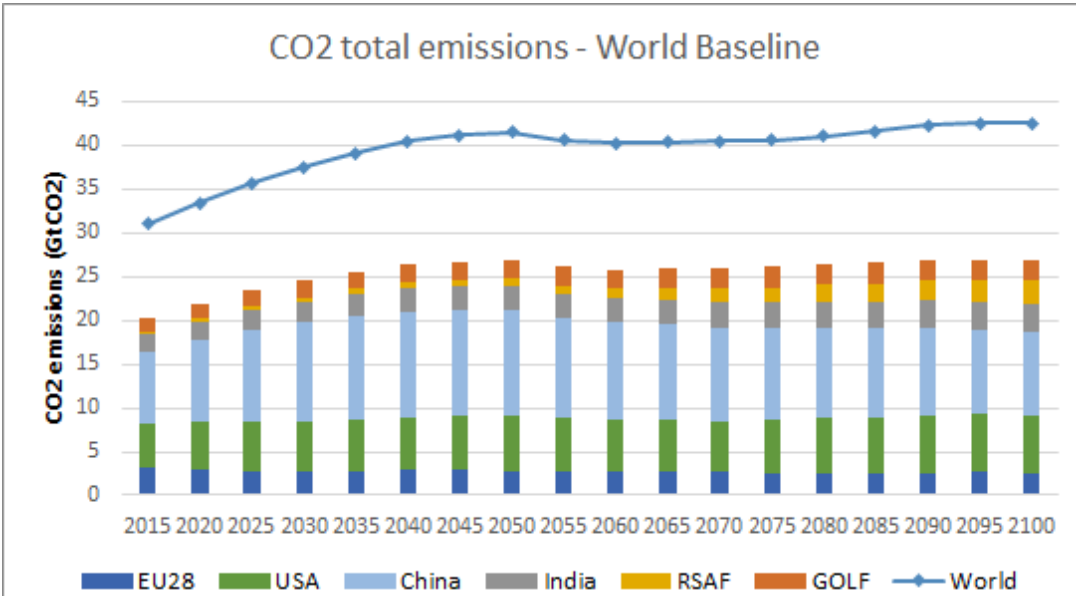
# IV – Sankey Diagram summary for resource consumption

## 2015, countries patterns

France



# VI – Scenarios and CO2 emissions



Key technologies for 2°C and <2°C scenarios : **Carbon Dioxide Removal** technologies

