Production of hydrogen-rich syngas from steam gasification of blend of biosolids and wood

H. McKinnon, W. Saw, I. Gilmour and S. Pang

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Biosolids (or dried sewage sludge)

- is the residue produced by the treatment of domestic and industrial waste-water
- is a mixture of C, P and N compounds with heavy metals and (in its wet state) microbial organisms

Biosolids (or dried sewage sludge)

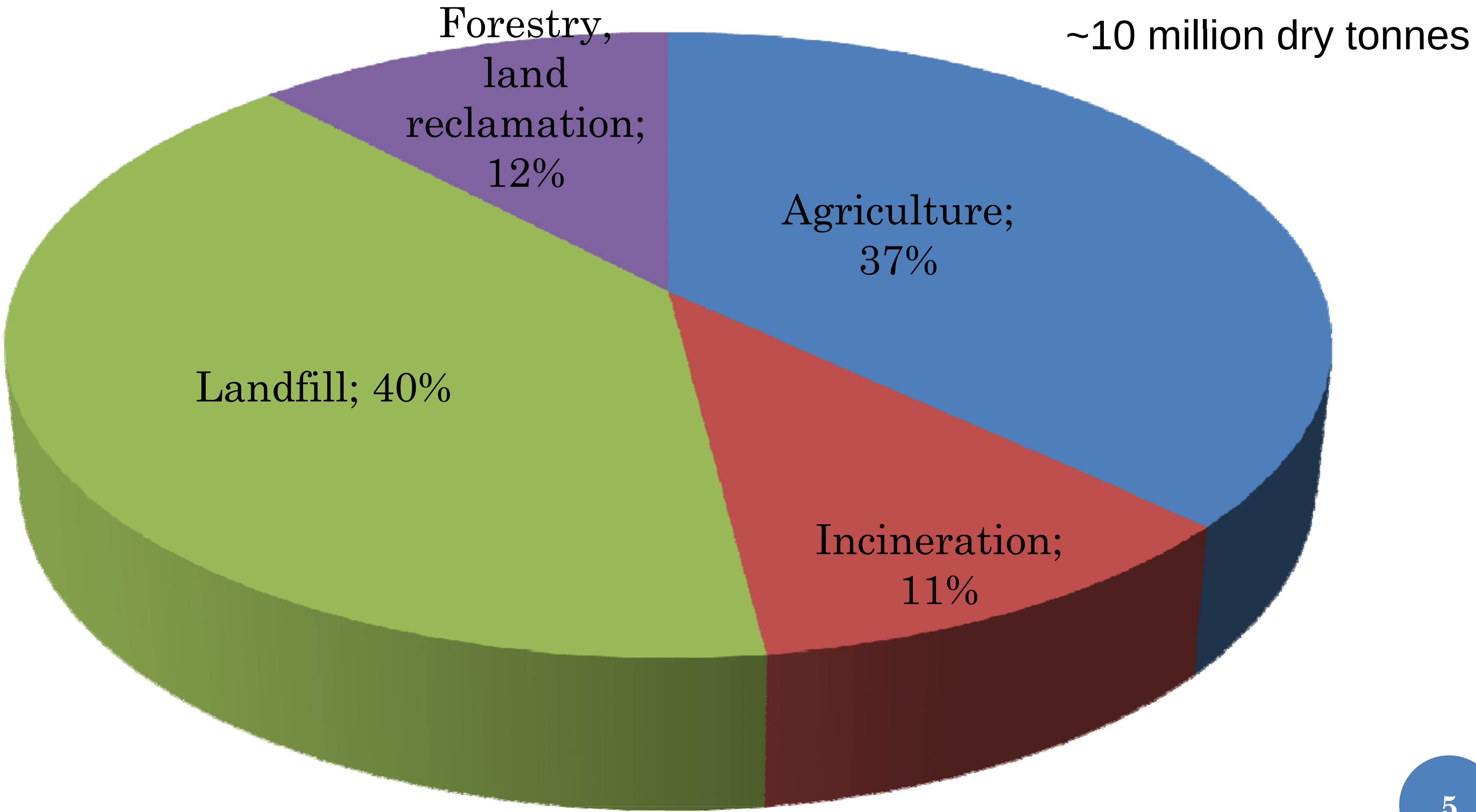
- is a valuable fertiliser (P and N compounds)
- is a renewable fuel due to its high C content
- is a free fuel and CO_2 neutral

Sample of biosolids

Biosolids disposal methods

- Land-filling
- Land reclamation
- Agricultural fertiliser
- Incineration/Combustion
- Gasification

