Sustainability opportunities through small-scale rice husk generators in China

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Outline

- Introduction to rice cultivation and rice husk
- Rice husk thermo-valorization and gasification
- Rice husk availability in Asia
- Experiences of rice husk gasifiers in China
- How to valuate the main business case variables
- Opportunities for mid-size plants in rural communities
- Socio-economical and environmental sustainability

Introduction: rice cultivation

- > 75 countries
- ~ 1/5 world's population engaged in cultivation
- Rice cultivations cover 1% of the earth's surface
- World's 2nd largest cereal crop (wheat is the first)

  …Produces the largest amount of crop residues

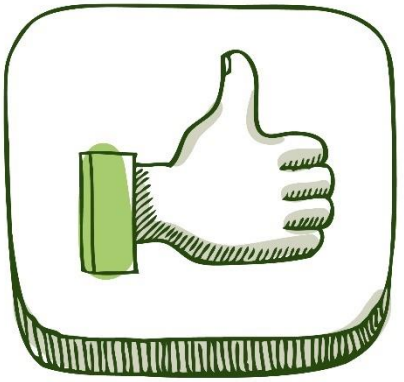
Introduction: rice husk

- Rice crop residue
- Hard protecting covering of rice grains
- Protects rice during the growing season
- It is separated from the brown rice in rice milling
- It is a by-product of paddy mill (on average 20% of the rice paddy is husk)

Introduction: rice husk treatement

- It's a waste, needs to be disposed:
  - Burnt?
  - Landfilled?
  - Dumped in open piles?

- It's a resource, can be exploited:
  - has a high calorific value
    - can be used as a fuel for electricity generation
  - is a renewable source of energy
    - carbon-neutral
  - is usually free
  - is one of the largest readily available biomass resource
  - does not threaten food supply
    - not involved in the "food or fuel" controversy

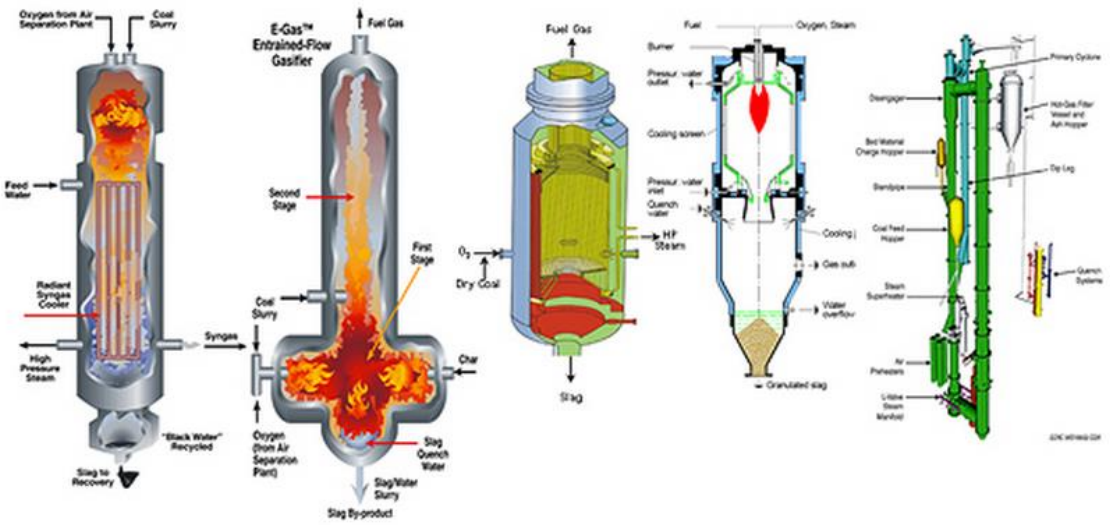


Introduction: rice husk gasifiers

- The best way to exploit the energy contribution of rice husks, as to international literature, is gasification
- First 60-kW rice husk fired biomass gasification and power generation (BGPG) was developed in ’60
  - several studies on rice husk power generation were performed
- Despite all this, power generation from rice husk is still quite under-utilised
  - the greatest part of R&D work and demonstration projects generators are still financed and commissioned by government or universities
- Lack of commitment of industrial sector

