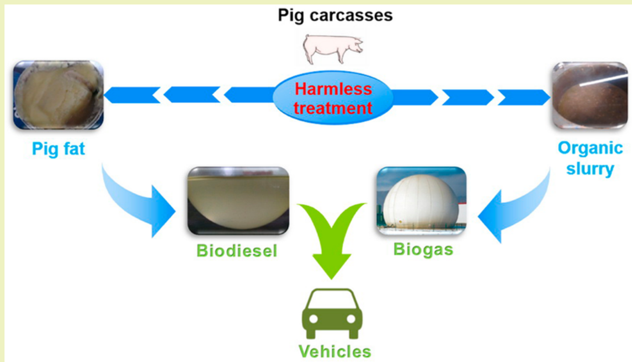
ACS Sustainable Chemistry & Engineering
Letter
pubs.acs.org/journal/ascecg

Waste Pig Carcasses as a Renewable Resource for Production of Biofuels

Zhiliang Zhang and Jianbing Ji*

Zhejiang Province Key Laboratory of Biofuel, College of Chemical Engineering, Zhejiang University of Technology, 18 Chaowang Road, Hangzhou 310014, P.R. China

ABSTRACT: Waste animal carcasses from livestock farming present serious potential problems for the environment and public health. Systems to dispose of carcasses should be safe but also economically and environmentally sustainable. In this study, the pig carcasses were tested for their potential as a renewable resource for the production of biodiesel and biogas. First, pig carcasses were sterilized under high temperature, which also yielded pig fat and organic slurry. Next, the pig fat and organic slurry were used as feedstocks to produce biodiesel and biogas. The results indicated that the yield of animal fat from the pig carcasses was about 20%. The rate of biodiesel conversion from the pig fat was 87%. The prepared biodiesel had the following characteristics: density, 881 kg/m^3; kinematic viscosity, 4.5 mm^2/s; flash point, 182 °C; water content, 220 mg/kg; and acid value, 0.3 mg KOH/g. These met the EN 14214 standard for biodiesel. After 30 days of digestion, the biogas yield from the organic slurry was 450 mL/g VS. The average CH_4 content of the biogas was 63%. An economic evaluation showed that based on a capacity of 1 million pig carcasses the disposal plant would generate a net income of $56/tonne. The results of this study demonstrated that there is a significant potential for the use of pig carcasses as a renewable resource for the production of biofuels.



KEYWORDS: *Animal carcasses, Renewable resources, Biodiesel, Biogas*

INTRODUCTION

Livestock farming is an essential human industry and is growing larger around the world.[1] Routine mortality of animals is an inevitable consequence of the industry, which generates a significant volume of animal carcasses.[2] If the carcasses are improperly handled, they can potentially pollute the environment and threaten human health. In 2013, more than 16 000 dead pigs that had been dumped in Jiaxing, China reached the Huangpu River, one of Shanghai's primary sources of drinking water.[3] Such events cause serious harm to the environment as well as public health.

Methods for disposal of animal carcasses include burial, incineration, composting, and rendering.[1,2,4,5] Burial has traditionally served as a convenient method for disposal of animal carcasses. However, burial would require the excavating of miles of trench pits that could not be disturbed for years.[5] Moreover, there are concerns that improper burial may result in the contamination of ground and surface water and thus transmission of diseases to humans and animals.[2] Consequently, this method was prohibited under the Animal Byproducts Regulations (ABPR) in 2003.[6,7] Incineration is the process whereby animal carcasses are burned at high temperatures to produce an inorganic ash.[2,5,7] This practice is recognized as a biologically safe method of disposal.[1] The persistent environmental concerns about incineration is the fear of emission of dioxins and furans in flue gas and fly ash.[2] In addition to harmful emissions, other concerns include the costs of fuel, required maintenance, and the replacement of incineration facilities.[8] Rendering has historically played a critical role in disposal of animal carcasses, accounting for about 50% of all routine animal carcass disposal and representing the preferred method of disposal.[5] Rendering converts carcasses into a value-added protein, byproduct meal. It can destroy most pathogens, but the spread of bovine spongiform encephalopathy is a risk.[5] Currently, commercial rendering facilities are scarce due to economic pressures on the industry.[9,10] Composting is a relatively inexpensive procedure for the meta-disposal of animal carcasses. Useful end products (e.g., fertilizers) can be created using this process.[11] Composting can serve as a temporary step, as the viruses are destroyed quickly and can be moved and permanently disposed of at other sites.[12]

Systems used for animal carcass disposal should be safe but also be economically and environmentally sustainable. Animal carcasses are rich in animal fats and organic matters that are useful renewable resources for the production of biofuels such as biodiesel and biogas.

