Prospects of Modern Wood Gas Cogeneration Renewable Energy Supply in Japan − Case Study of ICU

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Abstract

In this article we introduce scalable modern commercial wood gas cogeneration technology of micro scale, beginning at 35-45 kW electric power, scalable up to 800kW electric power, as offered by several international companies. Cogeneration means to use both electricity and heat, which leads to an overall efficiency of converting the chemical energy in wood of up to 90%. We discuss aspects of technology, systainability, forest ecology, local and international fuel quality standards, long term cost efficiency, potential for attracting various forms of official financial support and potential risks involved. In particular we make the general study concrete in the form of a case study on renewable energy supply for the International Christian University campus in Mitaka, western Tokyo. Changing scale parameters in order to adapt to the local energy demand, we expect that this case study can be transferred to other schools, universities, institutions, businesses and buildings in Japan. We further try to address the question as to what contribution this technology can make to the future national renewable energy supply in Japan.

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1. Scalable modern commercial wood gas cogeneration technology

The question which we address here is about the technology of using wood biomass in the form of wood chips (as opposed to wood pellets) for sustainable renewable energy production. This means both electricity generation and production of useful heat for heating, for (adsorption) cooling, for drying, and for warm water for living. We do not ask for the latest research laboratory level technology, but for technology that is on the market, well tested, fully competitive and commercial, i.e. off the shelf technology, free of technological adventures. We ask: is such technology now available and suitable for immediate use in Japan, four years after Fukushima? Our answer is affirmative: Yes, this technology is clearly available.

In order to reach this answer we have spoken with a wide range of domestic and international experts from the industry, government, administration, and public research laboratories, and we have visited a range of commercial profit making projects in several countries where wood gas cogeneration technology is in long term routine daily use, since several years [Project Activities 2015].

1.1 Wood gas cogeneration projects in Southern Germany by Austrian and German makers

The first was an Urbas Energy Technology wood gas cogenerator installation, which we visited. It is in use on the scenic German tourist island of Mainau in the Lake of Constance, in southern Germany. The machine is manufactured by an Austrian company Urbas Energy Technology. In this project wood from local forests is chipped on site (with a leased wood chipper, providing chips for several month in several hours) and continuously fed (Fig. 1) in the *wood gas cogenerator* (Fig. 2) producing heat for gastronomy (tourist restaurant facilities (Fig. 3), wedding receptions), and show green houses, open to up to 6000 daily visitors. The electricity produced is sold to the public utility company of the nearby City of Konstanz. The drawbacks of this model are that for detarification ceramic candles have to be periodically exchanged and cleaned before reuse. And the wood chips have to be relatively massive. [Urbas 2015], [Mainau 2015].

But how does it work? What happens in this wood gas cogenerator? Dry wood chips enter through a double door (to remove air) into an over 1000 ºC hot pyrolysis chamber from above. Automatic process control ensures that the wood molecules are thermally cracked completely into gas molecules, with a fine ash content of 1-2%. The fine dry pure carbon ash is automatically removed by textile filters, dropping into the ash removal pipe. The clean pure gas is cooled down with water for combustion in an off the shelf high quality, long life diesel (non turbo) engine, attached to an electric generator, rated 35, 40 or 45 kW. The removed heat corresponds to another appr. 100kW thermal power.

Fig. 1. Wood chips on Mainau Island.

Fig. 2 and part of Urbas wood gas cogenerator on German tourist island of Mainau in the Lake of Constance, Summer 2014.

Fig. 3. Mainau Island Restaurants space heating/warm water by Wood Gas Cogeneration.

Next, we toured one of the first wood gas cogenerators set up by the Lower Bavarian (German: Niederbayern) Company Spanner Re^2 on a cooperative farm in Herdwangen, in the southern Black Forest region. The farmers faithfully and enthusiastically operated this machine for over seven years and continue to experiment with inserting a variety of forest residues, even including loads of pine needles. The Spanner Re^2 type of wood gas cogenerator is technically advanced, so that pyrolysis under the right automatically controlled thermal and chemical conditions completely turns any tar into useful wood gas. The only residue is a few percentage points of pure high quality carbon ash, used as fertilizer on organic fields. The wood gas cogenerator has an overall efficiency of 90% of turning the wood's chemical energy into electricity (approx. 1/3) and heat (approx. 2/3). [Heggelbach 2015] [Spanner Re 2015] [Ecolifelab 2014]

Furthermore, we went to Giglberg/Velden in Lower Bavaria itself and toured two less than one year old state-of-the-art modern Spanner Re^2 wood gas cogenerators (Fig. 4 right, Fig 5) in continuous automatic operation of up to 7800 hours per year [Josef Strobl 2015]. An electric engineer in charge showed the machines in operation and explained various aspects of the facilities: Electricity (Fig. 5 right) and heat are used by local residents, who are connected to a small local district heating network. Wood chips (Fig. 4 left) are delivered periodically by truck, and the gas engines are maintained periodically, exactly like engines of commercial vehicles. The expected life time of these wood gas cogenerators is over 20 years.

