EVALUATING THE GASIFICATION PERFORMANCE OF VINE PRUNINGS

M. Simone [1,2], F. Barontini [1,2], C. Nicolella [1,2], L. Tognotti [1,3]

[1] Università di Pisa – Dipartimento di Ingegneria Chimica, Chimica Industriale e Scienza dei Materiali (UNIPI)
Largo Lucio Lazzarino, 1 56122 Pisa (ITALY)

[2] Centro di ricerca interuniversitario biomasse da energia (CRIBE)
Via Vecchia di Marina, 6 56122 Pisa (ITALY)

[3] International Flame Research Foundation (IFRF)
Via Salvatore Orlando, 5 57123 Livorno (ITALY)

ABSTRACT: This work deals with the gasification of vine prunings, a common agricultural residue in Italy. The testing facility is a 200 kWt downdraft gasifier operating with air as a gasifying agent. Pressure drop, syngas flow-rates, gas compositions and syngas outlet temperatures were monitored throughout the tests. Gas compositions were evaluated integrating a microGC and a FTIR analyzer. The first one allows evaluating all the gas species including hydrogen, nitrogen and oxygen but cannot provide a continuous measure of the gas compositions. Conversely the FTIR analyzer cannot detect homonuclear diatomic molecules but allows for a continuous detection of the syngas composition evolution. By this is way it was possible to provide both global performance parameters based on the average GC compositions and observations related to the gasifier dynamics. The gasification of vine prunings posed some operational issues. First the prunings had to be sieved in order to reduce the amount of dust which is harmful for the gasifier operation. Moreover vine prunings are a loose material; therefore the parameters of the feeding system had to be properly set in order to ensure the gasifier operation. The gasification of vine prunings led to quite satisfactory results in terms of gas composition and relatively low pressure drops. Therefore from an operational point of view the gasification of vine prunings is feasible after solving some issues.

Keywords: agricultural residues, gasification, syngas, pilot plant, characterization

1 INTRODUCTION

CRIBE (Centro di Ricerca Inter-Universitario Biomasse da Energia) is a research centre which involves several partners of the Università di Pisa and the Scuola Superiore Sant'Anna who have been studying biomass and energy from different perspectives. The University of Pisa has been focusing on biomass characterization and conversion, while the Scuola Superiore Sant'Anna has been investigating biomass production by means of dedicated energy crops.

The partners now integrate their skills and carry out joint activities related to biomass production and conversion since 2010 with the following aims:

- gain practical experience within the operation of different technological platforms;
- evaluate suitable biomass-conversion technology couplings;
- assess land destination suitability.

An important part is dedicated to the valorization of agricultural residues. This work reports a focus on the valorization of vine prunings.

In Italy there are nearly 800.000 ha of soil destined to vine cultivation, mainly for wine production. Every year vine plantations are pruned leading to an average production of 1.5 – 2.5 tons of vine prunings (moisture 50%) per ha per year [1].

Common practices for the disposal of these agricultural residues are:

- landfill in the fields;
- burning in fire at the field boarder.

The first practice may be unsuitable when the plant is attacked by parasites and the second one is often forbidden by the local Italian legislations. Therefore, some other options have to be found in order to solve the problem of the disposal of such residues.

Thermal conversion is an option for the valorization of vine prunings. These residues can be efficiently collected and chipped or transformed into pellets. Therefore, they are suitable for the use in small scale equipments for thermal conversion.

Moreover, the proper storage of vine prunings can lead to a biomass with very low moisture content (10%), which is very attractive for the thermal conversion.

Co-generation is a nice opportunity for farmers to get rid of these residues and, at the same time, develop a new income.

At a small scale, two thermal conversion technologies can be used for the utilization of vine prunings:

- combustion coupled with an ORC (Organic Rankine Cycle)
- gasification coupled with IC engine

The aim of this work is to evaluate the gasification performance of vine prunings. Gasification tests were carried out with a 200 kWt downdraft gasifier in order to provide experimental data which are representative of a small scale production.