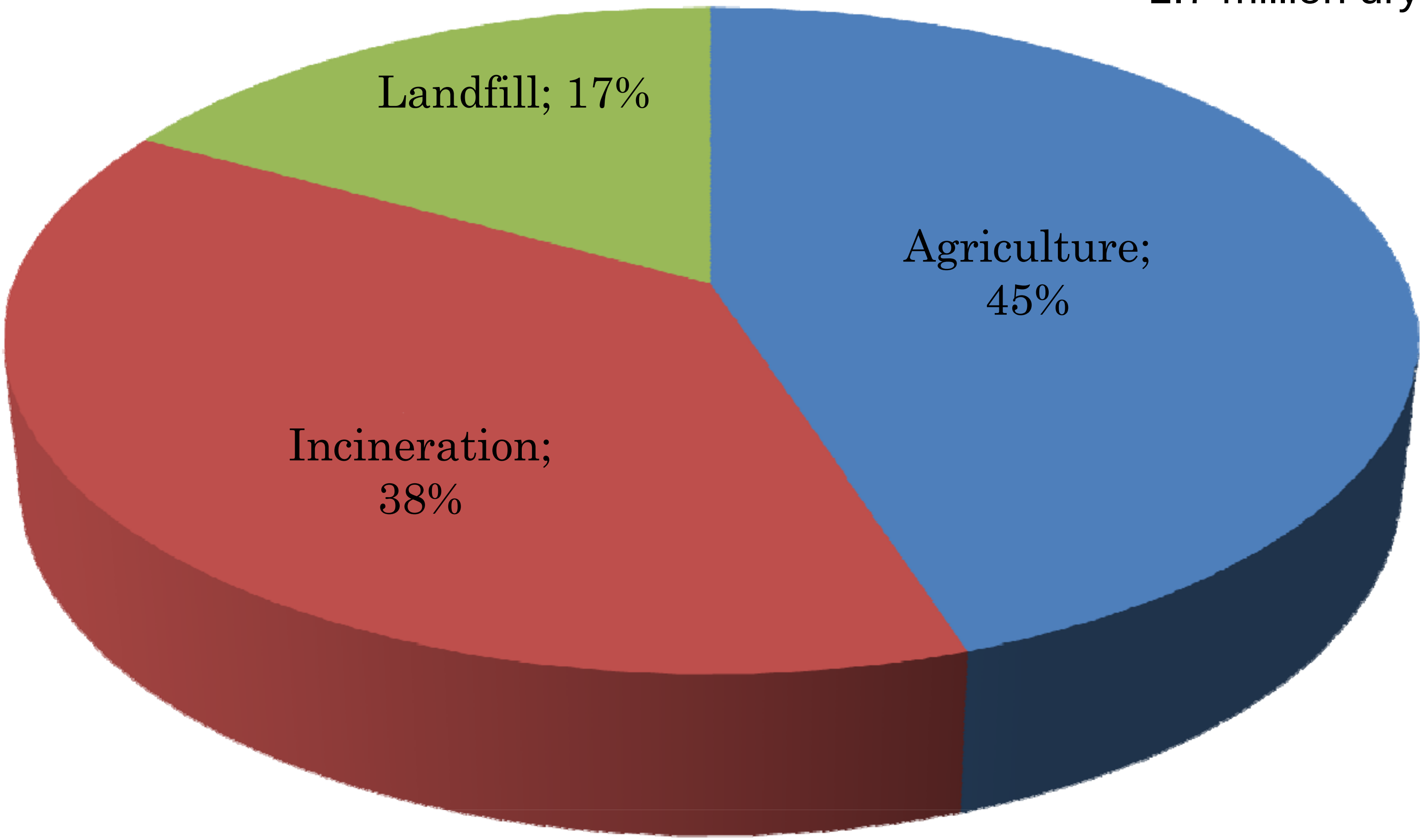
Biosolids disposal methods in EU



D. Fytili, A. Zabaniotou, Utilization of sewage sludge in EU application of old and new methods – A review, Renewable and Sustainable Energy Review, 12 (2008) 116-140.