Fig. 4. Spanner Re² wood gas cogenerator installed by Josef Strobl Heizung Solar in Giglberg and Velden/Vils/Lower Bavaria/Germany. Left: suitable wood chips. Right: modern 100% wood to gas pyrolysis unit.

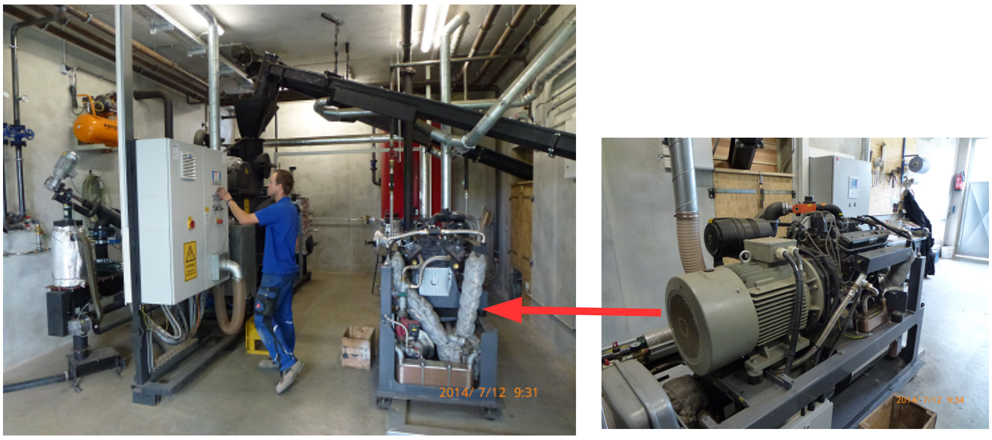

Fig. 5. Spanner Re² wood gas cogenerator installed by Josef Strobl Heizung Solar in Giglberg and Velden/Vils/Lower Bavaria/Germany. Left: pyrolysis unit in left image half. Gas engine and generator on right half. Right: enlarged image of Gas engine and generator.

The overall development in Germany shows, that wood gas cogenerator technology has since 2011 become market dominant over steam turbines and ORC turbines (see Fig. 6).

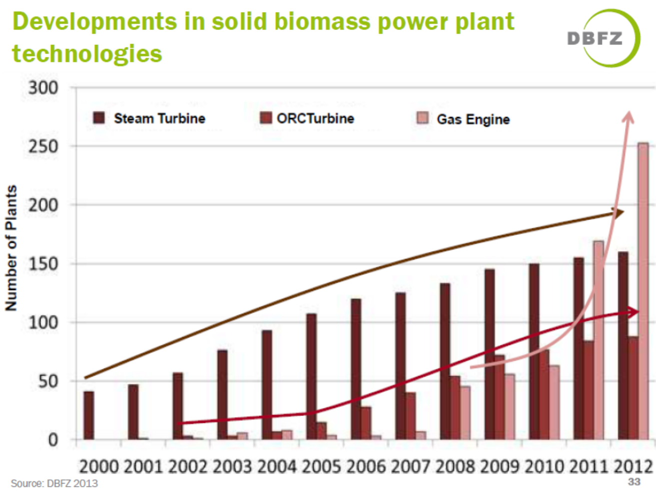

Fig 6. Development of solid biomass power plant technologies. Pink bars and trend curve for gas engines, i.e. predominantly wood gasification [Lenz 2014].

1.2 The first wood gas cogenerator in Japan

Spanner Re² has set up in 2014 a branch company in Tokyo, Japan, named Spanner K.K. [Spanner K.K. 2014] Spanner K.K. imported in 2014 the first Spanner Re² manufactured wood gas cogenerator (Fig. 7 right) to Ecomura in the mountains near Koriyama, Fukushima, where it has cogenerated electricity and heat since October 2014. It soon became the frequent target of curious visitors, who want to learn about this new commercial technology, operating for the first time in Japan. The fuel is locally produced wood chips. We were able to visit this machine and see it in operation in March 2015. This experience taught us how important it is to secure wood chips of sufficient dryness (less than 13% fuel moisture, Fig. 7 left) for the effortless smooth operation of a wood gas cogenerator. (Excess moisture in the wood chip fuel means some of the cogeneration heat will be used for completely drying the fuel. [Spanner Re 3-fach 2015][Volter Oy 2015])

Fig. 7. Wood gas co-generator of Spanner K.K. installed 2014 in Ecomura near Koriyama, Fukushima Prefecture, Japan. Left: automatic feed-in of wood chips. Right: Spanner Re² pyrolysis unit (wood to gas).