Biodiesel is a renewable biofuel consisting of fatty acid methyl esters (FAME), generally produced by transesterifica-

Received: March 17, 2014
Revised: October 30, 2014
Published: December 22, 2014

DOI: 10.1021/sc500591m
ACS Sustainable Chem. Eng. 2015, 3, 204–209

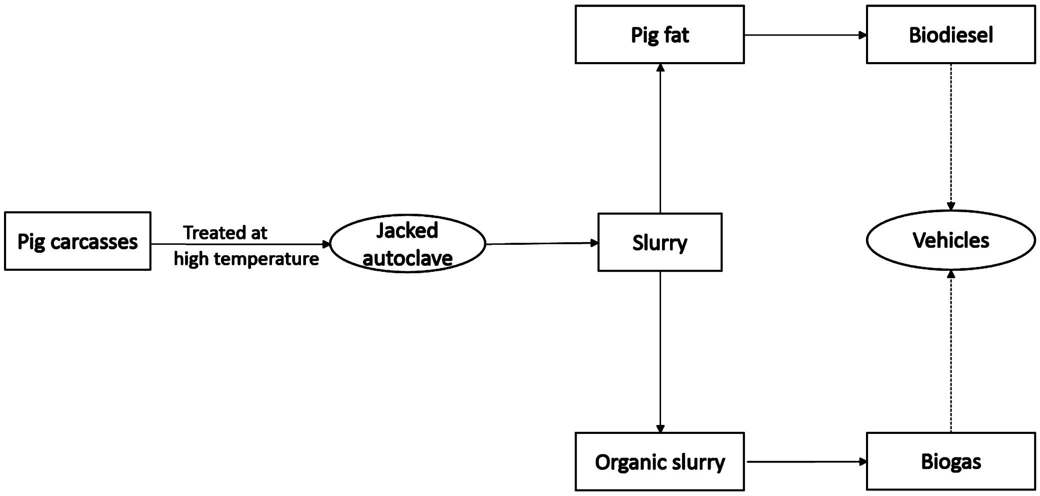


Figure 1. Flow diagram for the production of biofuels from pig carcasses.

tion of vegetable oils and animal fats.[13] It can replace diesel fuel in many different applications, such as fuel for boilers and internal combustion engines, without major modifications.[14] Biogas can also be used as fuel for motor vehicles or for the production of heat or electricity.[15]

Economical and environmentally safe conversion of animal carcasses into value-added biofuels has three potential benefits: addressing public health issues, environmental protection, and economic returns. In addition, as petroleum-based fuels are gradually depleted, there is an increasingly urgent need to produce biofuels from renewable resources (e.g., waste biomass) to fulfill the worldwide demand for energy.[16−21]

In this study, pig carcasses were tested as a potential renewable resource for the production of biodiesel and biogas. A flow diagram of the process is shown in Figure 1. The produced biofuels can eventually be used as fuels for vehicles. The economics of waste pig carcasses as a resource for biofuels production was evaluated. The challenges and future prospects related to producing biofuels from waste carcasses were also addressed.

Figure 2. Image of the jacketed autoclave for disposal of pig carcasses.

■ METHODS

Treatment of Pig Carcasses. A jacketed autoclave with a volume of 1 m^3 (Figure 2) was designed and manufactured for disposal of pig carcasses. The autoclave was indirectly heated by steam at 0.8 MPa. Five pig carcasses (died the previous day) weighing a total of 367 kg (24, 50, 78, 98, and 117 kg) were put into the autoclave along with 300 kg of water. The temperature inside the autoclave was kept above 160 °C for at least 6 h to ensure that bacteria and viruses were thoroughly killed. The pressure was also monitored, which was above 0.65 MPa (absolute pressure). The autoclave was then cooled naturally to 50 °C, and the pig fat was extracted using an oil−water separator to produce biodiesel.

