

The climate benefit of Swedish ethanol- present and prospective performance

IEA Bioenergy Workshop
19-21 September 2011
Campinas, Brazil

Pål Börjesson, Serina Ahlgren
& Göran Berndes

Environmental and Energy Systems Studies
Lund University, Sweden

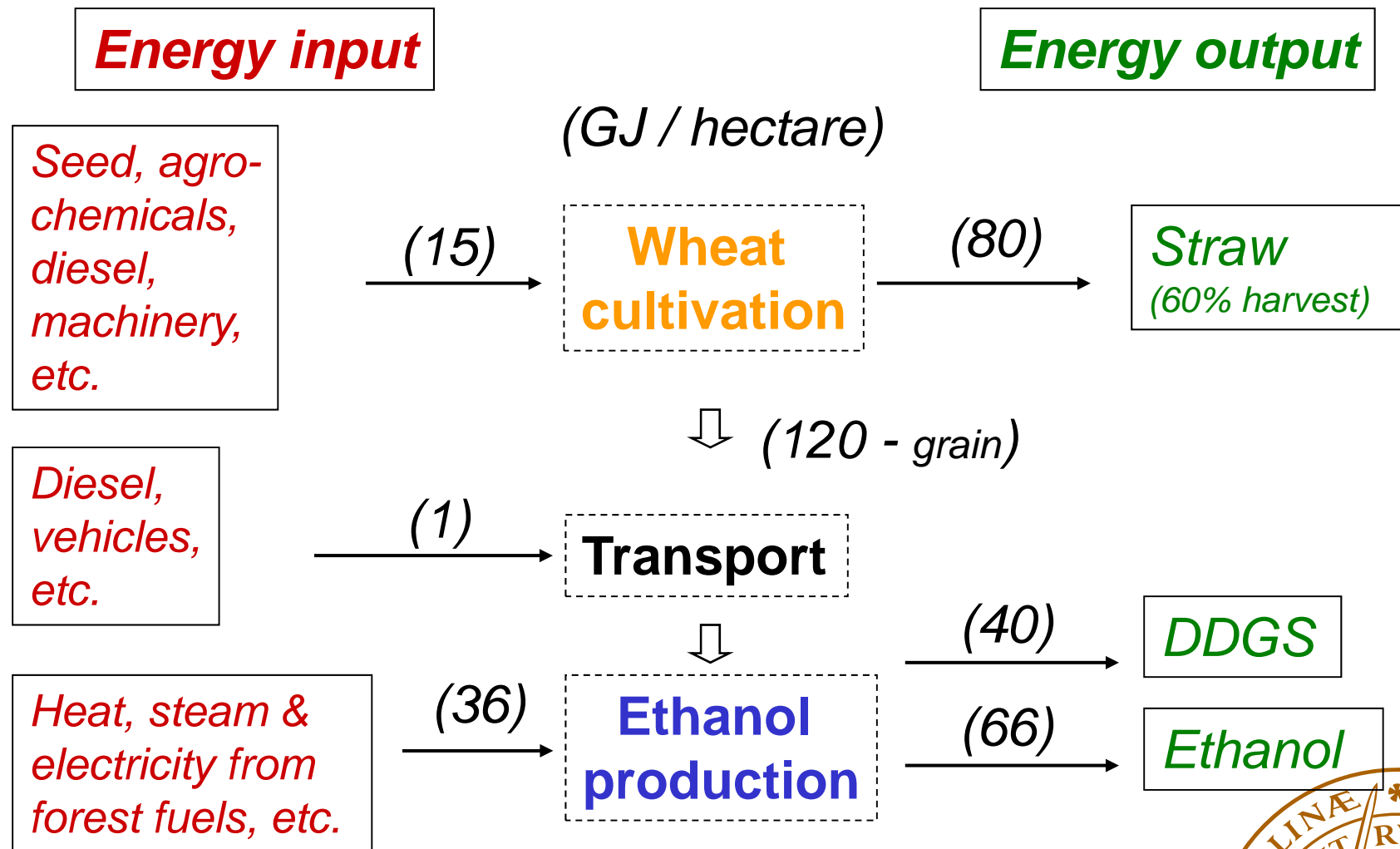


Background

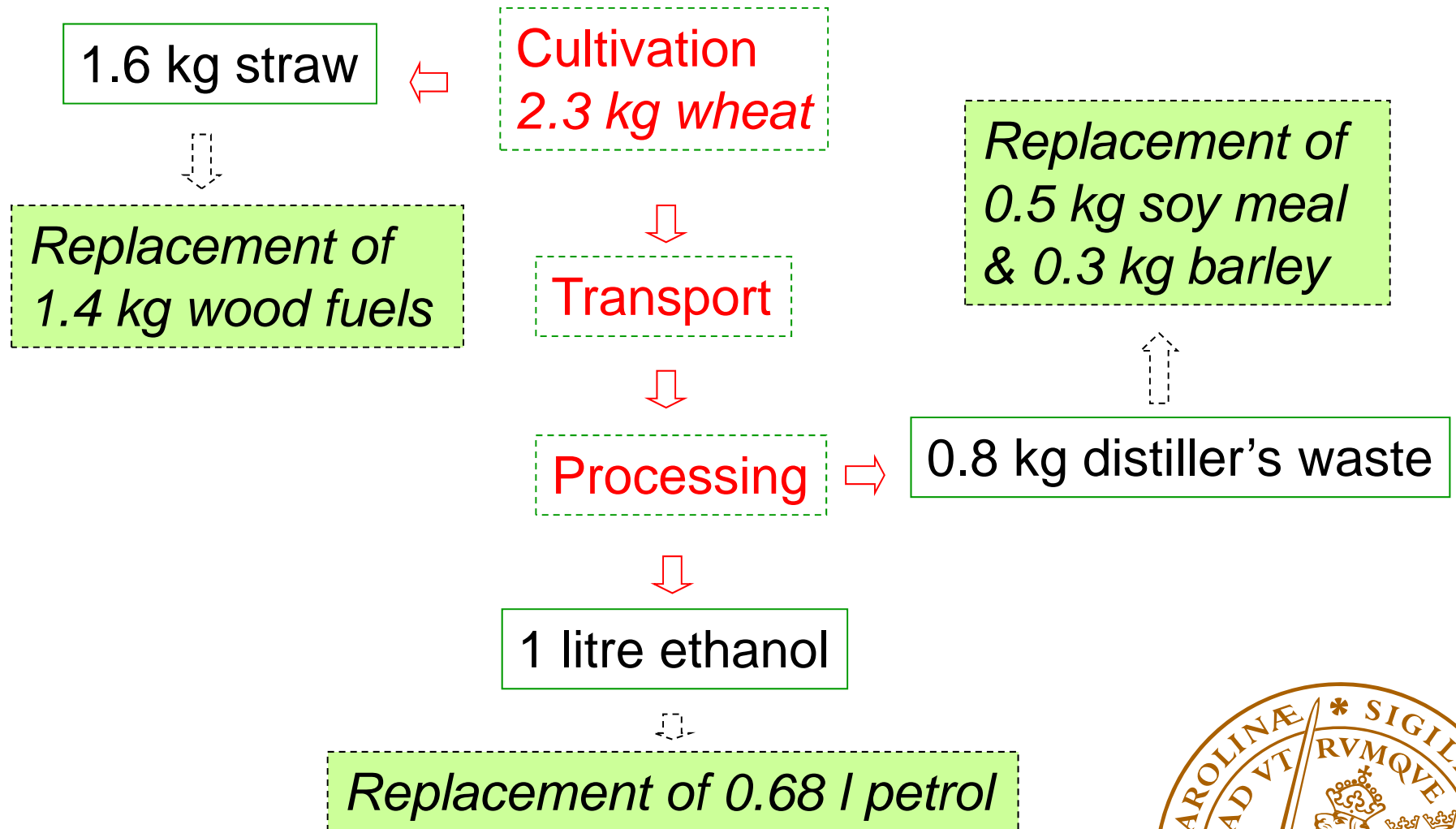
- Current 1G ethanol production is based on wheat where DDGS is used as protein feed, but this market is limited
- The wheat is mainly cultivated on open farmland but a future expansion may take place on excess grassland
- New feedstock including straw, short rotation woody crops, and forest biomass is estimated to increase in the future where the production of 1G and 2G ethanol could be integrated
- The purpose of this study is to show the implications on the GHG performance of an expanded ethanol production in Sweden