2 FEEDSTOCK

Vine prunings were produced in the province of Treviso and provided to the CRIBE.

The prunings were chipped and stored in such a way that their moisture content was very low when delivered to the plant. **Table I** reports the results of the characterization of feedstock.

The moisture content is rather low compared to fresh biomass. This feature is very interesting for the use of biomass in a downdraft gasifier, since it operates with very low moisture content (maximum 20%). So there is no need for a drying step, prior to conversion in the gasifier.

The properties of vine prunings are rather similar to woody biomass, except for the ash content which is somewhat high. This is due to the high amount of bark in vine. Vine prunings were characterized by a high amount of dust (Table II). Therefore, it was necessary to sieve them before being fed to the gasifier. This practice is fundamental for ensuring the gasifier operation, as the presence of fine particles reduces the bed permeability inside the gasifier, thus increasing the gas pressure drop and reducing the gasifier efficiency.

Table I: Properties of vine prunings

Parameter	Units	Value
Moisture ar	%	17.6
VM dry	%	80.84
FC dry	%	16.54
ASH dry	%	2.62
C daf	%	50.8
H daf	%	5.8
N daf	%	0.9
O daf	%	diff
LHV dry	MJ kg^{-1}	18.06
Bulk density	kg m^{-3}	280

Table II: Size distribution of sieved vine prunings

Size	Units	Value
< 3.35 mm	%	12.8
3.35-8 mm	%	34.1
8-16 mm	%	40.3
16-63 mm	%	6.3
>63 mm	%	6.5

3 GASIFICATION FACILITY

The gasification facility is described in details elsewhere [2]. Only a brief overview is presented here. The gasification facility is based on a 200 kWt downdraft gasifier operating with air as gasifying agent.

The plant is equipped with a clean-up line for syngas purification, which is designed to prepare the syngas for combustion in an IC-Engine. The plant is not equipped with an engine; therefore the syngas is burned with a flare.

The CRIBE gasification plant is equipped with two on-line instruments for gas sampling and analysis: a micro-gas chromatograph (GC) and a Fourier Transformed Infra-Red Spectrometer (FTIR). The second one is a new feature of the plant and it was not presented in previous works.

FTIR measurements are performed using a Bruker Tensor 37 FTIR spectrometer, installed in a specifically developed pressurized cabinet. The apparatus is equipped with a pump for gas sampling including valves and manometers for pressure control and a heated transfer line. A heated gas cell (stainless steel body, 10cm optical pathlength, 25ml volume, 200°C maximum temperature) is used for gas analysis.

4 EVALUATION OF THE GASIFICATION PERFORMANCE

The gasification performance takes into account several parameters:

1. syngas composition and calorific value;
2. biomass handling and flowability;
3. pressure drop and syngas flow-rate;
4. mass and energy balances
5. residues

First of all, it is necessary to determine whether the gasifier is capable to produce syngas and its calorific value. This is done by simply monitoring the evolution of the gas composition throughout the gasification tests.

However, this is not enough to ensure a satisfactory performance. The reliability of the gasifier operation depends also on the flowability of the biomass in the gasifier, which is a common issue when dealing with loose material. In particular the formation of a “bridge” can compromise the gasifier operation.

There is not a straight way to estimate how a biomass will flow inside a fixed bed gasifier. This depends on the biomass size distribution and bulk density, but the occurrence of problems is also related to the particular gasifier configuration. Therefore, it is necessary to perform tests in order to assess this feature of the feedstock.

The assessment is further extended to the evaluation of the pressure drop across the gasifier bed.

The pressure drop is a fundamental parameter for evaluating the performance of a fixed bed gasifier [3]. High pressure drops indicate poor bed permeability, with a consequent reduction of the syngas production. Conversely, low pressure drops indicate excessive bed permeability or the presence of by-pass channel. In this case there is not an intimate mixing between the gas and the solid phase, which result in a poor conversion of the solid material. A low pressure drop may also indicate low biomass content within the gasifier, with the gasification process switching to combustion.