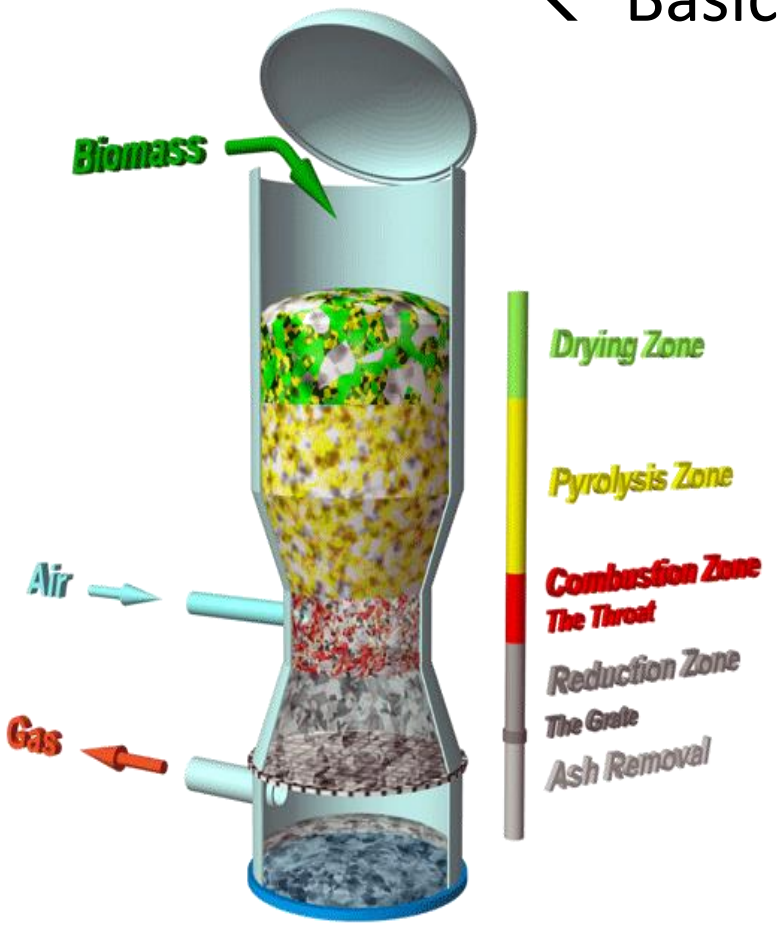
Introduction: biomass gasification

- Basic Process Chemistry
- Conversion of solid fuels into combustible gas mixture called producer gas ($CO + H_2 + CH_4$)
- Involves partial combustion of biomass
- 4 distinct processes:
  - Drying
  - Pyrolysis
  - Combustion
  - Reduction



Introduction: biomass gasification

← Basic Process Chemistry



Gas composition

Particulars	**Rice Husk**	**Woody Biomass**
CO	15-20%	15-20%
H_2	10-15%	15-20%
CH_4	Up to 4%	Up to 3%
N_2	45-55%	45-50%
CO_2	8-12%	8-12%
Gas CV (kcal/Nm^3)	Above 1050	Above 1100
Gas generated (Nm^3/kg of biomass)	2	2.5

Rice Husk Gas. Plants

Two typical sizes of gasification plants fuelled by rice husks:

- small plants (< 100 kW)
  - Typical use in underdeveloped countries, no need for efficiency but focused on energy availability
- large plants (> 1 MW)
  - A 27MW plant operates in California since 1989
  - Efficiency is main concern

No evidence of extensive use of average size plants….