Biodiesel Production and Analysis. A two-step catalyzed process was used to produce biodiesel from pig fat.[22] The process was carried out in a 500 mL three-necked glass flask equipped with a reflux condenser and a mechanical stirrer. In the first step, 200 g of pig fat was mixed with 60 g of methanol and 4 g of H_2SO_4. The reaction temperature was kept at 60 °C by heating in a water bath. After 2 h of vigorous stirring, the mixture was separated by gravity in a separatory funnel. The oil layer was subjected to the second step reaction, while the water layer was recovered for further use. In the second step, the collected oil layer was transferred to the flask. Methanol with six times the stoichiometric amount of the oil and KOH with a weight equal to 1.0 wt % of the oil were then added. The reaction was maintained at 60 °C for 1 h with vigorous stirring. After the reaction, the mixture was separated in a separatory funnel. The ester layer was washed with water until the washings were neutral. This was followed by rotary evaporation (90 °C, absolute pressure 25 KPa) and dehydration with molecular sieve. To obtain biodiesel, the ester was further refined using vacuum distillation (absolute pressure 0.1 KPa). The glycerol layer was also refined in a rotary evaporator (90 °C, absolute pressure 25 KPa) to produce crude glycerol. Specifications for the produced biodiesel, including the density, kinematic viscosity, flash point, water content, and acid value were measured according to the quality requirements of EN 14214. The composition of the biodiesel was characterized using Agilent 7890-5975C GC-MS.

Biogas Production. After separating the pig fat, the rest of the organic slurry was used as feedstock to produce biogas. The contents of the total solids (TS) and volatile solids (VS) in the organic slurry were analyzed according to the standard methods.[23] The C/N ratio of the organic slurry was analyzed using an elemental analyzer (Vario-EL-III, Germany). The inoculum was anaerobic sludge collected from a thermophilic anaerobic digester at a pig farm in Hangzhou, China. It had average TS and VS contents of 22.0% and 9.7%, respectively. Biogas production was conducted in a 1.5 L bath digester (with 10% VS loading) under anaerobic conditions at 38 °C for 30 days. A blank digester containing only the inoculum was also digested at 38 °C to compensate for the biogas produced from the inoculum.