The analysis is completed with typical parameters deriving form the mass and energy balances such as the specific gas production (Nm^3 of dry syngas / kg of dry biomass) and the cold gas efficiency (MJ of dry syngas produced / MJ of biomass).

Finally the analysis is integrated with the characterization of the solid residues produced by the gasifier.

5 RESULTS

5.1 Syngas composition and calorific value

Three tests were carried out with vine pruning as feedstock. The syngas compositions and calorific values are reported in **Table III**. The average gas compositions obtained from the three tests are quite similar and they are comparable with literature values [4]. The syngas composition and the lower calorific value were characterized by continuous fluctuations (see **Figure 1**).

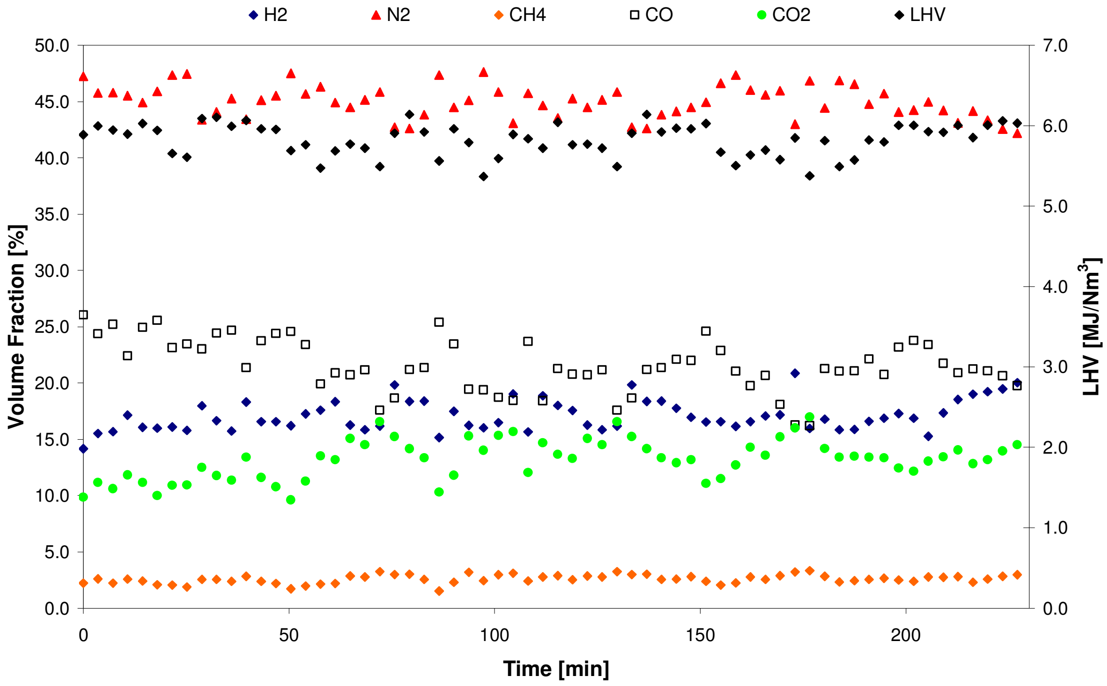

Figure 1: Syngas composition evolution during Test 1

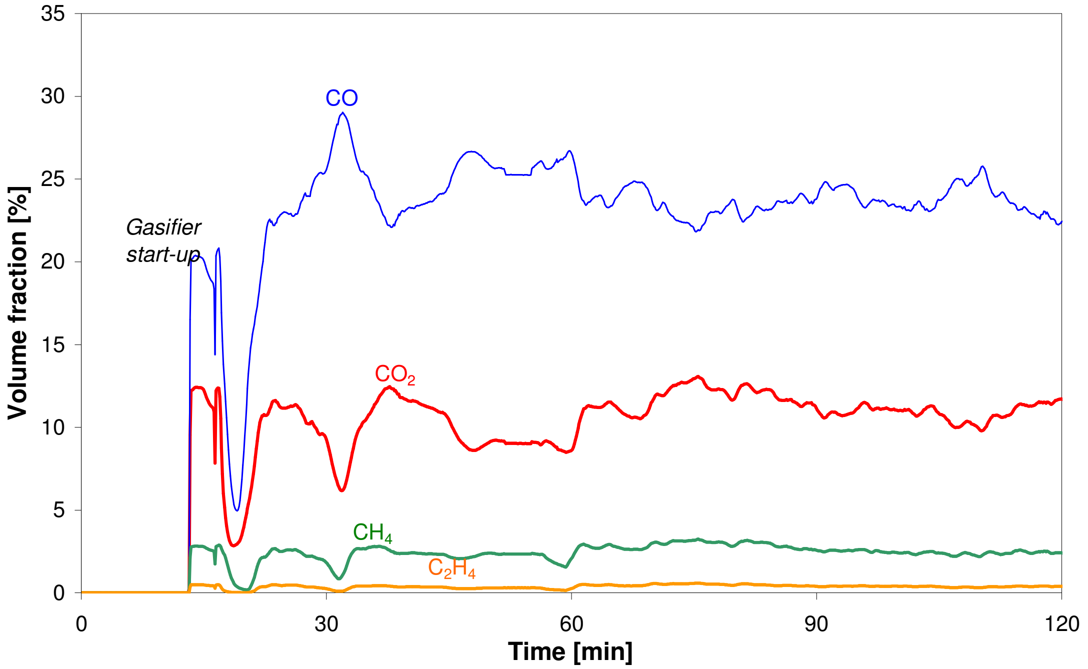

Figure 2: FTIR signals in the early stage of Test 3

Table III: Syngas compositions

	Test 1	Test 2	Test 3
CO [% vol]	21.74	22.28	20.05
H_2 [% vol]	17.06	16.76	18.06
CO_2 [% vol]	13.02	11.87	13.71
CH_4 [% vol]	2.55	1.85	2.55
N_2 [% vol]	45.07	46.69	45.04
O_2 [% vol]	0.02	0.20	0.00
C_2H_2 [% vol]	0.06	0.04	0.04
C_2H_4 [% vol]	0.42	0.28	0.50
C_2H_6 [% vol]	0.06	0.03	0.05
LHV [MJ/Nm^3]	5.82	5.50	5.75

For instance, the volumetric fractions of carbon monoxide and hydrogen exhibit absolute standard deviations of 2.31% and 1.37%, respectively. However, on the whole, the syngas composition and lower calorific value are rather stable. Therefore, the gasifier is characterized by a continuous dynamic, even if it has reached a steady operating point. It can be seen (**Figure 1**) that the lower the nitrogen content, the higher the lower calorific value of the syngas.

The continuous dynamic of the gasifier is even more evident from the FTIR signals reported in **Figure 2**.

The higher time resolution of FTIR allows highlighting some peculiar features of the syngas composition. It can be noted that positive deviations of carbon monoxide usually correspond to negative deviations of carbon dioxide and vice versa. This result can be explained either with a change in oxygen availability (probably related to variations of the bed permeability) or variations in the temperature of the reduction zone (the higher the temperature the more the equilibrium of the Boudouard reaction is shifted toward carbon monoxide).

Noteworthy, also the fluctuations of methane and ethylene exhibit correspondences (even if less remarked) with the fluctuations of carbon monoxide. In particular positive deviations of the carbon monoxide content are often coupled to negative deviations of the methane and ethylene concentrations.