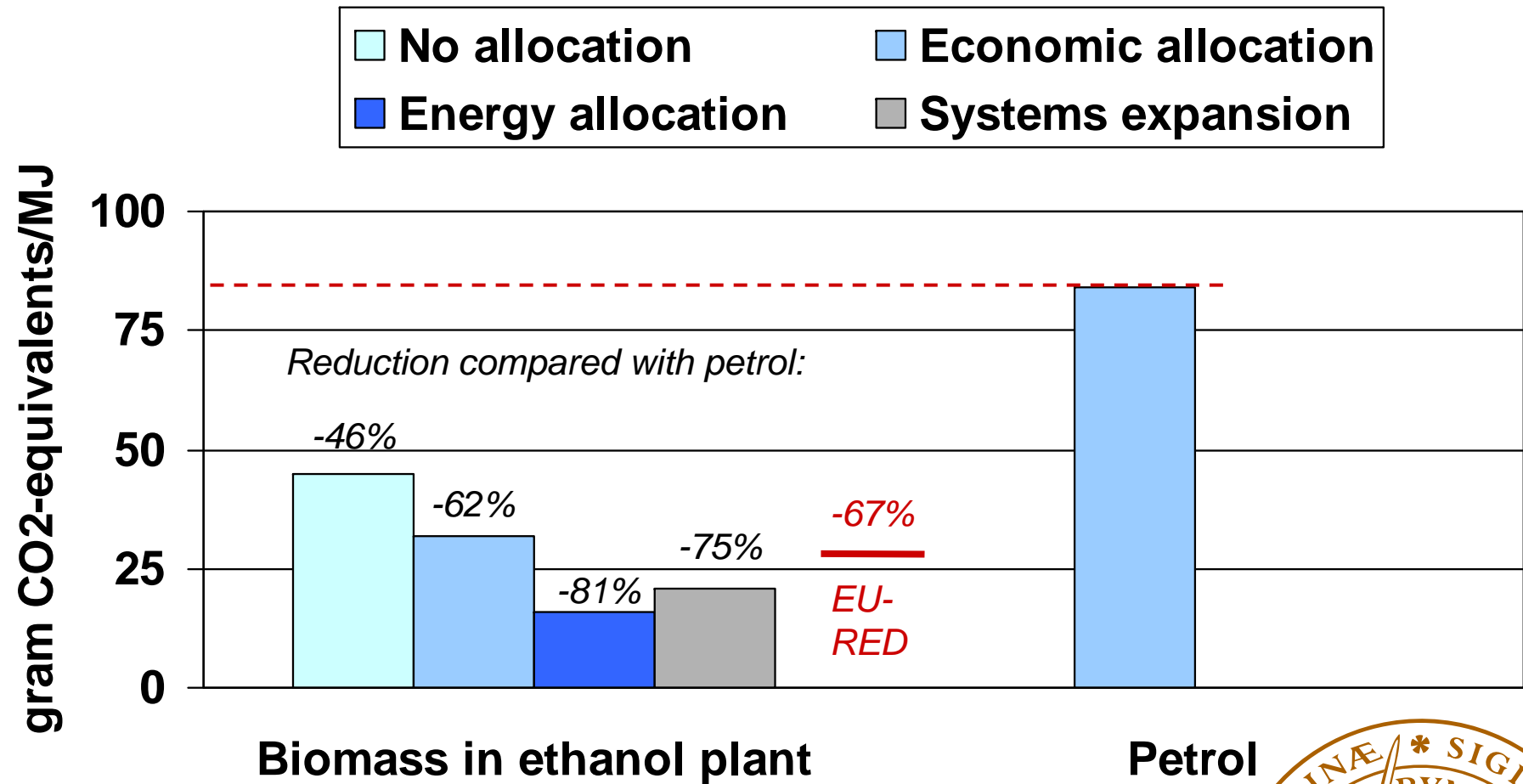
Swedish 1G ethanol production system



Swedish 1G ethanol production system



Emissions of greenhouse gases - per MJ ethanol

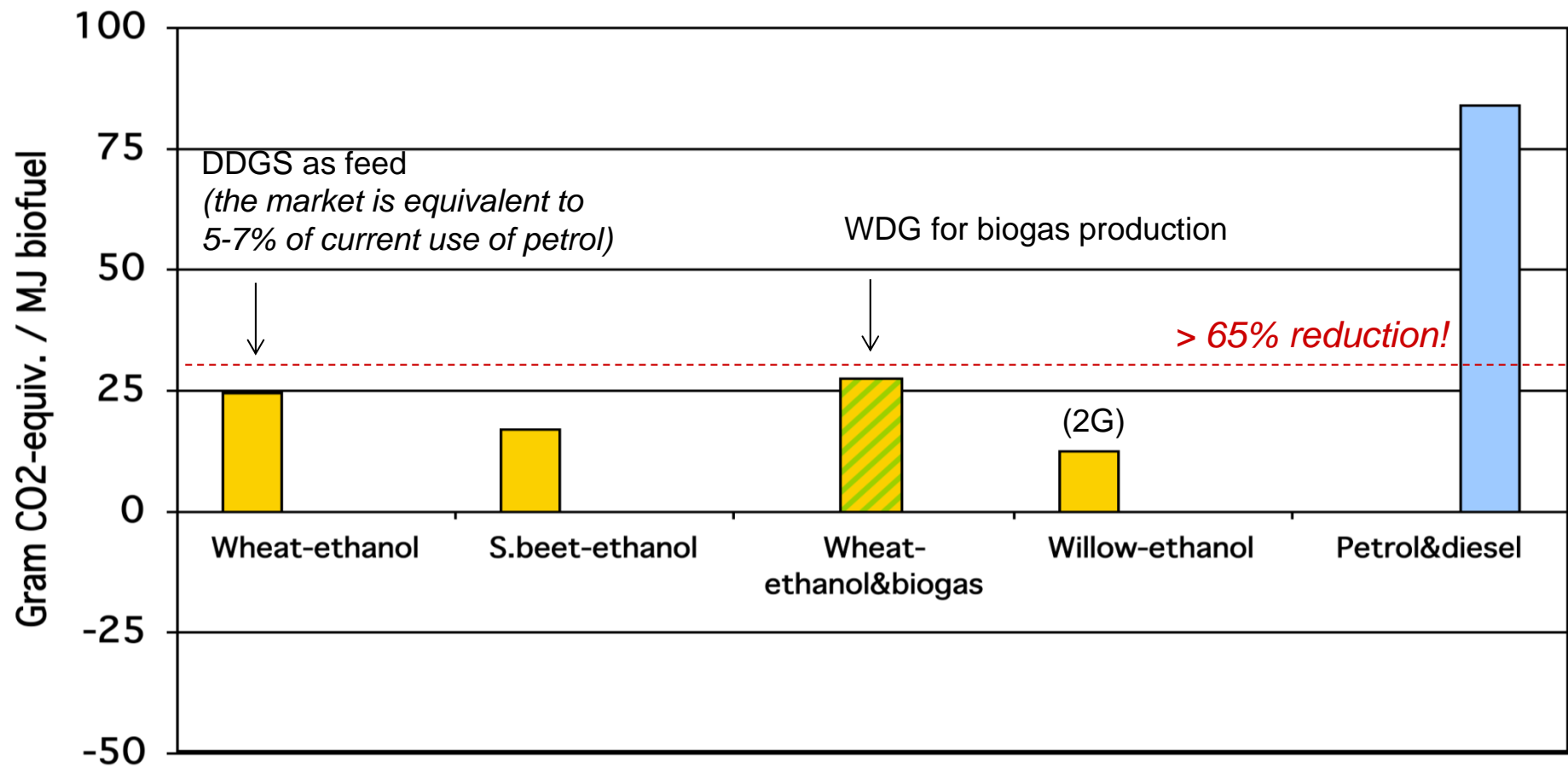


Ref. Börjesson (2009), *Applied Energy* (86) 589-594