Biosolids disposal methods in UK

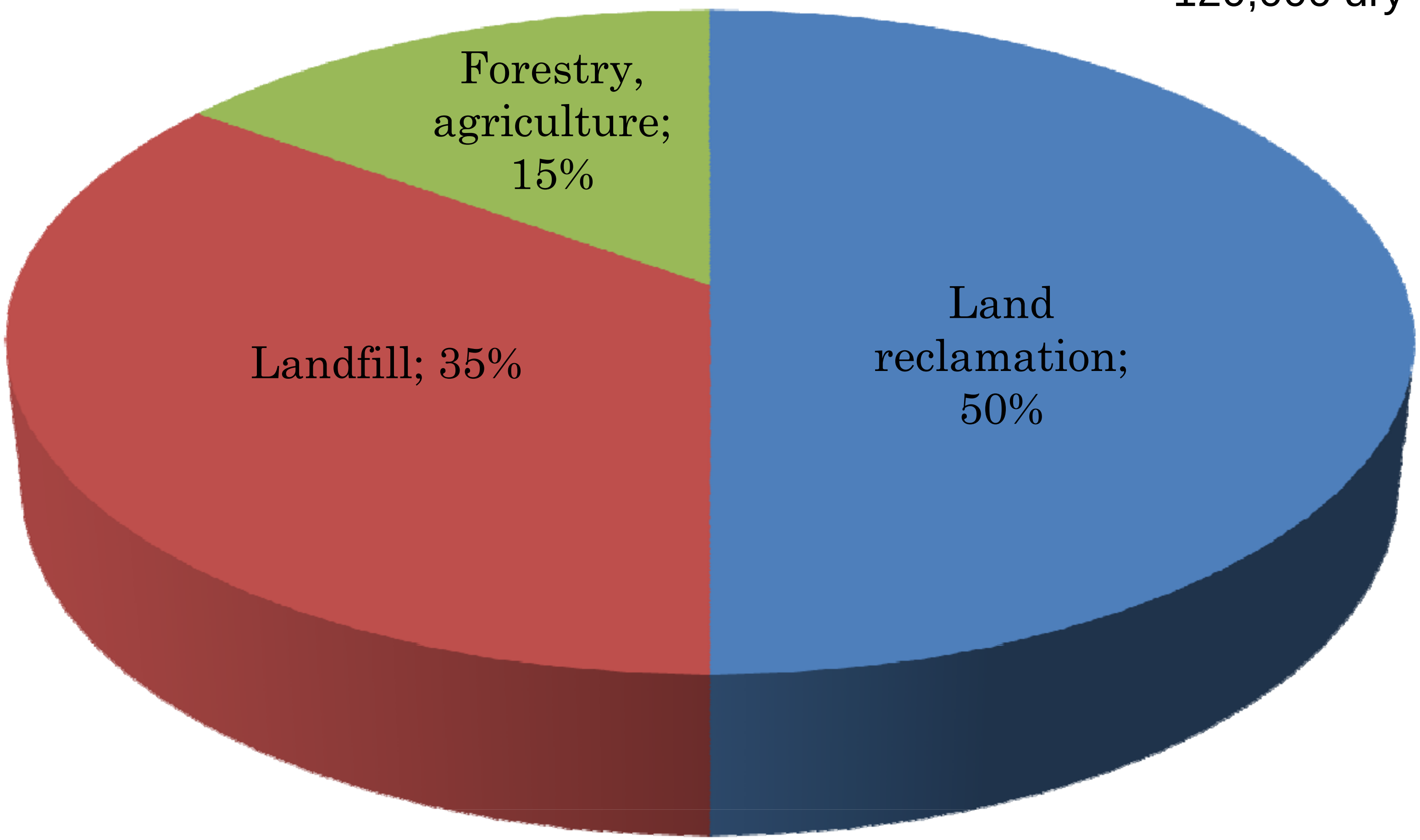
~1.7 million dry tonnes



A. Adegoroye, N. Paterson, X. Li, T. Morgan, A.A. Herod, D.R. Dugwell, R. Kandiyoti, The characterisation of tars produced during the gasification of sewage sludge in a spouted bed reactor, Fuel, 83 (2004) 1949-1960.

Biosolids disposal methods in NZ

~120,000 dry tonnes



Ministry for the Environment, Target in the New Zealand waste strategy-2006 review of progress, Ministry for the Environment 2007.