5.2 Biomass handling and flowability

Two main problems occurred when vine prunings were used as feedstock for the downdraft gasifier:

1. Interruption of the screw conveyor operation
2. Formation of "bridges" inside the gasifier

5.2.1 Interruption of the screw conveyor operation

Two consecutive screw conveyors bring the biomass at the gasifier top.

The screw conveyors are equipped with safety port which opens as the biomass volume exceeds that available in the screw.

During preliminary tests this problem occurred frequently. It was possible to solve the problem by reducing the volume of biomass in the loading tank.

5.2.2 Formation of "bridges" inside the gasifier

The biomass has to move toward the gasifier bottom in order to ensure the performance of the gasification process. In particular the biomass has to drop from the feeding tank position below the second screw conveyor outlet in the gasifier, as the lower sliding plate is open.

A frequent problem was the formation of bridges which can halt the biomass outflow, thus stopping the feed. The problem was partially solved by increasing the vibration provided by an external electric vibrator. However, bridge formation still occurred, even less frequently, at the feeding tank outlet. The problem can be related to two biomass properties [5]:

- size distribution;
- bulk density.

The presence of long pieces (the size depends on the gasifier geometry, in this case a long piece of vine pruning is longer than 100 mm) facilitates bridge formation, as long sticks reach the walls of the tank and provide a stable layer for the accumulation of other sticks, thus completing the bridge formation.

In addition, the lower the density of the biomass, the higher the tendency to form bridges, as the weight of the biomass above the bridge is not enough to break the structure.

For instance, the tendency of vine prunings to form a bridge is higher than wood pellets, since the latter is characterized by short stick (6 cm) and high density (650 kg/m^3) compared to vine prunings.

5.3 Pressure drop and syngas flow-rate

Table IV reports the average parameters describing the syngas flow in the gasifier (syngas flow-rate, pressure drop and X ratio). The X ratio is defined in Simone et al. (2012) [6] and it represents the permeability of the gasifier and it is an indicator of the gasifier performance.

Table IV: Average flow parameters

	Test 1	Test 2	Test 3
Syngas flow-rate [Nm^3/h]	108.2	94.7	90.0
Pressure drop [mmH_2O]	115.4	222.0	145.0
X [%]	13.3	6.0	7.0

In the three tests the average syngas flow-rate ranged from 90.0 to 108.2 Nm^3/h. Test 1 was characterized by the highest permeability of the bed leading to highest flow-rate and the lowest pressure drop.

It is worth to note that these pressure drops are lower than those obtained with wood pellets as feedstock [6].

The X ratio is for the three tests in the optimal range (5.0-15.0%) specified in Simone et al. (2012) [6]. The conclusion of that work is again confirmed here, since X ratios ranging from 6.0 to 13.3 lead to good syngas composition and calorific values.

Figure 3 plots the syngas flow-rates achieved during Test 3 against the corresponding X ratios. Each curve is obtained for a different opening of the by-pass valve connecting suction and discharge of the blower.

The reduction the opening of the by-pass valve increases the syngas flow-rate, which varies from nearly 60 Nm^3/h to 150 Nm^3/h. Therefore it is possible to operate the gasifier over a broad range of throughputs.

The gasifier performance is not compromised by the variation of the syngas flow-rate and consequently of the air adduction to the gasifier. This indicates the formation of a suitable gasification bed in the gasifier which allows controlling without much effort the gasifier operation.

The closure of the by-pass valve leads to a general switch of the X ratio towards higher values, but still within the optimal range.