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



GHG performance of crop-based ethanol (incl. dLUC)*



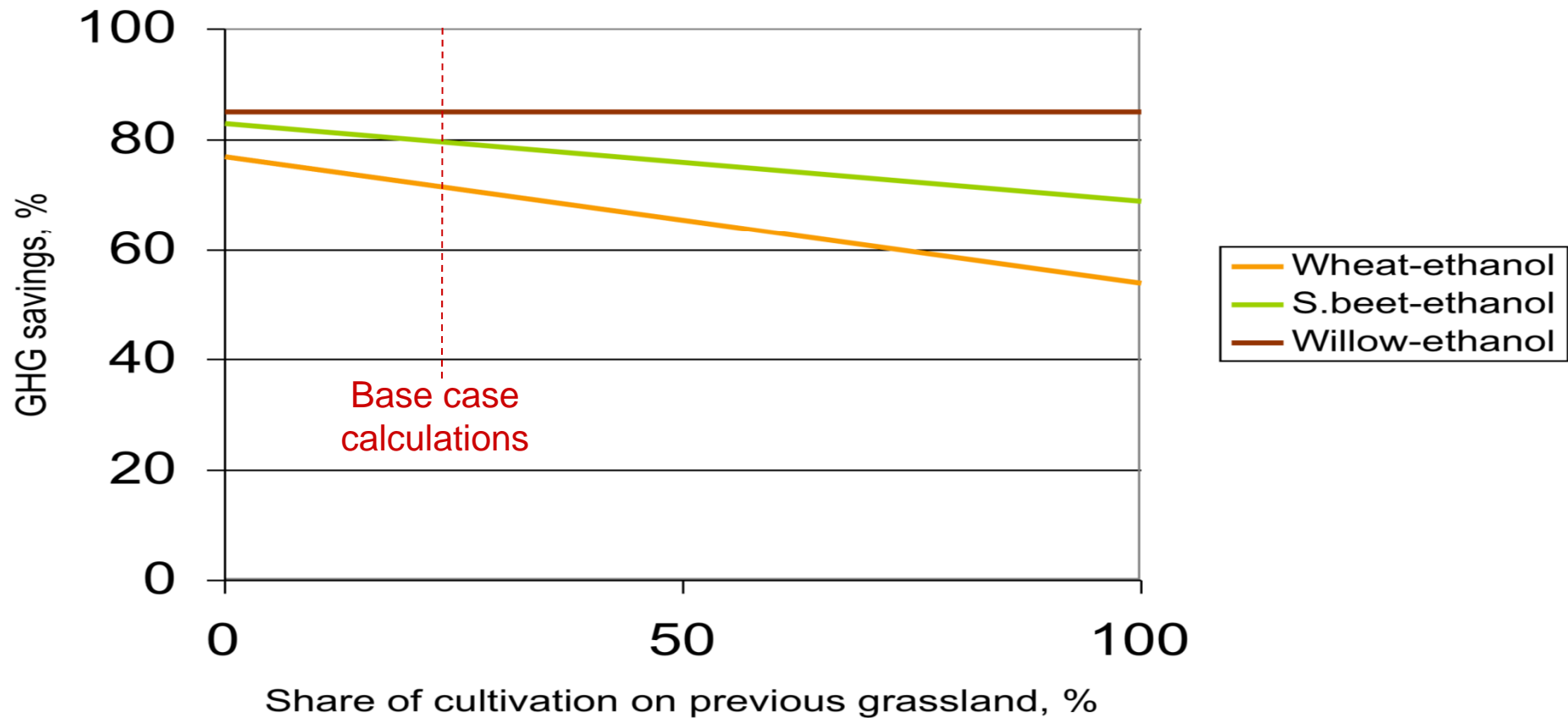
Ref. Börjesson & Tufvesson (2011), J Clean Prod (19) 108-120

* Based on system expansion and excluding straw. Cultivation on 25% previous grassland