Technological benefits for biosolids gasification in New Zealand

- Reduce the reliance of fossil fuel
- More efficient process than incineration or combustion of biosolids for power generation
- Less quantity of greenhouse gases (NOx and SO_2) generated, flying ash, dioxins, furans and heavy metals emissions
- Reduce volume of biosolids
- Reduce cost of transportation
- Eliminate pathogenic bacteria
- No contribution of heavy metals to soil-plant system with biosolids ash compared with digested or composted biosolids

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Gasification

- Gasification is a thermal-chemical conversion of carbonaceous materials (biomass, coal, biosolids) to producer gas/syngas (H_2 and CO) in a controlled environment (air/O_2/steam/CO_2)
  - Calorific value - 4 to 20 MJ/Nm^3
- Syngas can be a feedstock for liquid fuels or fuel cells
- However, tar is generated during gasification process
  - Tar - all organic compounds with a molecular weight higher than benzene (C_6H_6).
    - Cause significant fouling issues for downstream processes

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The high heating value (HHV) and chemical compositions of biosolids

	Biosolids
HHV (MJ/kg)	14
Proximate, %	
Moisture content	8.0
Volatile matter	43.5
Ash	32.0
Fixed carbon	16.5
Ultimate, %	
Carbon	34.0
Nitrogen	5.1
Sulphur	1.2
Hydrogen	3.5
Oxygen	16.2

- Approximately 6000 dry t/y of biosolids produced from Christchurch wastewater treatment plant.

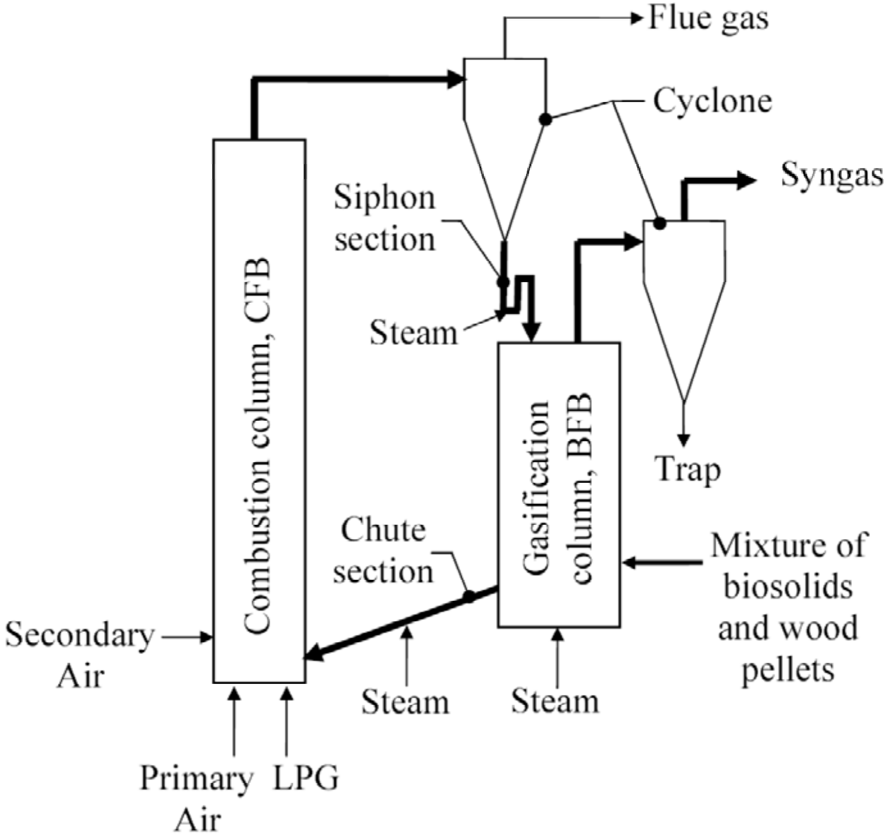
~16 GWh/y of thermal energy available

→mostly going to landfill and recover landfill gas for power generation.

Aims

- To investigate the biosolids proportion on syngas, cold gas efficiency and syngas composition (with focus on H_2 content);
- To examine the tar concentration as a function of the biosolids proportion in the fuel;
- To compare the syngas composition of this study with the previous studies, which used air, O_2 and CO_2/N_2 as the gasification medium.

100kW dual fluidised bed (DFB) gasifier



Schematic diagram of the DFB gasifier

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100kW DFB gasifier

- Gasification temperature: 720°C
- Bed material: Greywacke sand
- Feed rate: 15.5kg/hr
- Steam to feedstock: 0.7 (kg/kg)
- Feedstock: 7 trials with different premixed blend of wood pellets and biosolids
  - (100%, 80%, 60%, 40%, 20%, 10%, 0%)