R.Husk Gasification opportunities

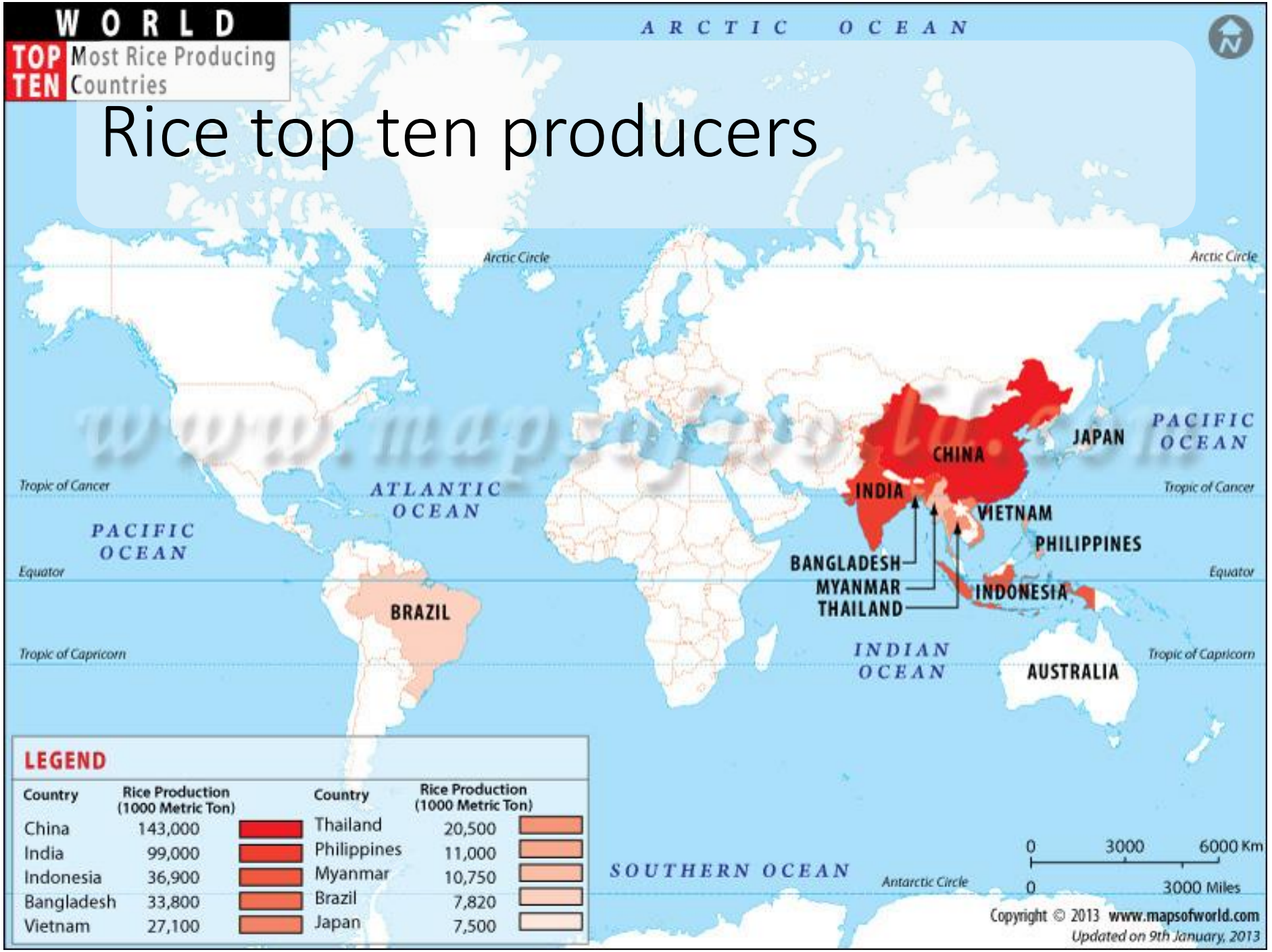
- New scenarios may arise from:
  - new gasification processes
  - new combustion technologies

→ biomass thermo-valorisation is becoming progressively more convenient

  - No need of gigantic plants to reach acceptable efficiencies
  - New opportunities to install mid-size biogas power plants in rural areas of several rice-producing countries

→ It is important to disseminate studies and reports

  - To help investors in fair evaluation of advantages and issues



Rice top ten producers

India

- 2nd rice producing country
- About 100 MTon/year
- More than 90’000 rice mills
- 22 Mton/y of rice husk
  - by-product from rice milling
- Typical small-size rice husk plants serve around 400 households
  - 8h power, primarily during the evening (illumination)
  - saving approximately 18,000 lt of diesel per year

Indonesia

- 3rd rice producing country
- Yielding almost 37 MTon/year
- However the major crop residues for power generation is palm oil processing residues
  - rice husk as an alternative fuel is still under study
- Steam power plants are still using coal (!)
- November 2013:
  - 2 rice husk gasification power plants commissioned in Sulawesi and Java

Bangladesh

- 4th rice producing country
- Yearly yield of more than 34 Mton
- 67-70% of rice husk is consumed for steam producing in rice mills
  - mainly in rice parboiling process.

→ huge wastage of rice husk, which is an important source of biomass.

Vietnam

- 5th rice producing country
- Yearly yield of more than 27 Mton
- Vietnam has abundant biomass sources:
  - bagasse, rice husk, coconut and woody residues
- Project for a Rice husks-fired cogeneration power plant in Hau Giang province (rice cultivation area):
  - Cost about 935.000 US$
  - Electric Power 500kW