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



GHG savings and direct land use changes (dLUC)*



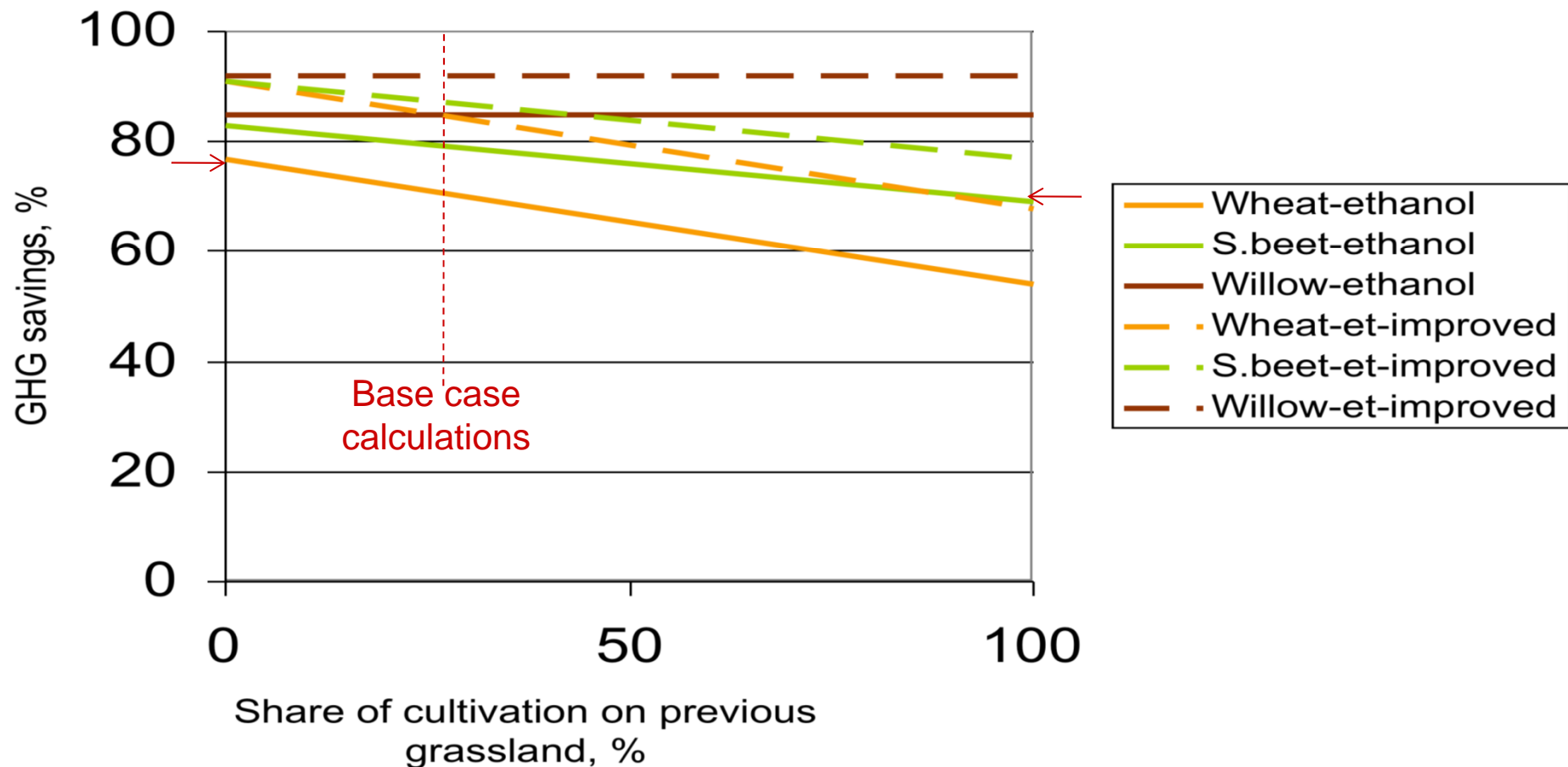
Ref. Börjesson & Tufvesson (2011), *J Clean Prod* (19) 108-120

* Based on system expansion and excluding straw.