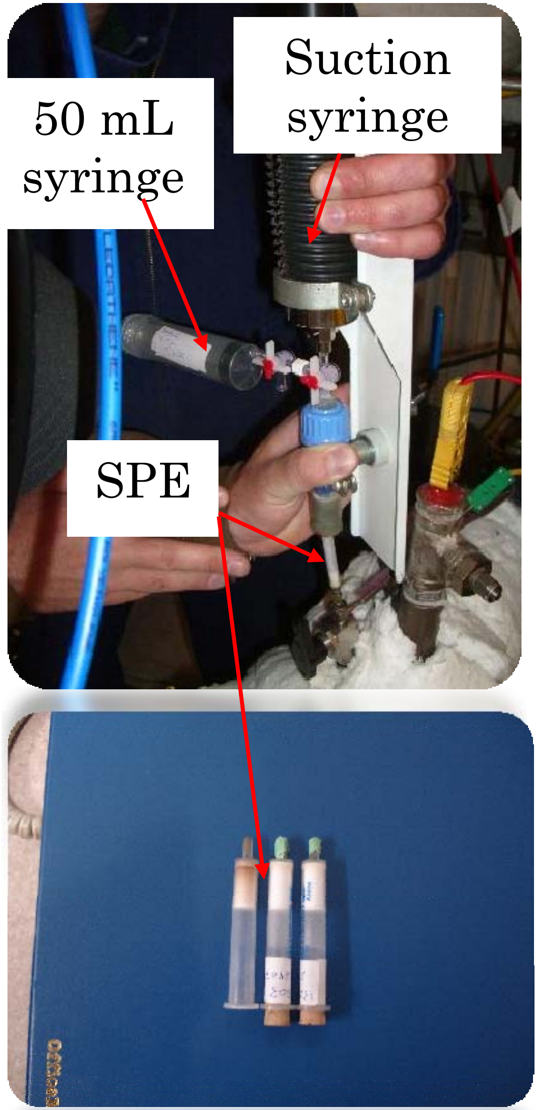
The HHV and chemical compositions of biosolids and wood pellets

	Biosolids	Wood pellets
HHV (MJ/kg)	14	18
Proximate, %		
Moisture content	8.0	8.0
Volatile matter	43.5	77.4
Ash content	32.0	0.4
Fixed carbon	16.5	14.2
Ultimate, %		
Carbon	34.0	47.2
Nitrogen	5.1	<0.2
Sulphur	1.2	<0.1
Hydrogen	3.5	5.4
Oxygen	16.2	38.7

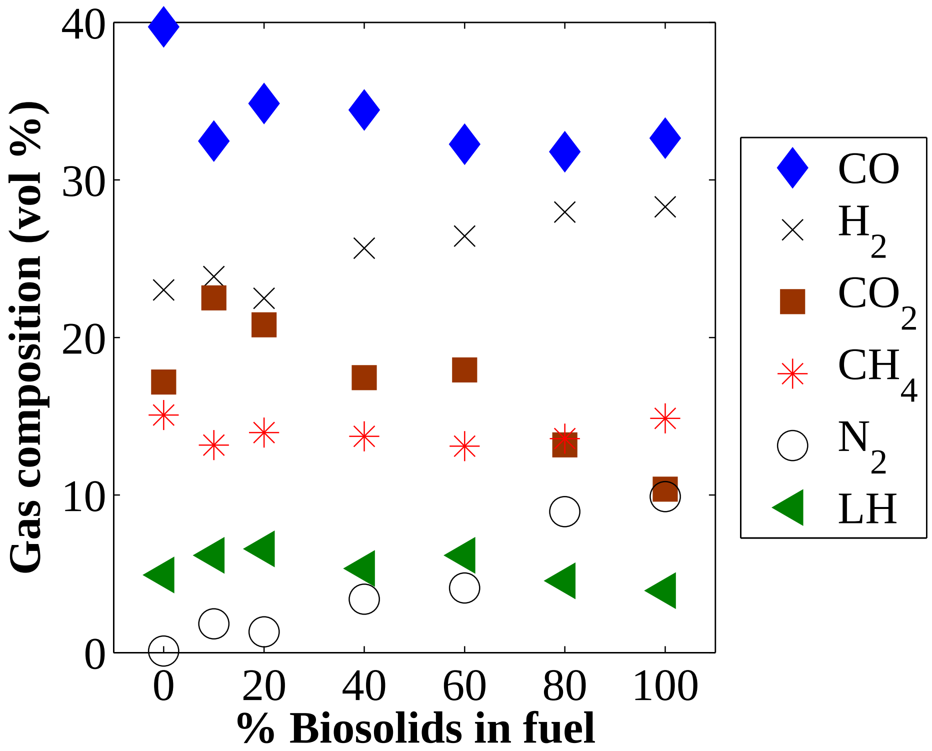
SiO_2	CaO	P_2O_5	Al_2O_3	Fe_2O_3	SO_3	MgO	Na_2O	TiO_2	K_2O	Mn_3O_4
44.5	15.6	13.6	8.8	5.2	2.4	2.3	1.9	1.6	1.6	0.1