DOI: 10.1021/sc500591m
ACS Sustainable Chem. Eng. 2015, 3, 204−209

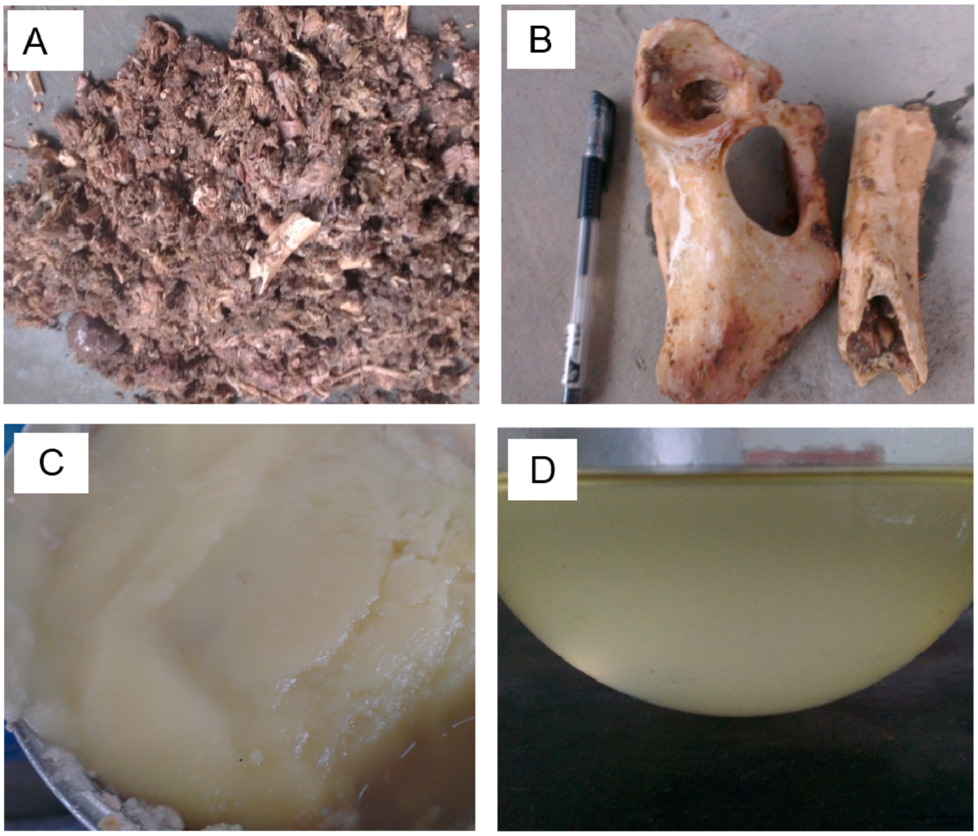


Figure 3. Images of (A) small pieces of lean meat and bones, (B) largest bone, (C) pig fat, and (D) biodiesel.

RESULTS AND DISCUSSION

Treatment of Pig Carcasses. The product of heating pig carcasses was an organic slurry (lean meat and bones mixed with pig fat). As illustrated in Figure 3A, the lean meat was fragmented into smaller pieces. The largest bone was about 10 cm and could be easily broken by hand (Figure 3B). About 74 kg of pig fat (Figure 3C) was separated from the organic slurry, accounting for about 20 wt % of the total weight of the pig carcasses. Therefore, it was estimated that 200 kg of pig fat could be obtained from 1 tonne of pig carcasses (Table 1).

Table 1. Products Obtainable from 1 tonne of Pig Carcasses

product	yield (kg)
pig fat	200
biodiesel	174
biogas	53 N m^3
glycerol	22

Production and Analysis of Biodiesel. An alkali-catalyzed biodiesel production process could achieve high purity and yield of biodiesel in a short time (30−60 min).[22,24] However, only oil with a low acid value (<3 mg KOH/g was adopted by our research group) could be used as feedstock in this process. The acid value of the pig fat was 5.6 ± 0.2 mg KOH/g. Therefore, a two-step catalyzed process was used to produce biodiesel.[16] The biodiesel prepared from pig fat is illustrated in Figure 3D. During the process of biodiesel production, glycerol was also produced as a byproduct (image not shown). The yields of biodiesel and glycerol were 87% and 11%, respectively. Therefore, based on a 20% yield of pig fat, approximately 174 kg of biodiesel and 22 kg of glycerol could be produced from one tonne of pig carcasses (Table 1).

Biodiesel GC-MS results are presented in Figure 4. The produced biodiesel was mainly composed of methyl palmitate (C_{16-0}, 22.9%), methyl palmitoleate (C_{16-1}, 2.5%), methyl stearate (C_{18-0}, 11.3%), methyl oleate (C_{18-1}, 41.7%), and methyl linoleate (C_{18-2}, 16.6%). Methyl oleate was the primary

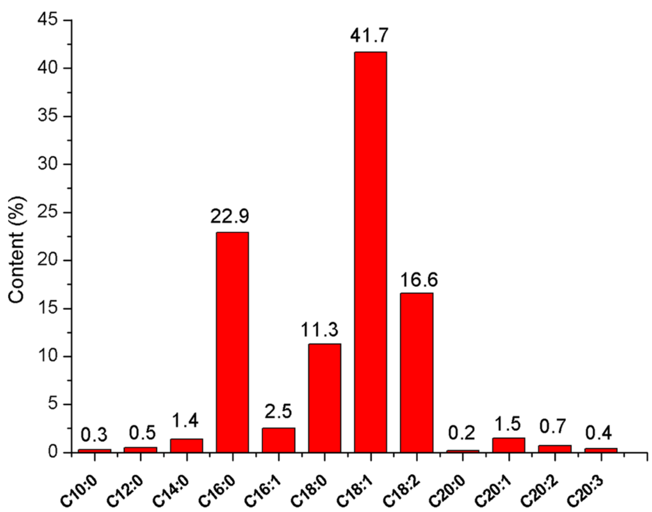


Figure 4. Composition of the biodiesel produced from pig fat (C_{10-0}, methyl caprate; C_{12-0}, methyl laurate; C_{14-0}, methyl myristate; C_{16-0}, methyl palmitate; C_{16-1}, methyl palmitoleate; C_{18-0}, methyl stearate; C_{18-1}, methyl oleate; C_{18-2}, methyl linoleate; C_{20-0}, methyl arachidate; C_{20-1}, methyl eicosanoate; C_{20-2}, methyl eicosadienoate; and C_{20-3}, methyl eicosatrienoate).