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



GHG savings, dLUC and GHG free N fertilisers*



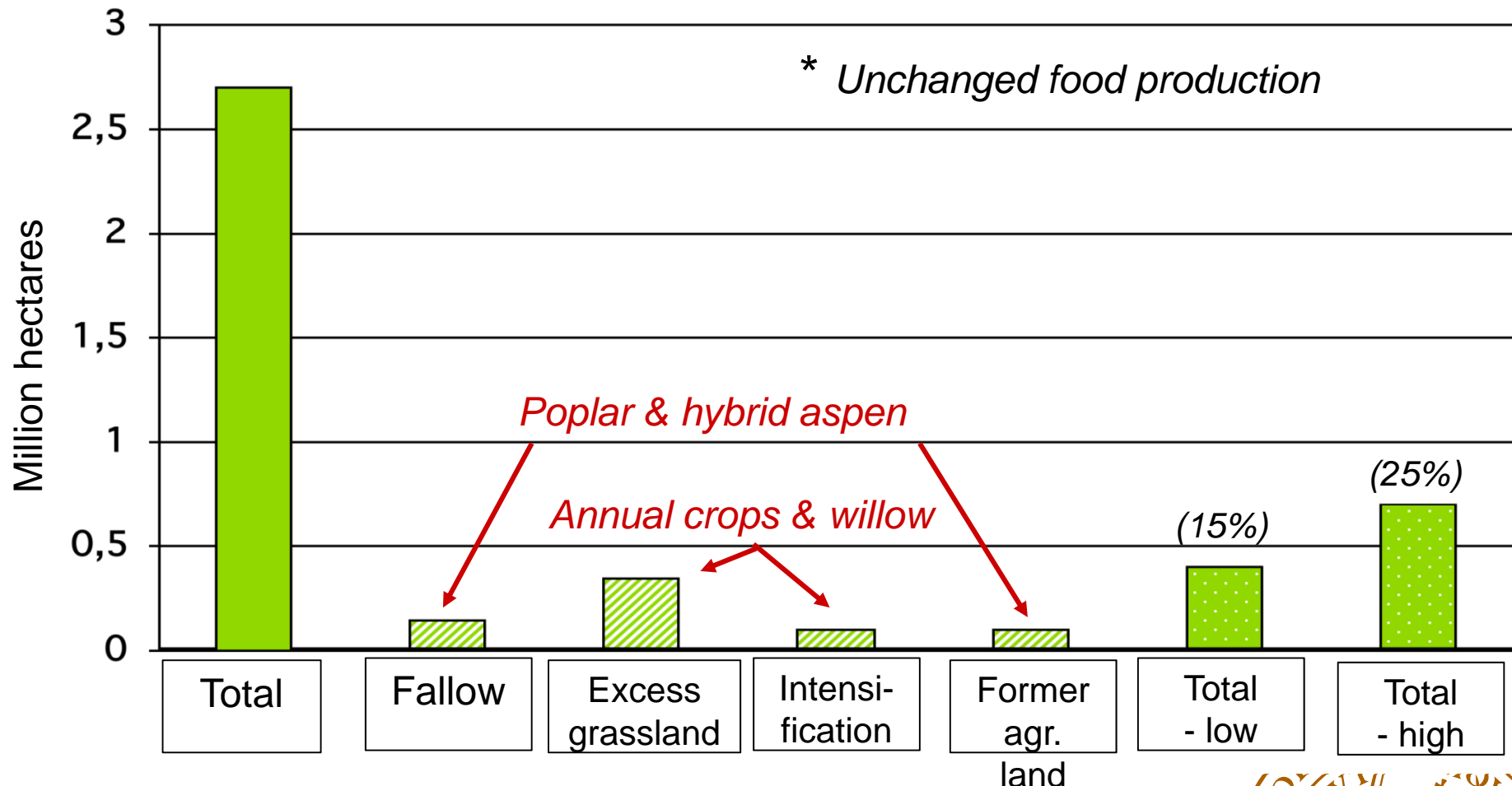
Ref. Börjesson & Tufvesson (2011), *J Clean Prod* (19) 108-120
& Ahlgren et al. (2008), *Bioresource Technology* (99) 8034-8041

* Based on system expansion and excluding straw.

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



Potential of arable land for bioenergy production – *dynamic effects in Swedish agriculture**



Refs. Swedish Board of Agriculture (2009); Statistics Sweden (2009)

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



The flowchart illustrates a biorefinery process for ethanol production from lignocellulosic biomass. The process begins with **Pretreatment**, which feeds into **Enzymatic Hydrolysis**. This stage also receives input from **Yeast Cultivation**. The output of **Enzymatic Hydrolysis** goes to **Solids separation (filtration, centrifugation)**. This separation unit produces **Lignin**, which is sent to **Combustion (CHP, condensing power)** for **Heat, power** generation. The **Liquid** stream from solids separation goes to **Distillation**. **Distillation** produces **EtOH** (ethanol) and a **Solid separation (centrifugation)** stream. The **Solid separation (centrifugation)** stream goes to **Drying**, which produces **Lignin pellet**. The **Liquid** stream from distillation goes to **AD** (Anaerobic Digestion). **AD** produces **Biogas** and **Sludge**. The **Sludge** goes to **WWT** (Wastewater Treatment), which produces **To Recipient**. The **AD** unit also feeds into **Combustion (CHP, condensing power)**. The **Combustion** unit produces **Heat, power**. The **WWT** unit produces **To Recipient**. The **AD** unit also feeds into **Combustion (CHP, condensing power)**. The **Combustion** unit produces **Heat, power**. The **WWT** unit produces **To Recipient**.

SSF (Simultaneous Saccharification and Fermentation) is indicated for the **Liquefaction**, **Enzymatic hydrolysis**, and **Fermentation** stages.

(Raw material & fermentation - 1G ethanol) is indicated for the **Distillation** and **Dehydration** stages.

Yeast Cultivation is a separate stage that feeds into **Enzymatic Hydrolysis**.

Enzymatic Hydrolysis is a separate stage that feeds into **Solids separation (filtration, centrifugation)**.

Solids separation (filtration, centrifugation) is a separate stage that produces **Lignin** and **Liquid**.

Lignin is sent to **Combustion (CHP, condensing power)** for **Heat, power** generation.

Liquid is sent to **Distillation**.

Distillation produces **EtOH** and a **Solid separation (centrifugation)** stream.