# VI – CO2 emissions and Carbon Dioxide Removal

## A. Afforestation & reforestation

**Tech readiness**  
Ready for large-scale deployment

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Reversible

## B. Bioenergy carbon capture & storage

**Tech readiness**  
Only 1 full scale demonstration

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Stable

## C. Biochar

**Tech readiness**  
Limited pyrolysis capacity

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Stable

## E. Direct air capture

**Tech readiness**  
Deployed in niche markets

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Stable

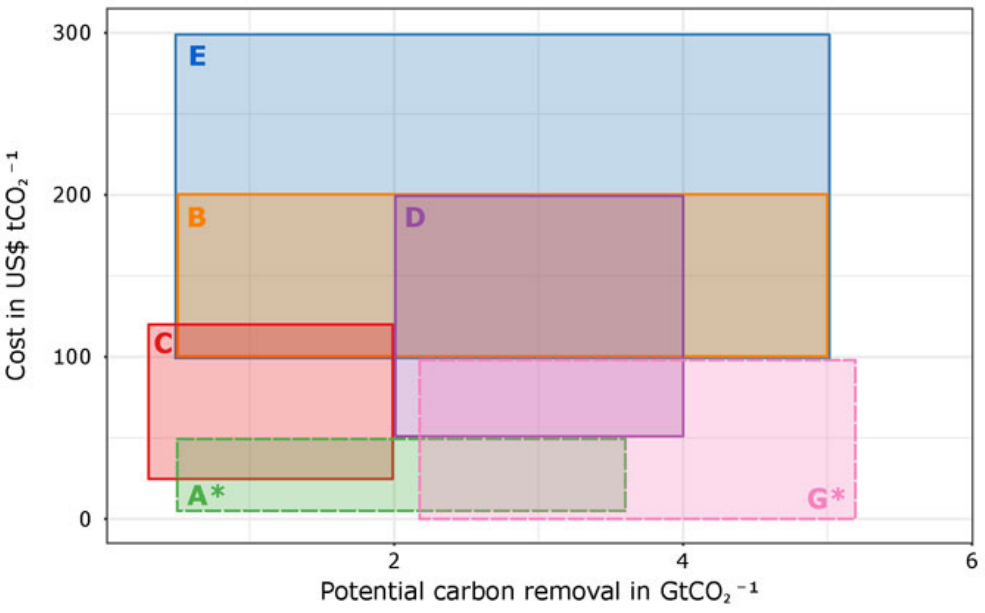
## F. Ocean fertilisation

**Tech readiness**  
10s of small demonstrations