DOI: 10.1021/sc500591m
ACS Sustainable Chem. Eng. 2015, 3, 204−209

component of the biodiesel and was suggested as a major component of modified (genetic or other modifications) biodiesel fuels.[16,25] The composition of the biodiesel obtained in this study was consistent with the value reported by Canoira et al., who analyzed the composition of biodiesel from waste animal fat.[16] Their results showed that C_{16-0} and C_{18-1} were the primary components, accounting for 28.35% and 42.19%, respectively.

Kinematic viscosity is one of the most important properties of biodiesel and is significantly influenced by the structure of compound.[26] The reported kinematic viscosity of C_{16-0}, C_{18-0}, C_{18-1}, and C_{18-2} methyl ester was 4.38, 5.85, 4.51, and 3.65 mm^2/s, respectively. The kinematic viscosity of the prepared biodiesel was 4.5 mm^2/s at 40 °C, which met the standard in EN 14214 (3.50−5.00 mm^2/s) and was consistent with the reported value concerning the influence of biodiesel composition.

Density is a factor that influences the efficiency of atomization and depends on the content of alkyl esters and the remaining amount of alcohol.[19] Density values between 860 and 900 kg/m^3 (15 °C) were adopted under the EN 14214 standard. The density of the pig fat biodiesel was 881 kg/m^3 at 15 °C.

Other properties of the pig fat biodiesel were compared with the waste fish oil biodiesel and poultry fat biodiesel reported in other studies (Table 2).[17,21] The results confirmed that the density and flash point of the pig fat biodiesel were higher than those of other biodiesels. The kinematic viscosity of the pig fat biodiesel was similar to that of the waste fish oil biodiesel and lower than the poultry fat biodiesel. The water content and acid value of the pig fat biodiesel were consistent with the standard, while the properties for the poultry fat biodiesel did not conform to the specification.

Table 2. Comparison of Pig Fat Biodiesel with Waste Fish Oil Biodiesel and Poultry Fat Biodiesel

property	pig fat biodiesel	waste fish oil biodiesel[17]	poultry fat biodiesel[21]	EN 14214 standard
density (kg/m^3)	881	867−869	877	860−900
kinematic viscosity at 40 °C (mm^2/s)	4.5	4.205−4.717	6.86	3.50−5.00
iodine value (g I/100g)	–	–	78.8	<120
flash point (°C)	182	164	172	>120
water content (mg/kg)	220	–	1201.0	<500
acid value (mg KOH/g)	0.3	–	0.55	<0.5

Biogas Production. The biogas-producing capacity of the organic slurry was tested under anaerobic conditions. Prior to the experiment, the C/N ratio and TS and VS contents of the organic slurry were analyzed. The analysis revealed that the organic slurry had a C/N ratio of 12.5 and contained 13.4% TS and 12.3% VS. The value of VS/TS was 91.7%, which was relatively high, favoring the anaerobic digestion.[27]

Representative temporal plots of daily and cumulative biogas yield are shown in Figure 5. The curve for daily biogas yield was in the shape of a parabola. The rate of daily biogas production was relatively low during the first 4 days of digestion, increasing to a peak of 50 mL/(d g VS) on day 11, and then declining after day 12. The cumulative yield of biogas increased rapidly until day 14. At the end of 30 days, the biogas yield of the organic slurry was 450 mL/g VS.

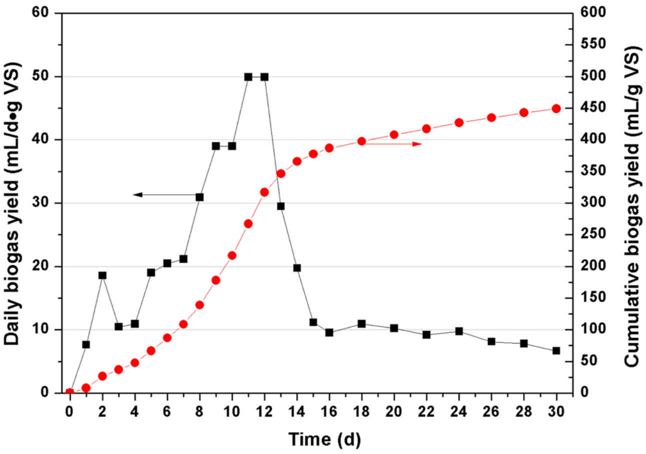


Figure 5. Curves for daily and cumulative biogas yield from the organic slurry.