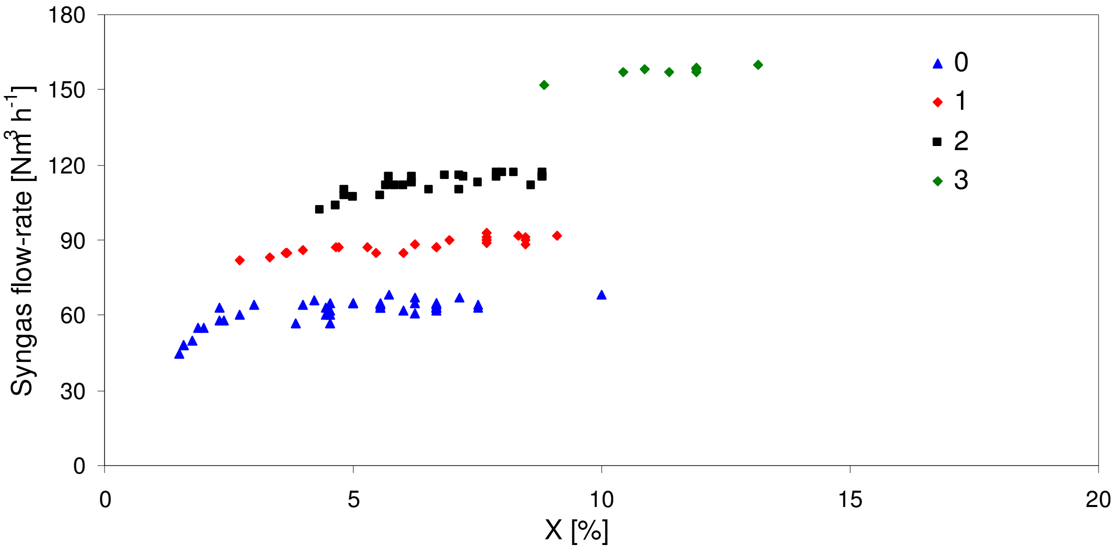

Figure 3: Syngas flow-rate plotted against the correspondent X ratio recorded during Test 3, numbers from 0 to 3 indicate the opening of the by-pass valve (0 - completely open valve, 3- completely closed valve).

5.4 Mass and energy balances

Table V reports the results of the mass and energy balances.

These calculations allow evaluating the average equivalence ratio (ER) and two indicators of the gasification performance as the specific gas production (PS) and the cold gas efficiency (CGE).

Notably, Test 1 and Test 3 operated with rather similar equivalence ratios, while Test 2 was characterized by a lower value.

This result can be related to the pressure drop presented in Table IV. Test 2 was characterized by the highest pressure drop across the gasifier bed, leading to the lower average syngas flow-rate and, as consequence, the lower air adduction to the biomass bed.

Therefore, the lower permeability of the bed led to a lower equivalence ratio.

The difference in the equivalence ratio is mirrored in the specific gas production. The higher the equivalence ratio, the higher the specific gas production, since the more air is fed to the gasifier the more the biomass is converted into gas. What is very interesting to observe is the large difference in the cold gas efficiency between Test 1 and 3 and Test 2. The latter test exhibited a lower conversion of the energy content of the biomass into syngas. In this case the higher the equivalence ratio, the higher the cold gas efficiency.

The worst performance of Test 2 can be easily explained on the basis of the lowest specific gas production and the lowest syngas calorific value (Table III). This is somewhat surprising since usually, lower equivalence ratio leads to higher calorific value of the syngas. However, the higher pressure drop of Test 2 may not only indicate a lower aid adduction but also a worse contact between the gas phase and the solid phase, leading to a lower conversion of the biomass into gas.

Test 1 and Test 3 appear quite similar in terms of PS and syngas calorific value, as a consequence the CGE values are close. Test 3 results a bit more efficient in converting the energy of the biomass into syngas, due to the higher specific gas production despite the lower calorific value of the syngas.

Table V: Average performance indicators of the gasification process and average equivalence ratios achieved in the three tests

	Test 1	Test 2	Test 3
ER [-]	0.294	0.249	0.313
PS [Nm^3/kg]	2.32	1.89	2.46
CGE [MJ/MJ]	74.5	57.4	78.2

5.5 Residues

The solid residues discharged at the gasifier bottom were sampled after each test in order to determine their calorific values. The proximate and ultimate analyses were carried out after Test 2 and 3.