Methods of sampling and analysis

- Syngas
  - 50mL syringe
  - Agilent 3000 Micro-GC
    - H_2,CO,CO_2,CH_4,C_2H_4,C_2H_6
- Tar
  - 3ml Bakerbond amino normal phase solid phase extraction (SPE)
    - Evaporative analysis
      - Weigh the evaporating dish before and after sampling 100ml of syngas

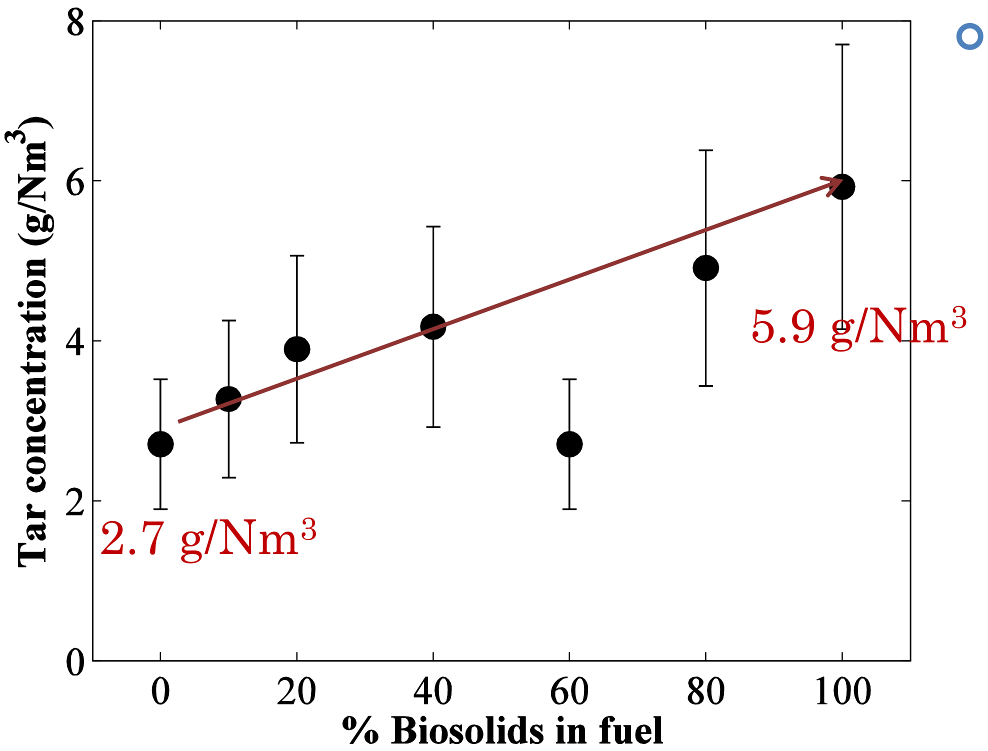