Solid separation (centrifugation) is a separate stage that goes to **Drying**.

Drying produces **Lignin pellet**.

AD (Anaerobic Digestion) receives **Liquid** from **Distillation** and produces **Biogas** and **Sludge**.

Sludge goes to **WWT** (Wastewater Treatment).

WWT produces **To Recipient**.

Combustion (CHP, condensing power) receives **Lignin** and **Sludge** and produces **Heat, power**.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

EtOH is the final output of the **Distillation** stage.

Heat, power is the final output of the **Combustion** stage.

To Recipient is the final output of the **WWT** stage.

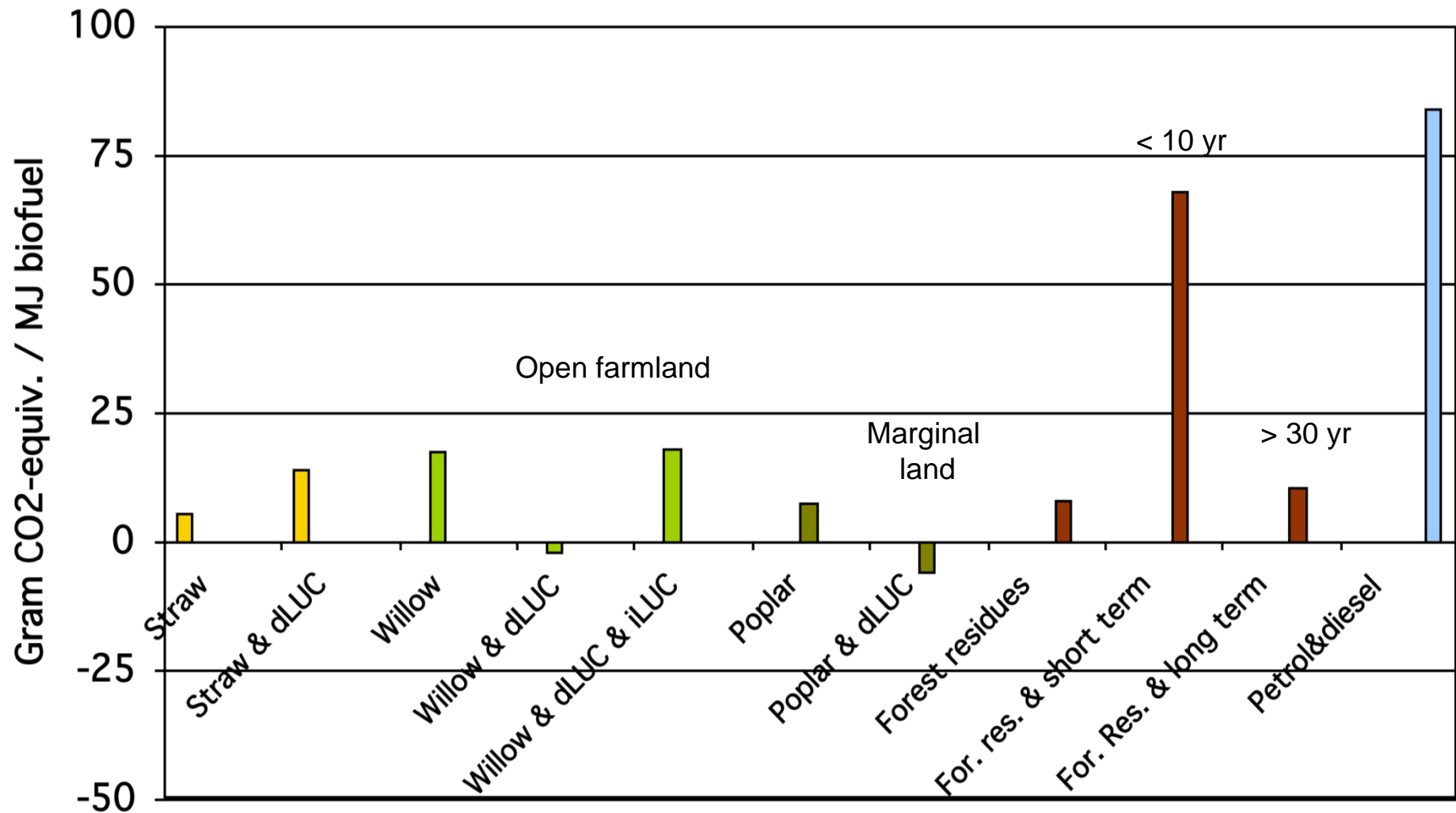
Biogas is the final output of the **AD** stage.

Lignin pellet is the final output of the **Drying** stage.