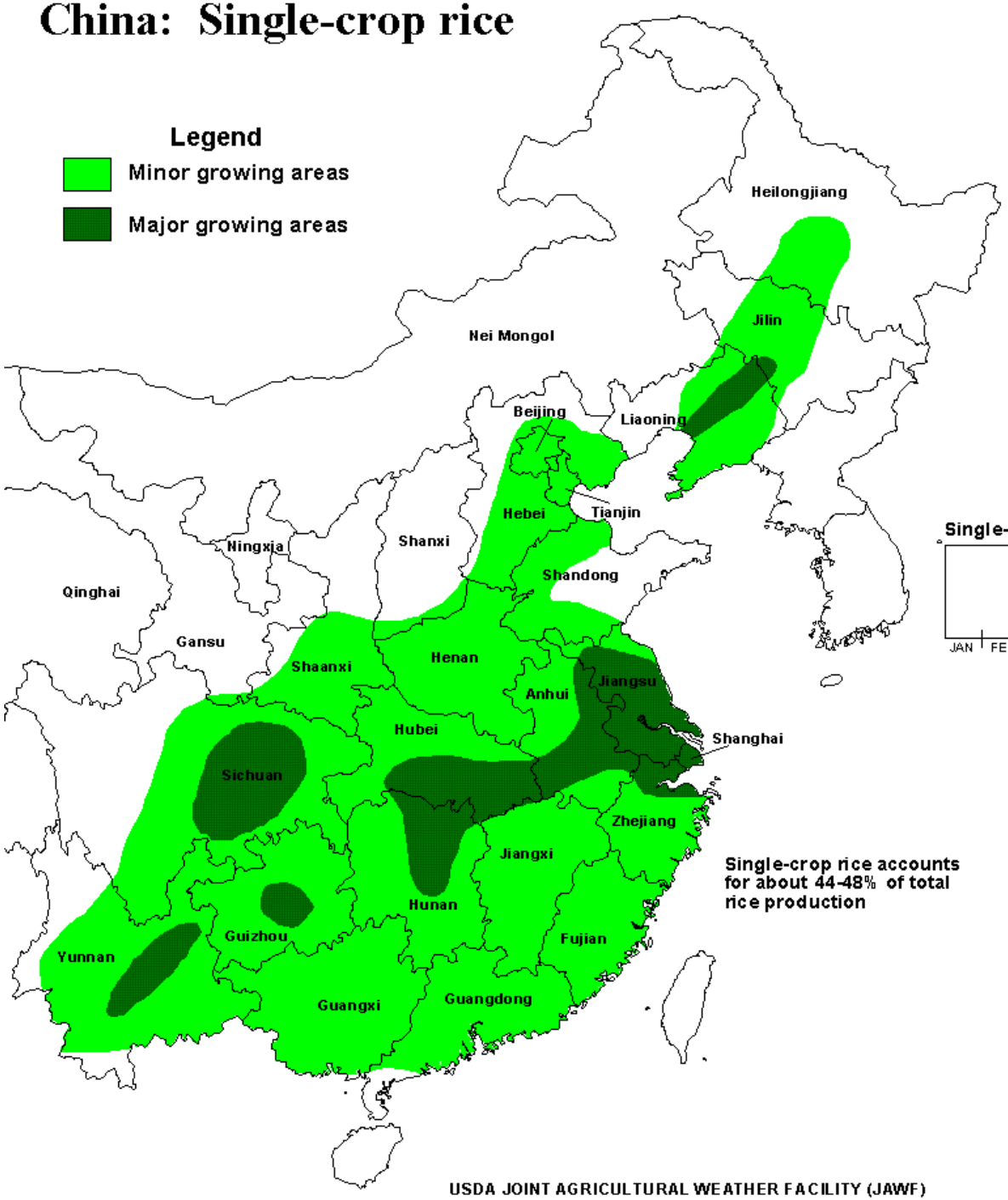
Thailand

- 6th producer, about 40’000 rice mills
- Production of about 20 MTon of rice per year
- Rice husk: about 5.67 MTon in 2010
  - high cost for collection, high cost of transportation
    → less than 10% of the available are currently used
  - evidences that some biomass gasification plants have shifted back to lignite
  - mainly due to increased prices and inadequate supply of rice husk
- 102 MW originated from rice-husk fired generators (2009)
- A 20 MW rice husk power generator is operative in a Thai Ceramic Company in Saraburi.

China

- 1st rice producer in the world
- ~ 140 MTon/year
- Vast territory and abundant biomass resource
  - Difficulties in logistic and transportation in rural areas
  - Suitable conditions to biomass utilization technologies
  - Opportunities for decentralized power generation

China: Single-crop rice

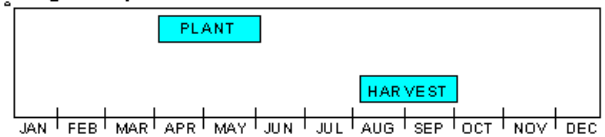


Percent of single crop rice production by province (1993-1997)

Sichuan	23.0%
Jiangsu	15.7%
Hubei	9.6%
Anhui	8.4%
Heilongjiang	6.2%
Yunnan	5.1%
Guizhou	4.7%
Hunan	3.8%
Liaoning	3.7%
Jilin	3.6%
Henan	3.4%
Zhejiang	2.3%
Fujian	2.1%
Jiangxi	1.8%
Shandong	1.1%
Hebei	1.0%

These provinces account for 95.5% of total production.