A modern Spanner Re² 45 kW electric, 105 kW heat wood gas cogenerator can normally supply 70 families with electricity and heat from storable, renewable and sustainable wood chip fuel. In the case of emergency up to 7000 families can be provided with high priority electricity for nighttime lighting and telecommunication [Safe City Japan Project 2014].

1.3 Advanced wood gas cogeneration in Finland

We also used an opportunity to visit the Gasification Technology Department of the National Finish VTT Laboratories in Espoo, near Helsinki, Finland [VTT 2015]. VTT's Mr. Illka Hiltunen, the experienced group leader of a group of 15 researchers guided us. He showed advanced industrial research laboratory setups, and explained various large-scale industrial biomass gasification projects that have been developed at VTT and are now in commercial operation since a number of years. The northern Finish company Volter Oy [Volter Oy 2015] from Kempele, near Oulu, contacted VTT in order to measure and certify the performance of Volter Oy wood gas cogenerators in downdraft technology. VTT researchers were utterly surprised by the high quality and reliability of the Volter Oy devices, developed independently in the industrial laboratory of the small Volter Oy company founded in 1998 by Juha Silipae, who is now Finland's new prime minister.

We subsequently paid a visit to the Volter Oy company itself in Kempele. The manager Jarno Haapakoski personally gave us an introduction, showed us the company's own device in operation, which powers a local grid-independent bioenergy village of some 13 houses, and showed us a range of residential projects (Fig. 8) powered by Volter Oy wood gas cogenerators in the region, in operation since a variety of years. Volter Oy devices seem to be the state-of-the-art world wide.

The process is higly efficient, and at the same time simplified. All components are made of stainless steel, to guarantee longevity of use. The utterly compact 4.5 ton machine itself with dimensions of 4.8 x 1.3 x 2.5 m^3 fits comfortably into a container or on a truck. Dry wood chip fuel consumption in full power operation is 4.5 tons/24h. It has 40kW electrical, 100kW heat and 20kW hot air output, and the electric output can be adjusted in operation between 30-100% within 60 seconds. Moreover for easy and fast startup the machine can be kept in standby mode for up to seven days. The only connections are for: electricity, water, automatic wood chip feed in, and a pipe for automatic ash powder removal. The device is so reliable and flexible in use, that Volter Oy recently even received an order from the Finish Yoensu University for a truck mounted wood gas cogenerator in order to provide energy for sports events, conferences and concerts, etc. [Volter Oy 2015] These wood gas cogenerators Volter 40 are now imported to Japan by Sanyo Trading Co. Ltd. [Sanyo 2015]