The average CH_4 and CO_2 contents of the biogas were 63% (v/v) and 37% (v/v), respectively. Thus, the methane yield of the organic slurry was 283 mL/g VS. It was estimated that 53 N m^3 of vehicle fuel biogas could be obtained from 1 tonne of carcasses (Table 1).

The methane yield obtained in this study was lower than the value obtained by Cho et al., who reported 482 mL/g VS for cooked meat.[28] It should be mentioned that the cooked meat tested by Cho et al. contained about 20% animal fat. In addition, the VS/TS of the cooked meat was 97%, which was higher than the VS/TS of the organic slurry tested in this study.

Economic Evaluation. The cost-benefit analysis is critical to any decision-making process.[29] Therefore, it is necessary to evaluate the economics of waste pig carcasses as a renewable resource for biofuels production. The evaluation was based on 1 million (about 50 000 tonnes) pig carcasses per year in Zhejiang (a province of China) from 32.7 million pigs (mortality of 3%) in 2013.

The entire disposal plant consisted of three parts: carcass disposal system (CDS), biodiesel production system (BDPS) with an annual production capacity of 10 000 tonnes biodiesel, and biogas production and purification system (BGPPS), with an annual production capacity of 5 million Nm^3. Table 3 presents an income/expense summary for the disposal plant.

For the CDS, the largest expense was in the waste disposal process ($1.85 million). Waste disposal costs included carcass transport, collection, storage, and other waste-handling costs. Transportation costs ($33/tonne) were relatively high because carcasses had to be collected together to prevent the transmission of pathogenic bacteria. The total costs of CDS ($63/tonne) were lower than those for burial ($81/tonne),[8] composting ($108/tonne),[8] and incineration ($313/tonne).[30]

In the case of the BDPS and BGPPS, the most significant costs were the initial investments ($1.3 million and $2.5 million, respectively). Operational costs (annual variable costs and fixed costs) were relatively low at $0.95 million and $0.94 million, respectively. It is worthy to note that the wastes generated by the BDPS and BGPPS could be used as industrial raw materials or fertilizers, and the revenues could offset the disposal costs. Those waste disposal costs were not included in this study.

DOI: 10.1021/sc500591m
ACS Sustainable Chem. Eng. 2015, 3, 204−209

Table 3. Income/Expense Summary for a Disposal Plant Based on 1 Million Pig Carcasses (millions of USD)[a]

item	carcass disposal system (CDS)	biodiesel production system (BPS)	biogas production and purification system (BPPS)	entire disposal plant
initial investment costs	0.50	1.30	2.50	4.30
annual variable costs				
fuel, electricity, water	0.25	0.20	0.15	0.60
labor	0.20	0.15	0.10	0.45
other	0.20	0.30	0.20	0.70
annual fixed costs				
annual depreciation	0.05	0.13	0.25	0.43
maintenance and repair	0.01	0.02	0.04	0.07
other	0.10	0.15	0.20	0.45
waste disposal costs	1.85	–	–	1.85
total costs	3.16	2.25	3.44	8.85
total costs per tonne of carcasses (USD)	63.2	45.0	68.8	177
value of products	–	10.36	1.32	11.68
total net income[b]				2.83
net income per tonne of carcasses (USD)				56

[a]Key production and financial assumptions: average weight of one pig carcass, 50 kg; value of biodiesel, \$1130/tonne; value of biogas for vehicles, \$0.5/Nm^3; value of glycerol, \$480/tonne; annual depreciation, 10 year life expectancy; maintenance and repair, 1.5% of investment; waste disposal costs include carcass transport, collection, storage, and other waste-handling costs; and transport costs, \$33/tonne, average distance to the disposal plant in Zhejiang is 200 km. [b]Total net income = value of products − total costs.

For the entire disposal plant, the costs were \$177 per tonne of pig carcasses, which were still lower than that of conventional methods such as incineration (\$313/tonne).[30] More importantly, due to the value-added biofuels produced, the entire disposal plant would generate a net income of \$56 per tonne of carcasses. These results indicate that the economic prospects for the use of waste pig carcasses as a renewable resource for the production of biofuels are good.