Syngas composition



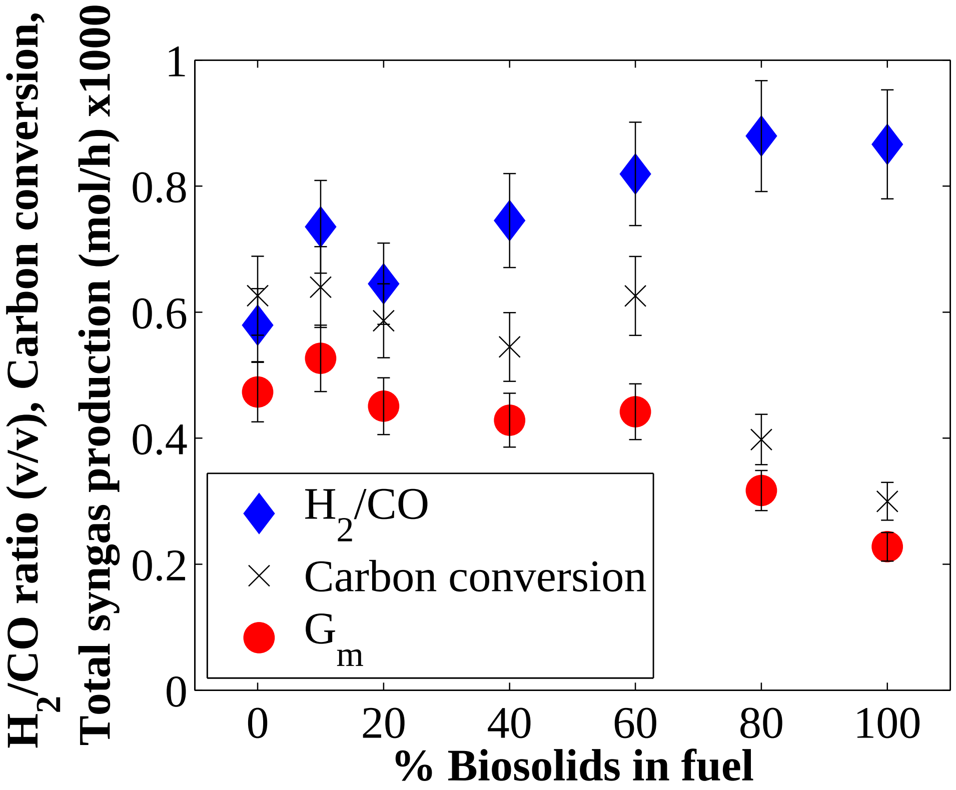
- The increase of H_2 could be due to the presence of catalysts in the biosolids:
  - CaO
  - Fe
  - Alkali salts (Na and K)

Total tar concentration



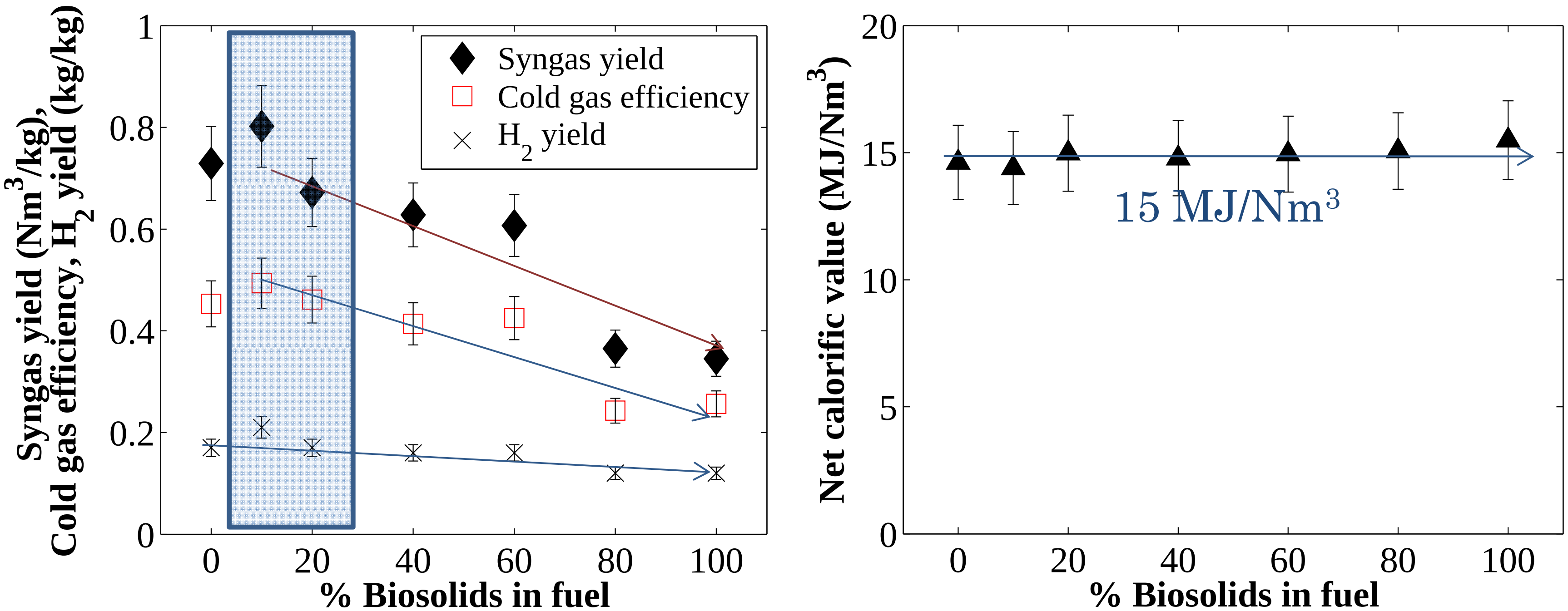
- The increase of tar concentration could be resulted from the complex molecular structure