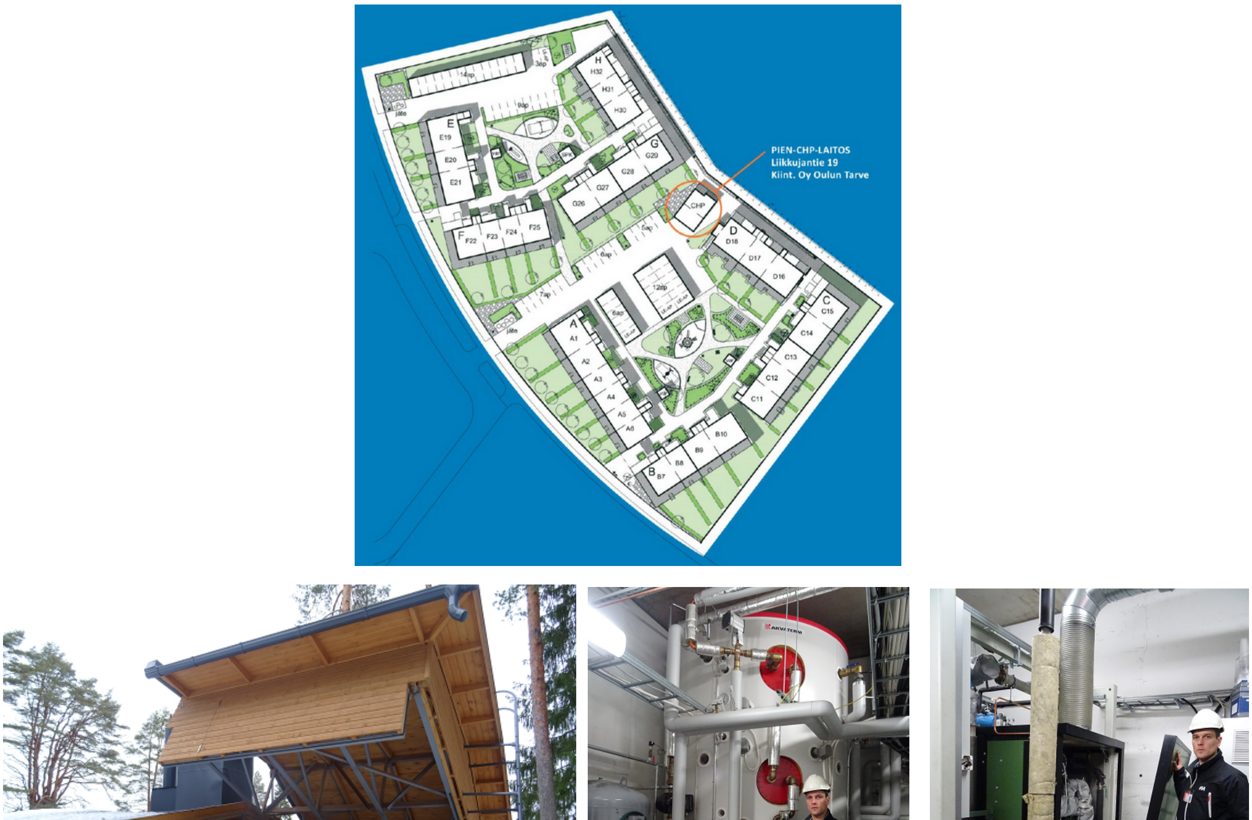

Fig. 8: Volter Oy wood gas cogenerator facilities near Kempele/Oulu/Finland. Left: hydraulic roof wood chip fuel storage. Center: warm water tank. Right: compact wood gas cogenerator. Supplying 32 residential units (see above layout drawing, blue) with total floor space of 2365 m^2 [Liikkujantie 19 2015].

The fuel supply can also be designed very practical and compact. One example is like a personal garage with a hydraulic roof (Fig. 8 left), that can be opened remotely, a wood chip truck moves in front of it, dumps its load of wood chips, and the roof is closed again remotely, thus providing supply for several weeks.

The general trend of the global wood gas generator market may be found in [Global Trend 2015].

2. **Wood chip fuel quality**

The next most important question to be clarified is on the necessary fuel quality. Visiting the Spanner K.K. wood gas cogenerator in Ecomura near Koriyama, showed how important it is to secure good sufficiently dry wood chip fuel supply.

Manufacturers [Spanner WC Quality 2015] specify wood chip quality for example by Austrian norm standard OeNorm M 7133 [Oenorm M 7133 2015], which specifies Illustrations, Dimensions, Ash contents, Definitions, Fuels, Energy economy, Wood, Classification, Standardization, Test specifications, Sampling, Testing, Bulk density, Terminology, and Water content. A typical choice [Spanner WC Quality 2015] is in terms of OeNorm M 7133 [Oenorm M 7133 2015] the wood chip size G30 to G40. G30 [G30 2015] means maximum length of 8.5 cm, area of 3 cm^2, wood dust (<1mm size) less than 4% weight, fine size chips (1-2.8mm size) less than 20%, medium size (2.8-16mm) should be 60-100%, and the maxiumum coarse chips (>16mm size) should be less than 20%. Further requirements are a *water content* of less than 13% [Spanner WC Quality 2015] or less than 18% (optimum less than 15%) [Volter Oy 2015]. Size and water content specifications vary slightly according to manufacturer [Spanner WC Quality 2015] [Volter Oy 2015].

We also have discussed this topic personally with experts like Mr. Illka Hiltunen of the VTT Lab. (in Espoo/Finland) Gasification Group (who had a long involvement in establishing product norms for wood chips), with Mr. Jarno Haapakoski of Volter Oy in Kempele/Finland, and with Dr. Volker Lenz of the DFBZ Research Institute in Leipzig/Germany. They all agree to the fact that for the smooth operation of a wood gas cogenerator wood chips of sufficient quality are necessary, with special importance given to limitting the water content, yet maker dependent, machines may be able to work well with wood chip water content of several percent higher.

According to Dr. V. Lenz (Email of 22nd of April 2015), there even exists an international ISO 17225 series product norm for wood chips. This norm allows users to uniquely define all types of parameters for the quality of wood chips. The norm ISO 17225 has as its predecessor a European Norm. Due to its international character, the norm ISO 17225 standard for wood chip product quality can, in principal, also be applied in Japan.

We identify the following open challenges in this area (Dr. V. Lenz, Email of 22nd of April 2015):
A) Training and knowledge transfer. Even in countries like Germany the knowledge of wood chip quality standards on the side of wood chip producers is yet insufficient.
B) There is a need for a certification system, which ensures, that the wood chips on the market, as classified by the producer, are in agreement with standards as established by norms like ISO 17225. Even in Europe this is not yet completely achieved, regarding wood chips, and therefore it remains the subject of further research and development activities. At this point even international research cooperation may prove fruitful, and the prospective operation of further wood gas cogenerators all over Japan (including the Tokyo metropolitan area), and the practical knowledge gain these operations under local conditions allow, are of great practical interest.