■ PROSPECTS AND CHALLENGES FOR THE FUTURE

As renewable resources, waste animal carcasses have a great potential for the production of biofuels. Nevertheless, its development faces a series of challenges. First, in the absence of government oversight, animal carcasses may be discarded by individual farmers. Second, because animal carcasses are usually associated with viruses and illness, they must be disposed of very carefully in order to prevent the spread of diseases. Third, there are some financial barriers to the production of biofuels from animal carcasses.

In order to use animal carcasses as a renewable resource for biofuels, a number of measures should be taken. First, demonstration project sites should be established, which could have a positive effect on the development of the industry. Second, a safe and efficient system for carcass collection, transport, and disposal should be adopted. Finally, preferential government policies and regulations for the use of animal carcasses in biofuel production should be established.

■ CONCLUSION

In this study, waste pig carcasses were used as a renewable resource for the production of biodiesel and biogas. Pig fat and organic slurry were obtained after sterilizing pig carcasses at high temperature. The yield of animal fat from pig carcasses was about 20%. The conversion rate of pig fat to biodiesel was 87%. The density (881 kg/m^3), viscosity (4.5 mm^2/s), flash point (182 °C), water content (220 mg/kg), and acid value (0.3 mg KOH/g) of the biodiesel met the EN 14214 standard. The yield of biogas from the organic slurry was determined to be 450 mL/g VS after 30 days of digestion. Methane accounted for 63% of the biogas produced. With a capacity of 1 million pig carcasses, the disposal plant generated a net income of \$56/tonne, indicating good economic prospects for the future. In conclusion, waste pig carcasses are a valuable potential renewable resource for the production of biofuels.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: jjb@zjut.edu.cn. Phone/Fax: +86 571 88320053.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was financially supported by the Science Research Fund of Zhejiang University of Technology (2013XY002).

■ REFERENCES

(1) Blake, J. P. Methods and technologies for handling mortality losses. *World Poultry Sci. J.* **2004**, *60* (4), 489−499.

(2) Gwyther, C. L.; Williams, A. P.; Golyshin, P. N.; Edwards-Jones, G.; Jones, D. L. The environmental and biosecurity characteristics of livestock carcass disposal methods: A review. *Waste Manage.* **2011**, *31* (4), 767−778.

(3) Parry, J. H7N9 avian flu infects humans for the first time. *Br. Med. J.* **2013**, *346*, f2151.

(4) Chen, T.; Huang, J. Anaerobic treatment of poultry mortality in a temperature-phased leachbed-UASB system. *Bioresour. Technol.* **2006**, *97* (12), 1398−1410.

(5) Carcass Disposal: A Comprehensive Review. Report written for the USDA. Animal and Plant Health Inspection Service, U.S. Department of Agriculture and National Agricultural Biosecurity Centre, Kansas State University: Manhattan, KS, 2004.

(6) Williams, A. P.; Edwards-Jones, G.; Jones, D. L. In-vessel bioreduction provides an effective storage and pre-treatment method for livestock carcasses prior to final disposal. *Bioresour. Technol.* **2009**, *100* (17), 4032−4040.

(7) The Animal by-Products Regulations (EC) No. 1774/2002. European Commission: Brussels, 2002.

(8) Crews, J. R.; Donald, J. O.; Blake, J. P. An Economic Evaluation of Dead-Bird Disposal Systems. In *Proceedings of the 1994 National*

Poultry Waste Management Symposium, Athens, GA, 1994, pp 304−309.

(9) Kalbasi-Ashtari, A.; Schutz, M. M.; Auvermann, B. W. Carcass rendering systems for farm mortalities: A review. *J. Environ. Eng. Sci.* **2008**, *7* (3), 199−211.

(10) Stanford, K.; Sexton, B. On-farm carcass disposal options for dairies. *WCDS Adv. Dairy Technol.* **2006**, *18*, 295−302.

(11) Sharrock, P.; Fiallo, M.; Nzihou, A.; Chkir, M. Hazardous animal waste carcasses transformation into slow release fertilizers. *J. Hazard. Mater.* **2009**, *167* (1−3), 119−123.