Single-crop rice calendar for most of China



Single-crop rice accounts for about 44-48% of total rice production

Percent of all rice production by province (1993-1997)

Hunan	13.0%
Sichuan	11.2%
Jiangsu	9.5%
Hubei	9.2%
Jiangxi	8.2%
Guangdong	7.9%
Anhui	6.8%
Zhejiang	6.6%
Guangxi	6.5%
Fujian	3.9%
Heilongjiang	3.0%
Yunnan	2.7%
Guizhou	2.3%
Liaoning	1.8%
Jilin	1.7%
Henan	1.6%

These provinces account for 98% of total production.

USDA JOINT AGRICULTURAL WEATHER FACILITY (JAWF)

Logistic in China rural areas…

- Rice husk collection has a great potential but also serious troubles

Chinese rural areas

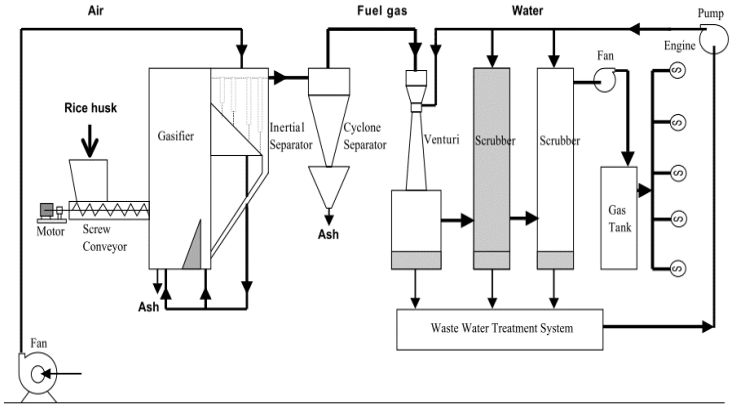
- Insufficient electricity supply in rural areas
- 1995: 25% of energy requirements in rural areas from low efficiency combustion of biomass in stoves
- 2020: the Chinese authorities plan to reduce it to 5%
  - No details defined on how to achieve this target (!)
  - Big potential for introduction of new technologies
    - rural families progressively passing to kerosene
    - Chinese Government hopes the adoption of high performance and less polluting technology

Rice husk in China

- Up to 15 years ago, rice husk used in rural areas:
  - as animal feed
  - as cooking fuel
- by now becomes useless
  - The Chinese Ministry of Agriculture forbade animal farmers to use it as an animal feed
    - due to the husk being less nutritious
  - As a fuel is used by direct combustion
    - less efficient
    - pollutes the environment
      - too much ash
      - too much smoke
- Rice husk disposal is becoming a major problem (to be solved urgently!)

China experience with Rice Husk Gasifiers

- Fujian Putian (pilot project)
  - 1MW (1998), one of the first rice husk fueled CFBG (circulating fluidized bed gasifier) in China.
  - investment: ~510.000 US$, 2 years payback
  - Total efficiency ~ 17%
- Hainan Sanya
  - 1.2 MW (2000), CFBG: investment: ~970.000
- Jiangsu Xinghua
  - 5.5 MW (2005), mixed biomass (rice husk, straw, nut shells)
  - Total efficiency ~ 28%



→ large plants supply is difficult in rural environment

Scope of this work

- Demonstrate whether in large areas of South East China, the average size rice husk gasifier may a sustainable opportunity
- Economic benefits
  - power generation and heat generation (for factories)
- Environmental benefits
  - Displacement of electricity from fossil fuel
  - Pollution reduction from avoided rice husk decomposition and piles burning
- Social benefits
  - availability of electric energy in rural areas
  - promotion of a waste into a byproduct

Test study: Guizhou province

Average values for 1MW (electricity) power plant

- produces ~ 4,5 MW of thermal energy, with η=20%
- burns 1.3 ~ 1.4 ton/h rice husk (8400 ton/y @ 6000 h/y)
- is related to a rice production of ~ 42'000 ton/y
- produces ~ 1700 ton/y of ash

→ The yearly rice production in Guizhou province (4.3+ Mton/y) may be be suitable to feed over 100 1MW gasification plants for a grand total of 100+ MWe