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Stable but uncertain



## D. Enhanced weathering

**Tech readiness**  
Limited mineral production

**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Stable

## G. Soil carbon sequestration

**Tech readiness**  
Ready for large-scale deployment

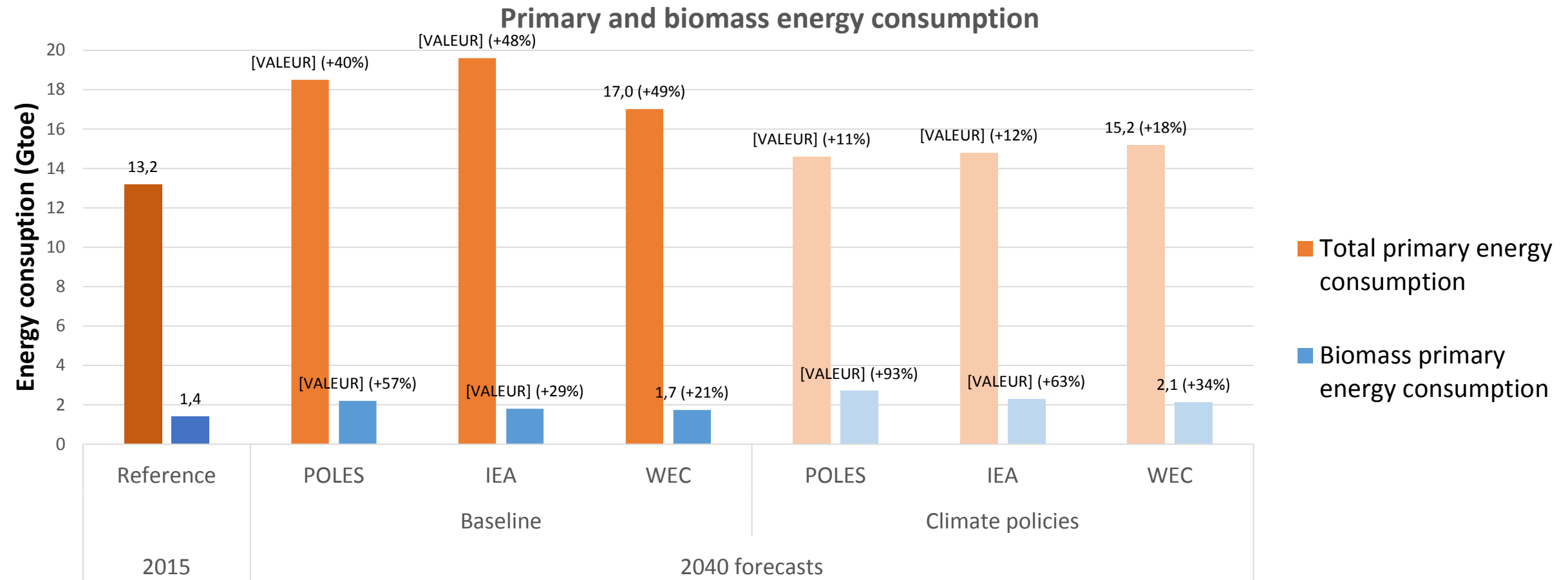
**Side-effects**

**Trend after 2050**  
Cost   
Potential

**Permanence**  
Reversible

- Side-effects**  
(+ positive, - risk of negative)
- Air pollution
  - Albedo
  - Ground/water pollution
  - Biodiversity
  - Mining and extraction
  - Ecosystem changes
  - Soil quality
  - Food security
  - Trace GHGs

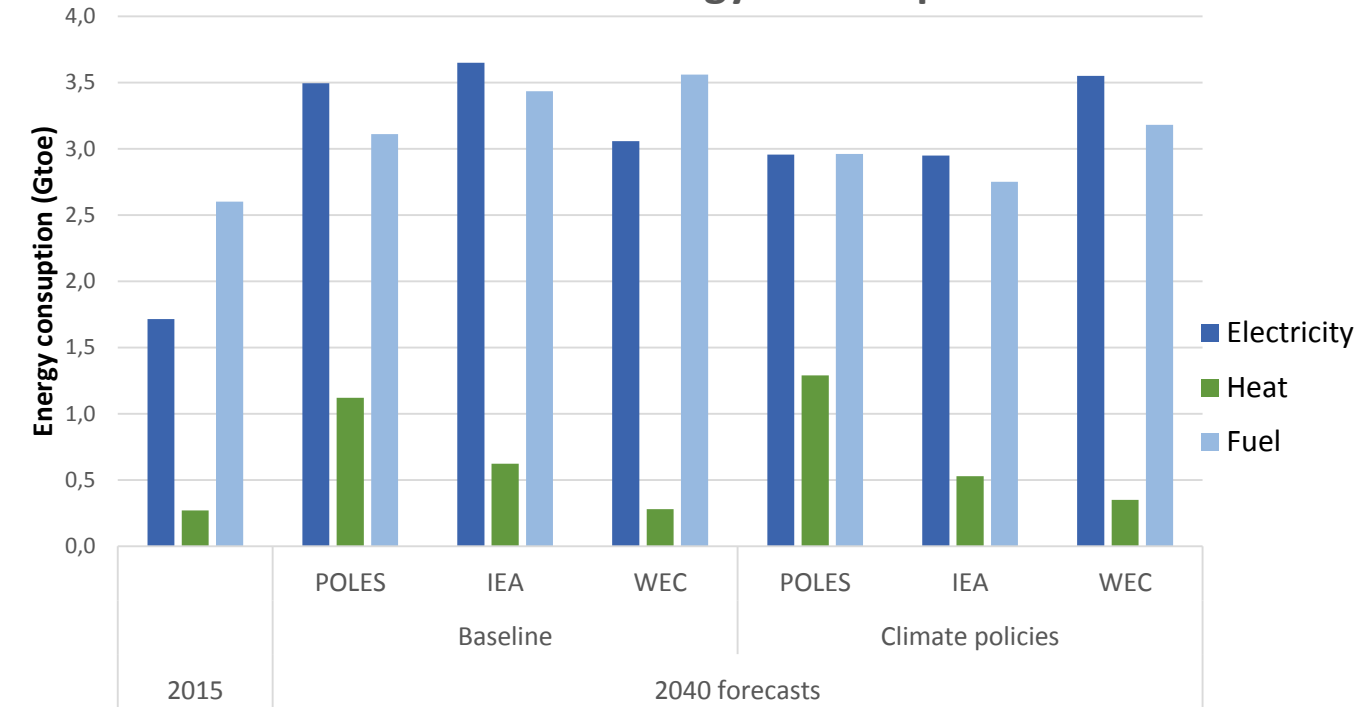
# IV – Results comparison: Baseline and climate policies scenarios from IEA and WEC