Table VI reports the properties of these residues.

The three residues exhibit very similar lower calorific values. The calorific value of the residues is nearly 40% higher than the original biomass (Table I), thus the process generates a residue with high energy content.

The residues are mainly composed of carbon (more than 80% of the organic matter) but exhibit also a rather high ash content compared to vine prunings. This indicates that biomass ashes are retained in the solid residue.

Given the rather high calorific value, this solid residue may be used as a fuel for heating or co-generation purposes. However, since the ash content is quite high compared to woody biomass it would be better to use it in mixture with a complementary biomass with lower ash content (for instance, wood pellets).

The high ash content indicates that the elements which are very important to the soil for plants growth are included in the solid carbonaceous residue. Therefore, another option for exploiting these residues is to use them as additive for organic compost.

Table VI: Properties of the solid residues produced by the gasifier after each test

	Test 1	Test 2	Test 3
VM dry [%]	-	13.1	9.3
FC dry [%]	-	78.5	81.0
ASH dry [%]	-	8.4	9.7
C daf [%]	-	83.8	82.1
H daf [%]	-	0.9	0.9
N daf [%]	-	1.0	1.0
O daf [%]	-	diff	diff
LHV dry [MJ/kg]	29.9	29.8	29.2

6 CONCLUSIONS

Experimental tests with a pilot scale gasification plant were carried out using vine prunings as feedstock.

These typical Italian agricultural residues produced a typical syngas composition with lower calorific value ranging from 5.50 to 5.82 MJ/Nm^3.

The biomass handling posed some issues. Given the presence of oversize sticks, the biomass exhibited the tendency to form bridges, especially in the feeding hopper positioned above the gasifier.

The problem was partially solved by increasing the shacking effect provided by the electric vibrator.

Vine prunings formed a suitable biomass bed inside the gasifier, which allowed operating with rather low pressure drops leading to an easy control of the syngas flow-rate.

The gasifier was found to operate within the X ratio presented in Simone et al. (2012) [6]. The result is further confirmed here, since the three tests generated a good quality syngas.

The gas pressure drop across the gasifier bed significantly influenced the gasifier performance. Test 2 which exhibited the highest pressure drop was characterized by the lowest specific gas production and cold gas efficiency. Conversely these two parameters were satisfactory for Test 1 and Test 3.

The gasification of vine prunings produced a solid residue with a rather high calorific value which may be used either for heating generation or as compost additive.

On the whole, vine prunings look like a suitable feedstock for downdraft gasifiers. The main issue to be solved is the removal of oversized particles that, given the low bulk density of the material, can compromise the biomass flowability in fixed bed systems.

7 REFERENCES

[1] L. Barella, A. Paniz, E. Antonini, L'uso energetico dei sarmenti della vite, (2010).

[2] M. Simone, E. Biagini, C. Nicolella, L. Tognotti. Proceedings of the 18th European Biomass Conference (2010).

[3] S. Dasappa S., D. N. Subbukrishna, K. C. Suresh, P. J. Paul, G. S. Prabhu. Indian Energ. Sust. Develop. (2011), pag. 231.

[4] J. D. Martinez, K. Mahkamov, R. V. Andrade, E. E. Silva Lora. Renewable Energy (2012), pag. 1.

[5] J. E: Mattsson. Biomass and Bioenergy (1997), pag. 199.

[6] M. Simone, F. Barontini, C. Nicolella, L. Tognotti. Biores. Tech. (2012), pag. 403.

8 ACKNOWLEDGEMENTS

This work benefited of the funds provided by the Cassa di Risparmio Foundation for the realization of the experimental infrastructures.

The authors gratefully acknowledge Mr. Bruno Lasi for his precious help in carrying out the experimental activities.

9 LOGO SPACE

Università di Pisa

Centro di Ricerca Interuniversitario Biomasse da Energia

International Flame Research Foundation