→ Any investigation should be welcome, but the matter is complex…

Several aspects to be investigated

- Technical feasibility
  - Logistics aspects
    - Plant location
    - Husk storage capacity
    - Husk handling capacity
    - Inbound transportation capacity
  - Technological aspects
    - Available technology
    - plant overall electrical efficiency
    - Processing capacity
  - Process parameters
    - Tolerance on rice husk humidity in input
    - Tolerance on emissions in output
- Economical convenience
  - Electric power cost and price
  - Rice husk cost
  - Rice husk ash price
  - Logistics cost
    - Rice husk collection cost
  - Plant cost
    - Investment
    - Operative costs
    - Maintenance costs

Example: heating value issues

Heating value (MJ/kg)	Specific electrical energy (husk mass/electric power generated kg/kWh$_e$)	Author
	1.3	Singh [1]
	1.7-1.9	Xiu Li [2]
	1.86	Sadrul et al. [3]
	2.1	Bridgwater et al. [4]
	1.75-2.43	Zafar [5]
13-16		Natarajan et al. [6]
16.5-17.3 (pellet)		Yoon et al. [7]
13.7 (straw) -16.3		Matsumura et al [8]

R. I. Singh, «Combustion of Bio-Mass in an Atmospheric Fbc: An Experience & Study,» in International Conference on Advances in Energy Research , December 12-15, 2007, Bombay, 2007.

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S. Zafar, «Biomass Resources from Rice Industry,» Bioenergy Consult, 30 March 2014. [Online]. Available: http://www.bioenergyconsult.com/tag/rice-husk/. [Consultato il giorno 27 May 2014].

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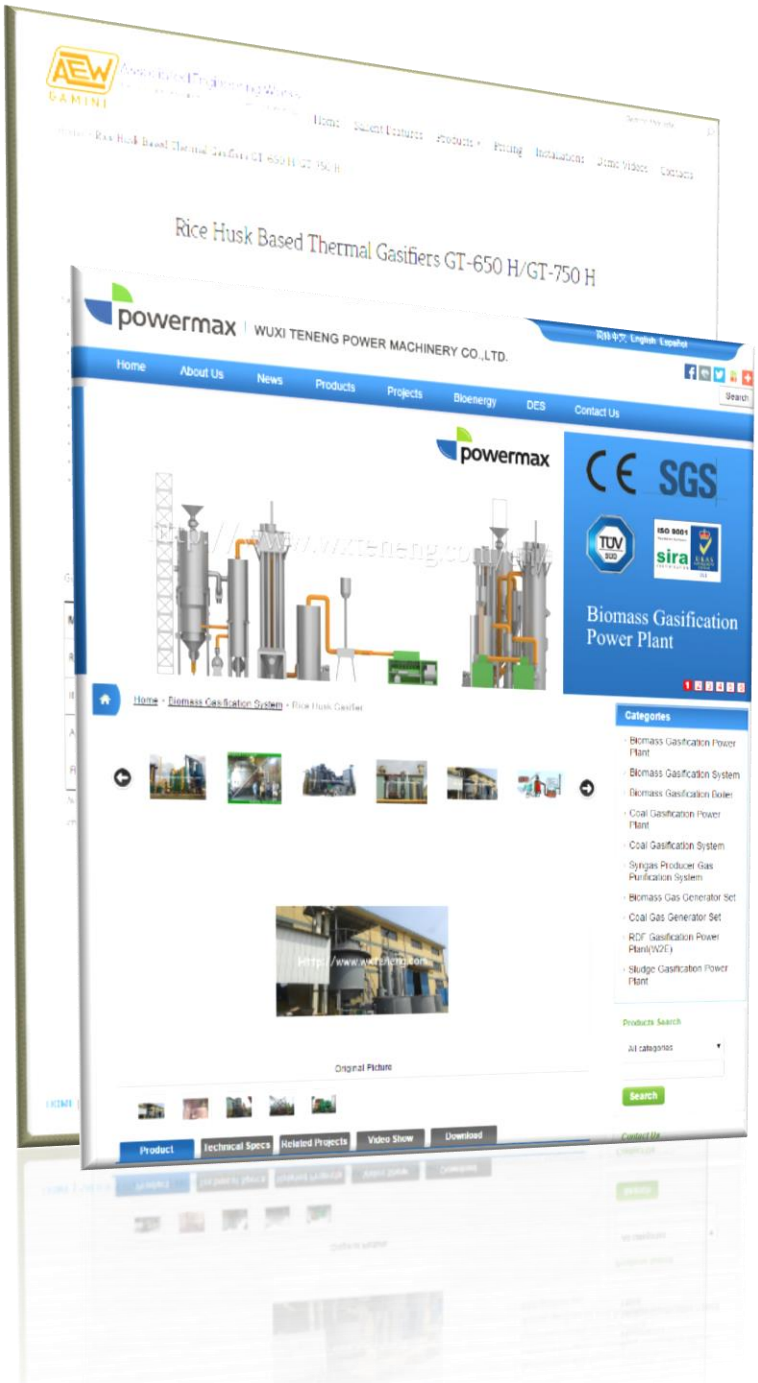
Y. Matsumura, T. Minowab e H. Yamamotoc, «Amount, availability, and potential use of rice straw (agricultural residue) biomass as an energy resource in Japan,» Biomass and Bioenergy, vol. 29, pp. 347-354, 2005.