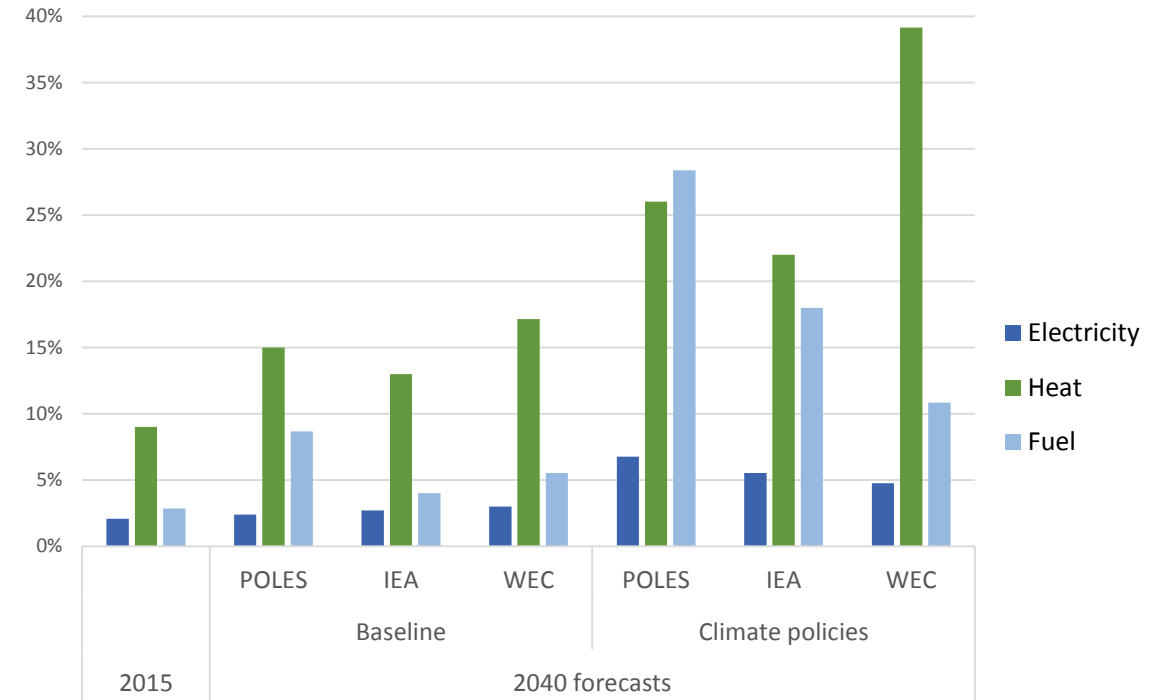
- Increasing of total energy consumption, more limited in scenarios with climate policies
- Increasing of biomass consumption, more pronounced in scenarios with climate policies with a growth of biomass proportion in the energy mix,

# IV – Results comparison: Baseline and climate policies scenarios from IEA and WEC

## Total world energy consumption



## Proportion use of biomass



- **Decrease** of proportion of traditional **direct use** of biomass (combustion), from 55% of total bioenergy in 2015 to around 30% in 2040.
- Higher % of use of biomass in **climate policies scenarios**
- Higher % of use of biomass in **heat sector** than others fields where competition is more present
- Increase in proportion in **electric** mix (from 2,1% of energy produced in 2015 to around 6,8% in 2040) and others advanced vectors heat and fuel thanks to methanisation and gasification.
- POLES model gives a little bit more importance to bioenergies than others even if the order of magnitude is coherent.