Finally, if the water content of the available wood chip fuel should be too high, some of the cogenerated heat from the cogenerator itself can optionally be used to complete the drying process. Makers already offer a wide range of products with such additional functionality as optional add ons, including drying conveyors, silo dryers, push floor dryers, drying containers, double bin dryers and combi dryers [Spanner Dryers 2015], [Sanyo 2015].

3. The sustainability of wood chip fueled wood gas cogenerators

We now turn to the question of sustainability of the use of wood chip fueled wood gas cogenerators. First what do we mean by *sustainability*? A standard definition says: "**b.** *spec.* The property of being environmentally sustainable; the degree to which a process or enterprise is able to be maintained or continued while avoiding the long-term depletion of natural resources. 1980 *Jrnl. Royal Soc. Arts* July 495/2 Sustainability in the management of both individual wild species and ecosystems..is critical to human welfare. 1992 *Oxon. Bull.* Nov. 1/1 This country is now pledged to move towards sustainability; that is, to conserve resources, to curb pollution, and to achieve the better balance between demand and supply that will protect the environment not only for us, but for our descendants." [Oxford English Dictionary 2013]

In general, wood biomass energy needs as primary resource wood biomass usually in the form of wood pellets made from saw dust, or *wood chips* from forest residues, waste wood, tree parts and trunks resulting from forest management. In this sense trees, and parts of trees naturally harvested from forests, even when mandatory or voluntary nature protection standards are observed, become a sustainable source of wood biomass, which in turn can be sustainably used for energy generation. The fundamental concept is that CO_2 produced when burning wood for energy generation is reabsorbed by newly growing trees in surrounding forests, and thus there remains no overall negative effect on the global content of CO_2 gas in the earth atmosphere.

But this is not the only aspect of sustainability. A further aspect is, that particularly in post-Fukushima Japan the energy thus generated, reduces in turn the use of fossil fuel. Fossil fuel use always increases the CO_2 content of the global atmosphere, thus the use of wood biomass energy in Japan can indeed contribute to the long term reduction of CO_2 in the global atmosphere, and therefore help combat the widely recognized problem of global warming.

Even in its supply and procurement, local wood biomass from public and private gardens and parks, and most important from domestic Japanese forests is superior in its eco balance, because it needs no or only negligible transport, compared to the import of fossil fuel from places as far away as the Arabian Gulf.

Taking a wider view, we notice, that seventy percent of the Japanese land surface is comprised of forests, due to the mountainous geography of the archipelago. These forests were completely replanted after World War II and have an average annual increase of mostly unharvested wood biomass of approx. 50 million tons/year over the last 50 years. The unused wood biomass from pruning trees (*kanbatsuzai* in Japanese) alone already amounts to annually eight million tons [Bellingrath-Kimura 2014a]. Currently intermediate trees are simply cut and left to rot in the forest, eventually releasing their CO_2 content to the atmosphere as well. So far there was no viable method for forest owners and caretakers to economically take out these trees and market them. The Japanese government, namely the national Japanese Forest Agency has identified this problem and, as we will see, has started to take appropriate measures to improve this situation [N. Ikeda 2014].

4. Economic sustainability of wood gas co-generation in post-Fukushima Japan

After the question of suitable commercial technology can be answered affirmatively, we also need to answer the question of long term cost efficiency, i.e. of financial and economic sustainability. For simplicity we assume that a suitable local wood chip supply chain has been established.

In this context we first note, that the Japanese government has raised on 1st April 2015 the 20-year long feed-in-tariff (originally signed into law just before 3.11) for electricity produced from wood biomass that comes from forest maintenance measures (kanbatsuzai) from the previous 32 JPY/kWh to a new current 40 JPY/kWh [Feed-in Tariff 2015]. Moreover, the *New Energy Promotion Council* of Japan (http://www.nepc.or.jp/) nowadays additionally subsidizes the heat energy produced with wood gas cogenerators.

In the following (compare the detailed Table below) we make a reasonable cost estimate under reasonable (or even conservative) assumptions:

That is, we do not factor in possible rebates on wood chip fuel prices, if we establish stable supply contracts at certain levels. We do not take the actual Japanese electricity price, but we rather take the bare price of electricity generation of 2013 in Japan of 13 JPY/kWh [Yanagisawa 2014]. It is certain that private and corporate consumers in Japan all pay more than the bare costs of generation [OECD 2015], but the actual prices are often not transparently revealed. Wood gas cogenerator operation times of more than 8000 h/year is possible [Noel 2014], but we only assume 7900 hours per year. Moreovery, we have not calculated in the electricity feed-in-tariff of 40 JPY/kWh [Feed-in Tariff 2015]. Finally, further savings on the initial investment can be expected when more than one machine is purchased [Spanner Re 3-fach 2015].