Example:
heating value

- Many different values in literature.
- Possible causes:
  - different testing conditions
  - density of the husk mass
  - husk varieties…
- More practical approach: ~~literature~~

  → refer to off-the-shelf technologies.



Example: heating value

- Commercial power gen. modules available in Asia:
- various types of circulating fluidized-bed rice-husk gasifiers are commercially available:
  - all based on a 200 kW_e modules
  - consuming 1.0-1.8 kg rice husk per kWh_e
  - →1.67 kg/kWh_e

Model	CFBGPP 200	CFBGPP 400	CFBGPP 500	CFBGPP 600	CFBGPP 800	CFBGPP 1000	CFBGPP 1200	CFBGPP 1500	CFBGPP 2000
Rated Power	200	400	500	600	800	1000	1200	1500	2000
Rated Frquencey	50/60								
Rated Voltage(V)	220/400/440/6300/6600/11000/13800								
Mode of Gasifier	CFBG200	CFBG400	CFBG500	CFBG600	CFBG800	CFBG1000	CFBG1200	CFBG1500	CFBG2000
Gasifier Type	Circulating Fluidized Bed Gasifier								
Biomass Moisture Requirement	≤16%(Wet Basis)								
Biomass Size Rquirement	≤8-10mm								
Biomass Consumption (Kg/Hr)	200-360	400-720	500-900	600-1080	800-1440	1000-1800	1200-2160	1800-2700	2000-3600
Gas Production (Nm3/h)	600-700	1200-1400	1500-1750	1800-2100	2400-2800	3000-3500	3600-4200	4500-5250	6000-7000
Ash Discharge Type	Dry Type								
Type Of Gas Purification	POWERMAX Semi Dry Type Gas Purification System								
Heat Valve of Gas	1200-1300Kcal/Nm3								
Gas Composition	CO-12～18%, CO2- 10～16%, CH4 - 4～8%, H2- 3～7%, CnHm- 1～1.4%, O2 - 0.5～1.2%, N2 - 54～60%.								
Model of Genset	100GFLB	400GFLB	500GFLB	300GFLB	400GFLB	500GFLB	400GFLB	500GFLB	500GFLB
Qty Of Genset	2 Sets	1 Sets	1 Set	2 Sets	2 Sets	2 Sets	3 Sets	3 Sets	4 Sets

Fuel cost

- Price changes with stock market and is referred to a 1-Ton pack at the loading port (FOB, free-on-board)
- No data are available on the eventual cost of the raw rice husk collected directly at the farm
  - it is fair to assume that, being delivered to the rice mill together with the paddy rice, rice husk should be accounted for free.
  - However, in order to incentive the farmers to deliver rice husk to the mill, economic compensation can been assumed.

Energy cost

- In Guizhou Province, according to the national electricity price policy of renewable energy produced by biomass the selling price is between a min price of 0,074$/kWh and a max of 0,123$/kWh.