# IV – Results comparison: meta-analysis for scenarios

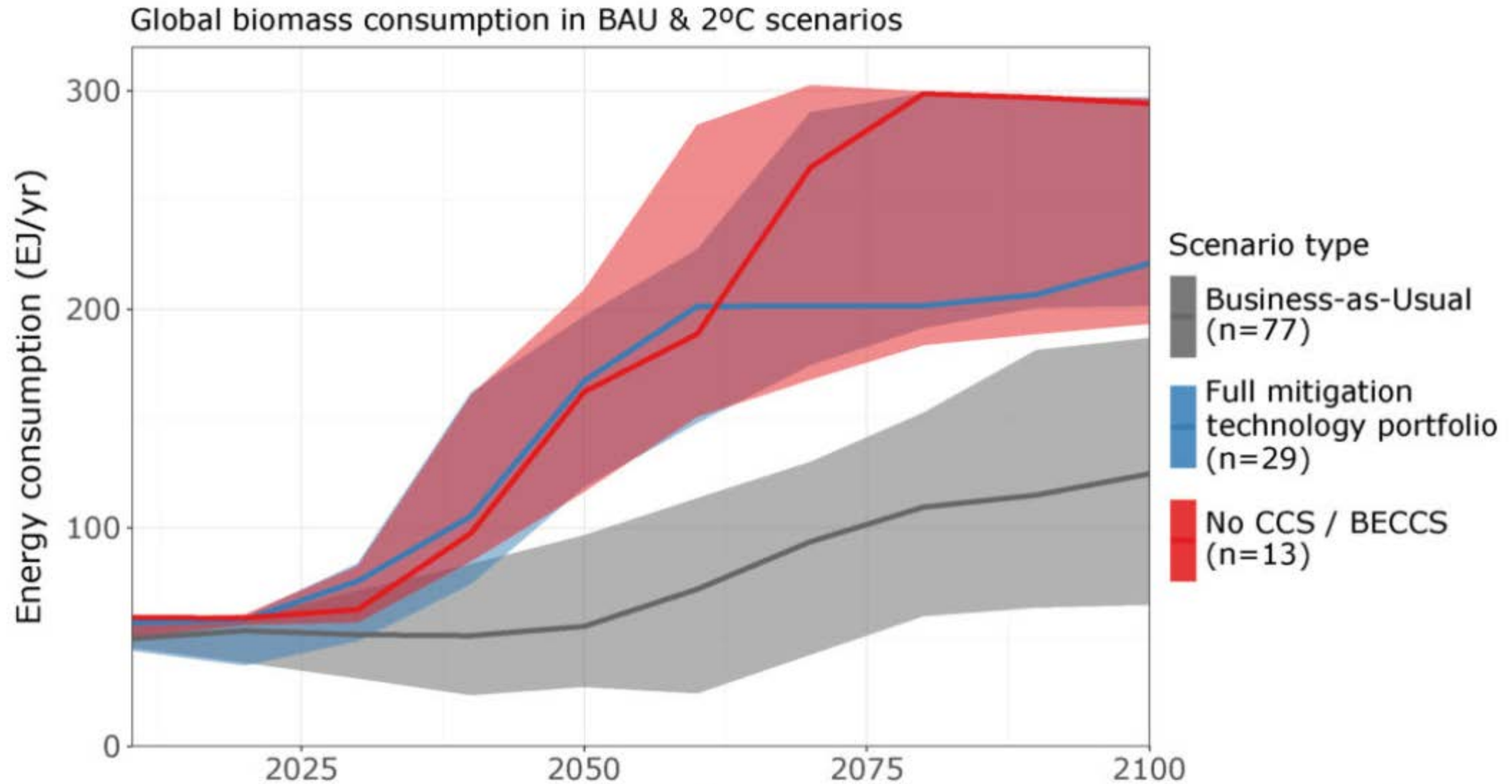


Figure shows baseline scenarios (grey), scenarios with all mitigation options including BECCS (blue) and scenarios excluding BECCS (red), which have higher biomass consumption than the blue and grey ones. Source: Minx et al. (2018)