Spanner K.K. 45 kW electric, 105 kW thermal #	
Number of machines	**1**
Electric power in kW	45
Thermal power in kW	105
Annual electricity (90%*365*24h) 7900h	
Produced Electricity / kWh /y	355,500
Produced Heat / kWh /y	829,500
Heat / MJ /y/ (1kWh = 3.6MJ)	2,986,200
Kerosene energy density 37.4MJ/L [Wikipedia]	
Heat in Kerosene saved in L / y	79,845
Value of saved kerosene in JPY/y (1510 JPY/18L)	6,698,102
Generation cost 2013 [IEEJ stat]: 13JPY/kWh	
Value of electricity saved in JPY/ y (at 13JPY/kWh)	4,621,500
Total saving electricity+kerosene in JPY/ y	11,319,602
Fuel needed 350 tons/year in kg	350,000
Fuel cost in JPY/y (At 8 JPY/kg)	2,800,000
Total saving minus fuel cost in JPY/y	8,519,602
Hard ware cost of one Spanner KK unit	
With 45kWe+105kWth 55,000,000 JPY/machine	55,000,000
Years needed to repay machine	6.46

Not factored in: (1) Electricity Feed in tariff of 01 April 2015:
40 JPY/kWh. (2) New Energy Promotion Council susbsidizes heat!

Table. Showing cost estimate of power output (electricity and heat), annual energy output, kerosene equivalent of heat output, annual financial savings based on electricity and heat production, annual wood chip fuel costs, total annual savings, estimated hard ware investment for one wood gas cogenerator (taking Spanner K.K. 45KW electric, 105kW thermal as example), number of years to cover hardware investment by annual cost savings. [Kerosene Price 2015]

We learn from the table (compare the detailed Table below), that even with the above conservative estimates, the costs savings on the electricity and kerosene (or natural gas, or city gas) bill, will be 8.5 million JPY/year, which would allow to fully set off the initial investment after less than seven years. Taking the very high current feed-in-tariff into account by selling all or part of the electricity, or taking the actual price paid for electricity on the consumer side into account, taking cost savings on other necessary investments to comply with mandatory CO2 emission reductions (like the institutional requirements by the Tokyo Metropolitan Authorities) into account, and as explained below, the possibility of a range of subsidies by national, prefectural and local city authorities into account will certainly reduce this time span even further. Furthermore other context dependent cost savings may contribute positively: For example if an institution has waste wood from its own operations, it could save on the removal and disposal fees.

We want to draw attention to the fact, that currently in Japan, institutions which decide to start with wood gas cogeneration can apply for a number of further subsidies, like for disaster resilient shelter site establishment, etc. Moreover, there are nowadays in Japan subsidies available for heat from biomass from the *New Energy Promotion Council* of Japan (http://www.nepc.or.jp/). Examples are (O. Bartenstein, Emails of 10 May 2014, 19+21 April 2015):

1. 平成26年度次世代エネルギー技術実証事業費補助金(次世代エネルギー技術実証事業), http://www.nepc.or.jp/topics/2014/0407_4.html
2. 平成26年度独立型再生可能エネルギー発電システム等対策費補助金 http://www.nepc.or.jp/topics/pdf/140421/140421_4_1.pdf
3. 平成26年度再生可能エネルギー熱利用加速化支援対策費補助金 http://www.nepc.or.jp/topics/2014/0421_1.html

Other institutions, which may provide further related subsidies are, e.g.:

4. オフィスビルへのコージェネレーション導入に対する補, 助金 http://www.tokyo-co2down.jp/subsidy/cogene/
5. 事業用太陽熱利用システムに対する補助金 http://www.tokyo-co2down.jp/shugo/

Like for a car, a truck, a diesel generator, a natural gas cogenerator, etc. regular maintenance will be needed (Appr. 1 hour per week [Volter Oy 2015]. Note, that the machine is generally supposed to operate non-stop). But since the machinery is relying on standard combustion engine technology, even excluding advanced methods like turbo fuel injection, maintenance staff does not need any special high level of technical skills. Car maintenance and wood gas cogenerator maintenance are on the same technical level.

> We therefore summarize from this section that *economically wood gas cogeneration is currently in Japan a very attractive option*, with payback times of less than seven years and potentially much less than that, if feed-in-tariffs, actual consumer side energy costs, available subsidies and further likely cost savings are properly taken into account.

5. Risk level considerations

Every technology has benefits and risks. So we ask: Does wood gas cogeneration have any hidden risks, like new untested technologies typically have, or risks due to operating with technology at the bare limit of human control capacity, or risks regarding fuel supply, etc. ?