H_2/CO ratio, C conversion and total syngas production



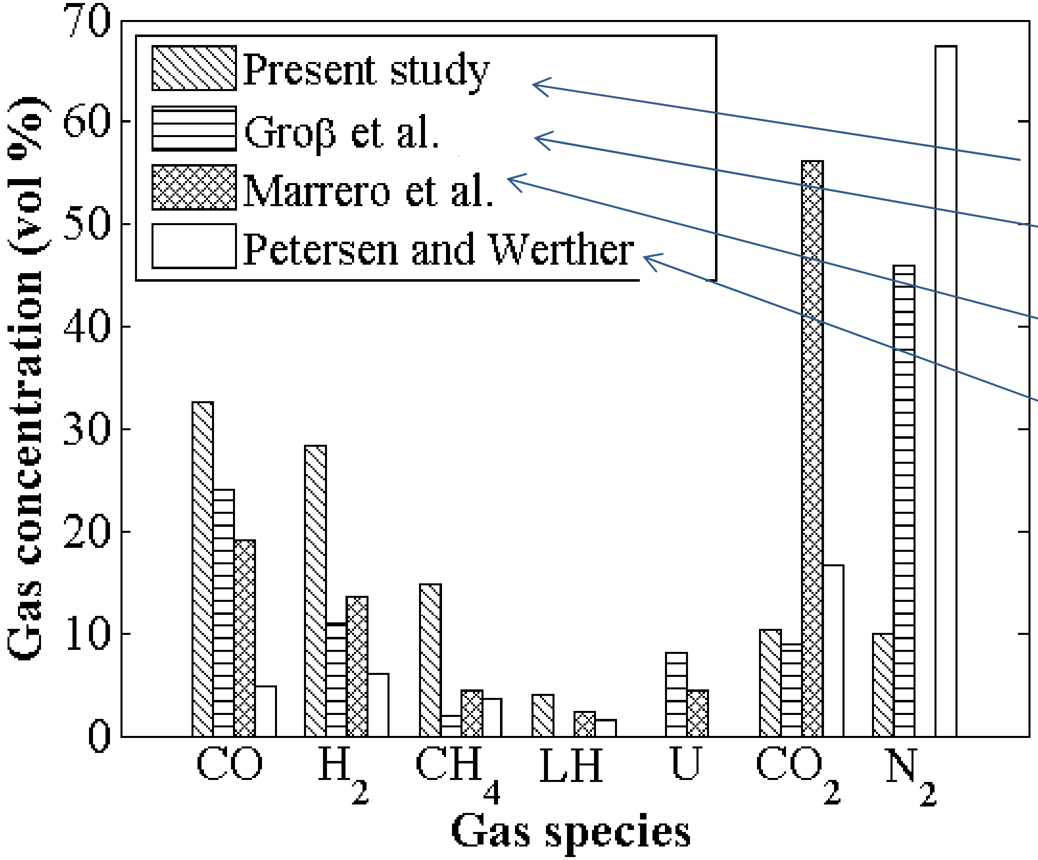
- The decrease in C conversion rate was due to the friable nature of the dried biosolids
  - Entrainment of biosolids
    → Fixed carbon and volatiles were reduced significantly
- This issue can be reduced by densification, e.g. pelletising

Syngas and H_2 yields, cold gas efficiency and net calorific value



- The ash quantity per weight in biosolids is higher than wood pellets (32% vs 0.4%).
- The biosolids being biologically digested prior to gasification

Comparison of syngas generated from 100% biosolids



- **Gasification medium:**
  - Steam, DFB
  - Air, Two-stage BFB
  - O_2, Fixed bed
  - CO_2/N_2 ($\Psi CO_2 = 0.2$), CFB

- The H_2 and CO were found to be 40% higher than for those under other gasification media
- The CO_2 was found to be at least 30% lower than that under O_2 and CO_2/N_2

Conclusion

- the syngas from biosolids had higher content of H_2 (29%) compared with that from pure wood (22%);
- the syngas and H_2 yields and cold gas efficiency in steam gasification decreased dramatically at 100% biosolids loading compared with 100% pure wood loading;
- the increase of 10 to 20% loading of biosolids in the fuel did not diminish the yields and the cold gas efficiency;
- the concentrations of H_2 and CO in this study with 100% biosolids was found to be at least 40% higher than those using O_2, CO_2/N_2 or air as the gasification medium.

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