(12) Brglez, B. Disposal of Poultry Carcasses in Catastrophic Avian Influenza Outbreaks: A Comparison of Methods; Technical Report for Master of Public Health; University of North Carolina, Chapel Hill, NC, 2003.

(13) Salvi, B. L.; Panwar, N. L. Biodiesel resources and production technologies−A review. *Renewable Sustainable Energy Rev.* **2012**, *16* (6), 3680−3689.

(14) Kumar, N.; Varun; Chauhan, S. R. Performance and emission characteristics of biodiesel from different origins: A review. *Renewable Sustainable Energy Rev.* **2013**, *21*, 633−658.

(15) Weiland, P. Biogas production: Current state and perspectives. *Appl. Microbiol. Biotechnol.* **2010**, *85* (4), 849−860.

(16) Laureano, C.; Miguel, R.; Enrique, Q.; Ramn, A.; Magn, L.; Fermn, O. Biodiesel from low-grade animal fat: production process assessment and biodiesel properties characterization. *Ind. Eng. Chem. Res.* **2008**, *47* (21), 7997−8004.

(17) Yahyaee, R.; Ghobadian, B.; Najafi, G. Waste fish oil biodiesel as a source of renewable fuel in Iran. *Renewable Sustainable Energy Rev.* **2013**, *17*, 312−319.

(18) Shi, Y.; Ge, Y.; Chang, J.; Shao, H.; Tang, Y. Garden waste biomass for renewable and sustainable energy production in China: Potential, challenges and development. *Renewable Sustainable Energy Rev.* **2013**, *22*, 432−437.

(19) Banković-Ilić, I. B.; Stojković, I. J.; Stamenković, O. S.; Veljkovic, V. B.; Hung, Y. Waste animal fats as feedstocks for biodiesel production. *Renewable Sustainable Energy Rev.* **2014**, *32*, 238−254.

(20) Talebian-Kiakalaieh, A.; Amin, N. A. S.; Mazaheri, H. A review on novel processes of biodiesel production from waste cooking oil. *Appl. Energy* **2013**, *104*, 683−710.

(21) Mata, T. M.; Cardoso, N.; Ornelas, M.; Neves, S.; Caetano, N. S. Sustainable production of biodiesel from tallow, lard and poultry fat and its quality evaluation. *Chem. Eng. Trans.* **2010**, *19*, 13−18.

(22) Wang, Y.; Pengzhan, L. S. O.; Zhang, Z. Preparation of biodiesel from waste cooking oil via two-step catalyzed process. *Energy Conv. Manage.* **2007**, *48* (1), 184−188.

(23) *Standard Methods for the Examination of Water and Wastewater*, 18th ed.; American Public Health Association: Washington, DC, 1998.

(24) Dorado, M. P.; Ballesteros, E.; Lopez, F. J.; Mittelbach, M. Optimization of alkali-catalyzed transesterification of Brassica carinata oil for biodiesel production. *Energy Fuels* **2004**, *18* (1), 77−83.

(25) Kinney, A. J.; Clemente, T. E. Modifying soybean oil for enhanced performance in biodiesel blends. *Fuel Process. Technol.* **2005**, *86* (10), 1137−1147.

(26) Knothe, G.; Steidley, K. R. Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. *Fuel* **2005**, *84* (9), 1059−1065.

(27) Zhang, R.; El-Mashad, H. M.; Hartman, K.; Wang, F.; Liu, G.; Choate, C.; Gamble, P. Characterization of food waste as feedstock for anaerobic digestion. *Bioresour. Technol.* **2007**, *98* (4), 929−935.

(28) Cho, J. K.; Park, S. C.; Chang, H. N. Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. *Bioresour. Technol.* **1995**, *52* (3), 245−253.

(29) Ekboir, J. M. *Potential Impact of Foot-and-Mouth Disease in California: The Role and Contribution of Animal Health Surveillance and Monitoring Services*; Agricultural Issues Center, University of California: Davis, CA, 1999.

(30) Henry, C. G.; Bitney, L. L. *Disposal Methods of Livestock and Poultry Mortality*; EC727; University of Nebraska-Lincoln: Lincoln, NE, 2001.

DOI: 10.1021/sc500591m
ACS Sustainable Chem. Eng. 2015, 3, 204−209