Wood gasification was invented already in 1839 by Karl Gustav Bischof, professor of chemistry at Bonn University in Germany [Krenkel 1955]. (As a side remark it is interesting to note that Bischof "suggested that both asphalt and petroleum were likely derived from decaying plant matter, and predicted that the effects of air, heat and pressure might explain the formation of different types of coal." [Zittel 1901].) A wood gas generator for mobile use was invented in 1921 by the French-German engineer Georges Imbert [Hagen 2015]. At the end of the 1930ies ca. 9000 wood gas powered vehicles were in use [Decker 2015] and during WWII approx. six million [Hagen 2015]. Eckhard Hitzer remembers to have seen in the museum of Fukui prefecture an old wood gas powered truck. It seems, that in the time of WWII, also in Japan when gasoline was rare, wood gas became a viable alternative fuel for automotive transportation. So the technology itself is indeed an old and very mature technology, basically comparable to the combustion engine technology of cars, not in any way more complicated or more risky. Gas engines in modern wood gas cogenerators are nothing but robust high quality (and long life) diesel truck engines bought off the shelf.

Japan with its enormous largely unharvested annual increase in wood biomass poses no risk regarding the stability of fuel supply in the foreseeable future. [Bellingrath-Kimura 2014a] Here it is dramatically different from (less risky than) the supply situation and price variability of fossil (coal, oil, natural gas, shale gas) and nuclear fuels.

Proper fire safety for the fuel storage should be taken into account. But in general storing wood is far safer and easier than storing kerosene or diesel, because in the latter case it is challenging to prevent the accidental lighting of constantly emanating fumes.

Also sufficient ventilation of the machine room should be taken care of, especially during times of maintenance.

6. Aspects of forest ecology

Since wood chips originate from forests, a systematic holistic view of wood gas cogeneration should also pay attention to the implication of this use of wood biomass for energy generation. Since this aspect will be subject to strong variations depending on local conditions, we decide to representatively discuss the most concrete example, we can think of, i.e. the situation of our own ICU campus forest in the western outskirts of Tokyo.

The ICU has a comparatively rich campus forrest on its 600,000 square meter campus in Mitaka, western Tokyo. Extended empirical research shows [M. Ohno 2015], that currently the oldest trees date back some 90 years. The natural tree vegetation of the campus is, related to its climatic zone, evergreen laurel trees, as they can partly be seen even on today's campus. The desiduous trees, such as maple trees and oaks, have been planted by humans to provide pleasure to the eye. Thus the ICU campus forest is indeed intensively maintained and could be viewed rather like a tree garden. Since most of the campus is in use for education and research, care has to be taken to avoid accidents from branches and whole trees breaking and falling in heavy winds, heavy rains and snowfall, etc. Therefore the campus forest is constantly monitored by experts and especially older trees near roads, foot paths and buildings are cut down every year. For further interesting details on ICU forest ecology we refer to the detailed ongoing empirical study reported by M. Ohno in his contribution to the independent *Seminar on Renewable Energy and Energy Efficient Building at ICU* (Re3build ICU) in January 2015 [M. Ohno 2015].

Regarding the concrete situation of the ICU campus forest in Mitaka, we have asked yet another outside expert Asst. Prof. Dorothea Sonoko Bellingrath-Kimura of the Tokyo University of Agriculture and Technology (now Head of Institute of Land Use Systems at the Leibniz Centre for Agricultural Landscape Research in Muencheberg, Germany) to first lecture generally on "Forest in Japan – Current situation and challenge" at the Re3buildICU seminar on 2nd Sep. 2014 [Bellingrath-Kimura 2014a]. Subsequently Prof. Bellingrath-Kimura performed a time-consuming detailed inspection if the ICU Mitaka campus forest [Bellingrath-Kimura 2014b]. Together with the campus map material of the ICU Mitaka Campus Masterplan 2012, she came to the conservative estimate of an annual wood biomass yield of at least 50 tons per year, or more. The details depend on the concrete ICU forest management, but at least 50 tons per year or more will always be provided in a sustainable way without invading the protected natural area. Meaningful ecologically sustainable forest management may further increase this number even by a factor of up to five. Regarding the concrete local environment of the ICU Mitaka Campus, Prof. Bellingrath-Kimura came to the further conclusion, that additional tree and wood cuttings from routine public garden and park management measures in the City of Mitaka surrounding the university campus could easily supply enough wood biomass for the continuous yearly operation of a wood gas cogenerator.

7. Feasibility of university campus introduction of modern wood gas cogeneration

Universities are active players in the front line of introducing commercial and profitable renewable energy technologies. An additional incentive may be the obvious educational benefits by involving students in planning, design, set up, operation, maintenance and monitoring. And it provides a very interesting socially very relevant context for research and development. Some institutions like the University of Hokkaido [Ozasa 2015] in Japan, or the University of British Columbia (UBC) [UBC 2015] in Canada embed this in their principal future campus development master plans and in their main stream offer of education and research programs and activities.