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



GHG performance of 2G ethanol incl. dLUC & iLUC*

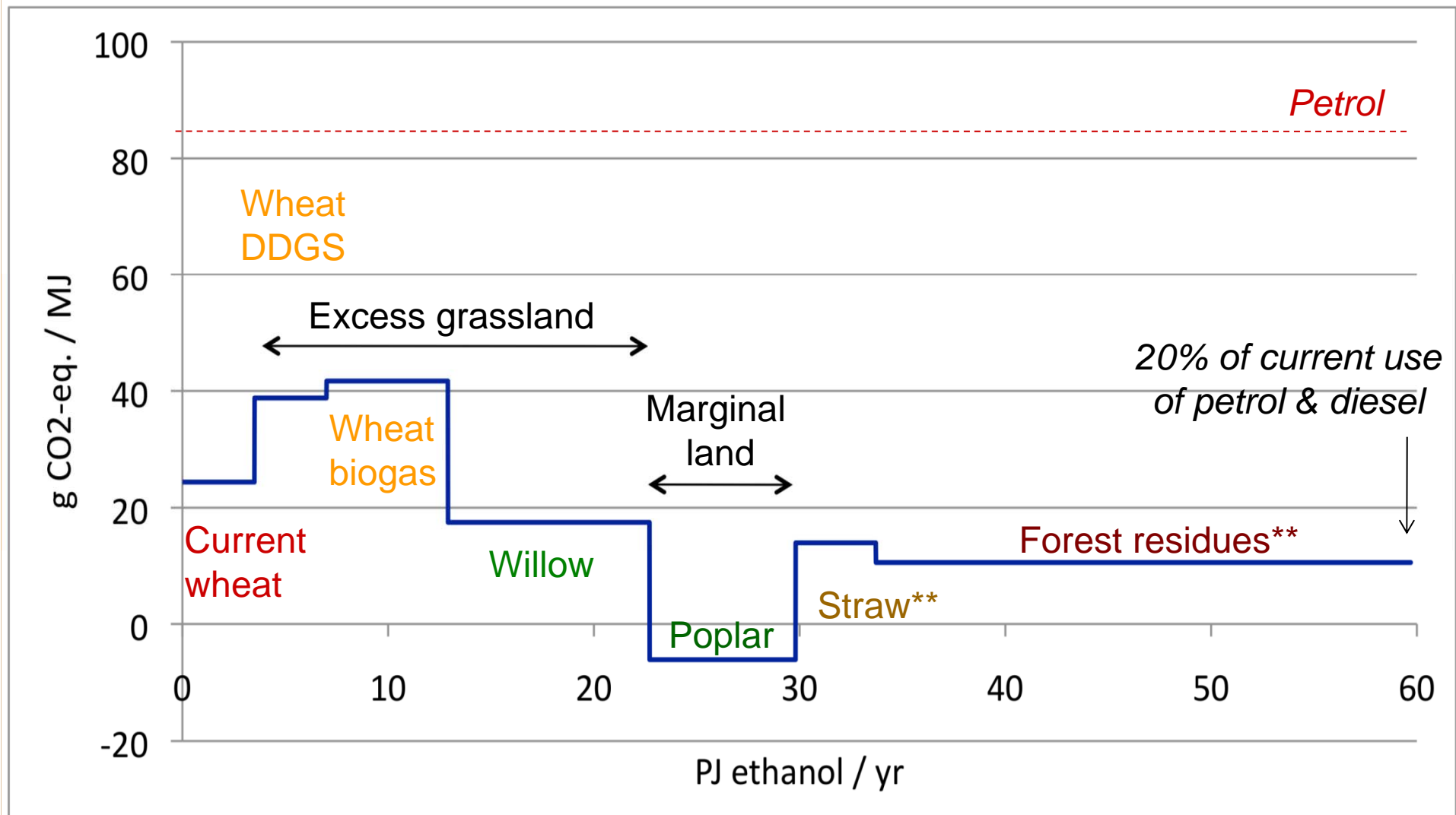


* The iLUC factor is assumed to be 20 g CO₂-equiv. / MJ

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



Expanded ethanol production and GHG performance*



* Based on system expansion, incl. dLUC; ** 50% of available, unused potential

Pål Börjesson, Environmental & Energy Systems Studies, Lund University



Conclusions

- An expansion of 1G ethanol equivalent to 7% of current fossil vehicle fuels will increase GHG emissions from around 25 g/MJ to around 40 g/MJ due to dLUC during a transition period, but not affect current food and feed production (thus no iLUC)
- Improved production technologies (e.g. GHG free N fertilisers) could almost counteract these negative dLUC
- Willow-based 2G ethanol on excess grassland, instead of 1G ethanol, will result in GHG emissions of around 17 g/MJ
- Poplar-based 2G ethanol on abandoned arable land could result in “negative” GHG emissions (-5 g/MJ) due to positive dLUC during a transition period (30-50 years)



Conclusions

- Straw-based 2G ethanol equivalent to current amount of 1G ethanol will give GHG emissions of around 15 g/MJ (incl. dLUC)
- Forest residue-based 2G ethanol will result in GHG emissions of around 10 g/MJ in a mid- and long-term perspective (> 30 years), but higher emissions during an initial phase (< 10 years)
- Swedish ethanol production could expand equivalent to 20% of current use of fossil vehicle fuels having an average GHG performance of roughly 15 g/MJ, in a 30 year perspective
- Thus, it is motivated to use a certain share of an allowed GHG emissions space in relation to GHG targets for short-term GHG emissions in the development of long-term sustainable bioenergy system, such as “good” ethanol systems

Pål Börjesson, Environmental & Energy Systems Studies, Lund University