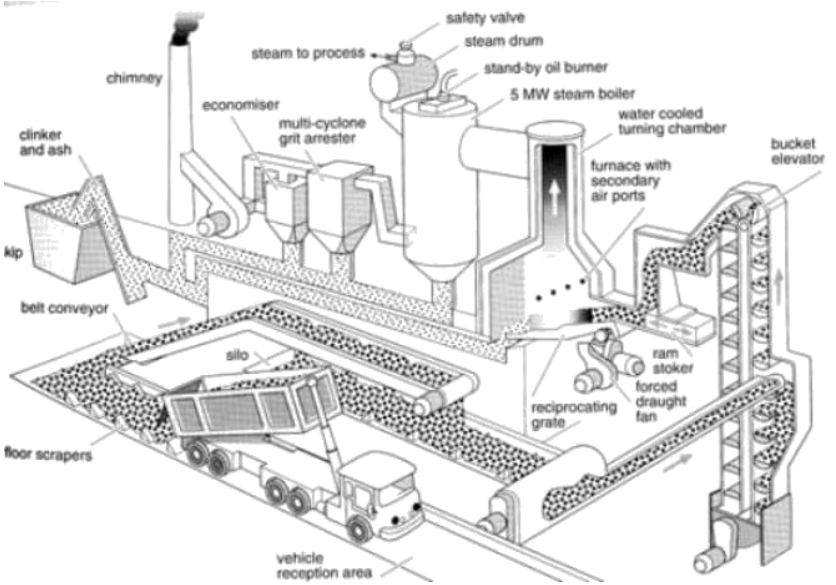
Guizhou Province		CNY/kWh
Not industrial or General industrial utilization	< 1 kV	0,6670 ¥ (0,109 $)
	1-10 kV	0,6570 ¥ (0,107 $)
	110-200 kV	0,6470 ¥ (0,106 $)
Industrial utilization	1-10 kV	0,4943 ¥ (0,081 $)
	35-110 kV	0,4743 ¥ (0,078 $)
	110-200 kV	0,4593 ¥ (0,075 $)
Domestic utilization	<1 kV	0,4556 ¥ (0,074 $)
	1-10 kV	0,4456 ¥ (0.073 $)
	110-200 kV	
Commercial utilization	<1 kV	0,8980 ¥ (0,147 $)
	1-10 kV	0,8880 ¥ (0,145 $)
Agricultural utilization	<1 kV	0,4200 ¥ (0,069 $)
	1-10 kV	0,4100 ¥ (0,067 $)
	110-200 kV	0,4000 ¥ (0,065 $)

Plant cost

(ratios for big plants)

- Total capital investment = 184% of purchased equipment
  - Purchased equipment cost (PEC)
  - Piping = + 12% of PEC
  - Electical = + 19%
  - Civil works = + 66%
  - direct installation = + 30%
  - auxiliary services = + 15%
  - instrumentations and controls = + 10%
  - site preparation = + 10%
  - engineering = + 12%
  - start-up = + 10%
- Indirect costs
  - Maintenance costs = 3% of PEC
  - Insurance & general costs = 1% of PEC

Test case in Guizhou Rice Mill



- Mid-size rice factory
  - 1300 kg/h rice husk available
- 4 x 200 KWe modules (η = 16%)
  - 4000 KWt → 1256 kg/h rice husk in input ✓
- Total cost (Lump Sum Turn Key) 880’000 US$
  - according to a detailed quotation
- Storage: up to 8000 m^3 required to store the rice husk and ensure continuous operability
- 4 operators are needed to manage the plant (limited size of the equipment)

The Guizhou Rice Factory:

- Currently does not pay for rice husk, which is delivered together with paddy rice from farmers
- Presently sells rice husk to larger farmers - which still use it to feed animals (!!!) at 0.052 US$/kg
- Presently pays electricity 0.0784 US$/kWh
- With these values, rice husk power generator payback is 15 year. But:
  - rice husk cannot be used to feed animals anymore
    → opportunity to sell husk is not feasible anymore
  - electricity can be sold up to 0.123 US$/kWh (+57%)
    → Payback is 8 years
  - rice husk ashes can bring additional opportunities
    → Selling ashes at commercial price brings payback period to 5.5 years

Opportunities from selling rice husk ash

- Rice husk is higher in ash (RHA) compared to other biomass fuels
  - close to 20%.
- RHA is valueable in many industries
  - 92% to 95% silica
  - highly porous and lightweight
  - with a very high external surface area
  - absorbent and insulating properties
  - valuable additional material in some industries.
    - glass and brick manufacturing
    - steel industry
    - semi-conductor industry
  - But varies considerably according to the burning technique (needs a specific study to exploit this opportunity)

Sustainability issues

- Social benefit:
  - at village / rural community level, eventually mini-grid systems, available electricity for heating, electric devices,…
  - Farmers could enjoy an additional remuneration resulting from the delivery of rice husks
- Environmental benefit
  - Pollution reduction
    - The rice husk is neither left to rot in open fields (bad smell, makes the soil less fertile)
    - Nor burnt in open air
  - Displacement of electricity from fossil fuel to renewable ones

Future work

Still some aspects must be considered:

- Ash handling, NOx control
- Joint storage constraints and seasonalities/climate impacts on power plant capacity usage
- Eventual subsidization opportunities for pollution decrease, tax credits or other governmental incentives
- husk management costs impact for growers
- Influence of RHA quality on combustion efficiency

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