Moreove in the concrete case of wood gasification and its applications universities like UBC, Yoensu University of Finland [Yoensu 2015], Technical University of Dresden/Hochschule Zittau in Germany [Zittau 2009] have decided to actively research and apply wood gas cogeneration.

It appears therefore perfectly natural for a university as the ICU situated in the mid of a rich campus forest, located next to major public parks (including forest land as well), and in viewing distance from the western forests surrounding western Tokyo, to seriously contemplate the manifold advantages the introduction of wood gas cogeneration could have for the university, for its students, faculty and staff, for the surrounding city of Mitaka, the whole of Tokyo Metropolis, and the wider Kanto region.

As already outlined in the previous sections of this publication, a university like the ICU could use its own natural resources, augmented by neighboring and nearby wood biomass resources to acquire more than sufficient wood chip fuel at low and stable costs for the continuous operation of one or more wood gas cogenerators on campus. Regarding its energy related campus facilities, the university's central power station (CPS), erected in 1971, seems an ideal location for setting up wood gas cogenerators, and the adjacent fuel storage. The CPS has sufficient space, road access, elelctric power line connections, and hot and warm water pipe connections.

Currently perhaps as many as 20 wood gas cogenerators would immediately cover all the electric and thermal energy requirements of ICU. And power stations with nearly 20 wood gas cogenerators operating in parallel already can be set up, and the upscaling leads to cost savings of ca. 30% [Spanner 1MW 2015]. But we want to emphasize, that the ICU has the strong desire to reduce its energy consumption and to proactively use renewable energy, as pointed out in its Campus Master Plan of 2012, Article 6: "Conservation of Energy and Resources. In planning its facilities, ICU is to make efforts to conserve energy and resources and work proactively to use renewable energy and decrease the burden it places on the environment." [ICU CMP 2012]. And indeed many students and faculty look forward to the realization of these plans on renewable energy use at ICU. Furthermore the Campus Master Plan recommends all future campus buildings and facilities to be built as zero-carbon-buildings. This means that we can expect that the future energy consumption of new dormitories, lecture halls, laboratories, on campus staff houses, and new physical education facilities will be near zero.

In the view of these future developments towards an environmental green campus, we suggest to initially only set up very few wood gas cogenerators, for example three or four. Even this could be done in two stages: First set up one wood gas cogenerator and gather one year of operation and maintenance experience and then proceed to add more machines depending on the prospective future energy needs of the university. As part of its own future renewable energy mix, an institution like the ICU could consider further meaningful and cost efficient renewable energy sources, like solar PV on university roofs and geothermal energy (in the wide spread form of ground source heat pumps), etc. [Power RE Future].

The above considerations on cost recovery within 7 years or most likely over an even shorter period of time, show that the introduction of renewale energy to a unviersity like ICU can also lead to what experts [Iida GEC 2015] call decoupling of profit and fossil and nuclear energy consumption, accompanied by decoupling of energy consumption and quality of living. The first decoupling refers to the fact that nations like Germany and Denmark who reduce fossil and nuclear energy consumption and substantially increase renewable energy consumption follow a new pattern of solid economic growth decoupled from increases of fossil and nuclear energy consumption. The second type of decoupling refers to the increase in comfort of living in a clean environment, including a high indoor air quality and indoor comfort environment, only available in modern ultra low energy buildings, while at the same time residential and education related energy consumption is reduced to a small fraction of the current values [PH handbook].

8. Contribution to future national renewable energy supply in Japan

We further try to address the question as to what contribution this technology can make to the future national renewable energy supply in Japan. We note that "Modern wood gas cogenerators could turn these 50 million m^3/year [of sustainably harvestable wood biomass in Japan] into 10.7 TWh electric energy/year, and 26.7 TWh heat energy/year, flexibly delivering electricity and heat round the clock." [PRI 2015] National electricity energy consumption in Japan as of 2012 was 875 TWh. So even the sustainable production of wood biomass electricity via wood gas cogeneration could flexibly provide more than 1% of the national electricity needs [Japan Statistics Yearbook 2012]. The potential thermal cogeneration of 26.7 TWh could contribute a major offset to natural gas and city gas consumption for warm water production in Japanese households and in addition of kerosene for space heating in the winter, as well as substantially reduce electricity consumption for summer air conditioning by applying cogeneration heat for adsorption cooling. Other private and public schools, universities and colleges, private and public institutions, businesses and buildings of whatever type and purpose in Japan can adapt wood gas cogeneration with similar expected benefits. The next forested mountain in Japan is always nearby – flying across Japan immediately shows its main geographic character as an archipelago composed of intensely green rolling forested hills and mountains.

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