

## FOSSIL RESOURCE SUBSTITUTION BY ORGNIC WASTE CARBON RECYCLING

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### Overview

Annual global harvest in our decade amounts to circa 13Gt dry matter of biomass<sup>i</sup>. In energy content this represents roughly 50% of world's primary energy equivalent. Only 2% of energy consumption<sup>ii</sup> is covered by the conversion of primary biomass into secondary energy forms such as heat (75%), electric power (10%) or transportation fuels (15%)<sup>iii</sup>.

About 40% of the world's annual harvest ends up as organic waste, mostly just discarded or in some higher income countries gets incinerated. All together this represents 20% primary energy equivalent of quite ineffective secondary resource use. Even if everything was incinerated and all landfill gas combusted, all post primary use, end of lifecycle biomass or decay being "Hydro Carbonic Matter" is transformed into CO<sub>2</sub> only. Wherever done so, it commonly is regarded Carbon neutral today and praised "Best Available Technology" [BAT].

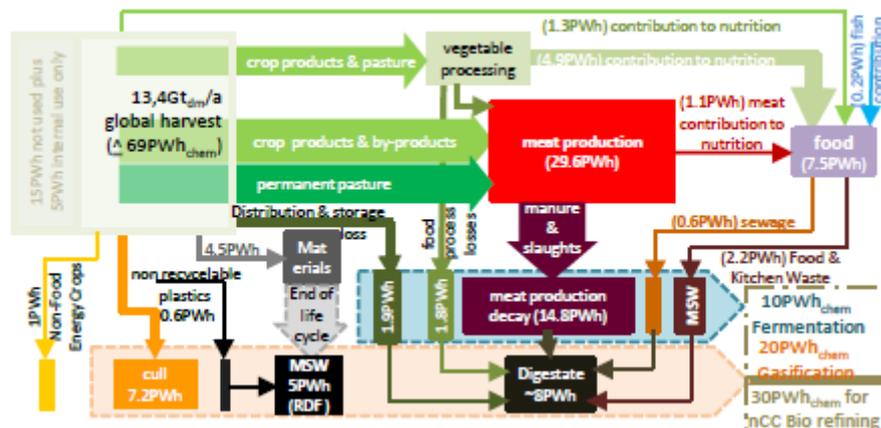


Fig. 1<sup>iv</sup>

Today we live in a world of Hydrocarbon Energy Carriers, whether

- Natural Gas [NG] (CH<sub>4</sub>),
- Gasoline (C<sub>6</sub>H<sub>12</sub>, C<sub>7</sub>H<sub>18</sub>, C<sub>8</sub>H<sub>18</sub>, etc.),
- Kerosene (C<sub>17</sub>H<sub>36</sub>, C<sub>18</sub>H<sub>38</sub>, C<sub>19</sub>H<sub>40</sub>, C<sub>20</sub>H<sub>42</sub>, C<sub>21</sub>H<sub>44</sub>, C<sub>22</sub>H<sub>46</sub>, etc.)
- and so on;

actually using the CARBON as a CARRIER for Hydrogen, delivering most part of the desired Energy! They are storable and have worthwhile, logistically manageable energy densities.

Among 49 (±4.5) GtCO<sub>2</sub>eq / yr in total anthropogenic GHG emissions in 2010, CO<sub>2</sub> remains the major anthropogenic GHG accounting for 76 % (38 ± 3.8 GtCO<sub>2</sub>eq / yr) of total anthropogenic GHG. 16 % (7.8 ± 1.6 GtCO<sub>2</sub>eq / yr) come from methane (CH<sub>4</sub>), 6.2 % (3.1 ± 1.9 GtCO<sub>2</sub>eq / yr) from nitrous oxide (N<sub>2</sub>O), and 2.0 % (1.0 ± 0.2 GtCO<sub>2</sub>eq / yr) from fluorinated gases. 38 GtCO<sub>2</sub>eq / yr relate to 20% of our planet's metabolic capacity for CO<sub>2</sub> (120Gt by vegetation + 70 Gt by waters). But together with all the natural CO<sub>2</sub> emissions, ~15% of anthropogenic GHG emissions pile atmospheric CO<sub>2</sub> stock (totaling 500 Gt today). For staying with 2°C mean temperature increase climate change scenario this stock should never surpass 800 Gt. MSW ~5% of GHG (doubling till 2050) today already accounts for ~40% of the current 6.5 Gt/yr stock piling rate and represents 1/3 of the total potential shown in Fig. 1.

Therefore we have modeled a Carbon Capture for Use Refinery concept together with Austria's scientific sector for New Energy Technologies. It yields about 70% of its feedstock's energy content in pure ( $H_2:CO = 1$ ) Synthesis Gas for any desired downstream Chemical Synthesis output product<sup>v</sup>

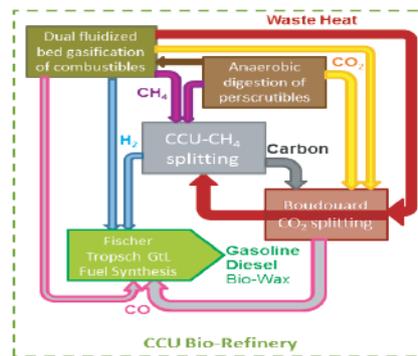


Fig. 2

## Methods

Common Waste Management practices have been driven by the paradigm of collection for extraction of reusable valuables followed by remediation of the “rest” at least net cost. Depending on availability of land filling space (and regulatory compliance cost) thermo-chemical processing had evolved to minimize need for final sanitary sink space and maximize inertness of ultimate residues.<sup>vi</sup>

However, none of these concepts seem adequate for emerging or developing countries, usually urbanizing the most dynamically and augmenting their living standards continuously – resulting in an exponential increase of waste management needs.<sup>vii</sup> Further, sustainability would in addition require Resource Efficiency sensibility, suggesting the 4R Waste Pyramid.<sup>viii</sup>

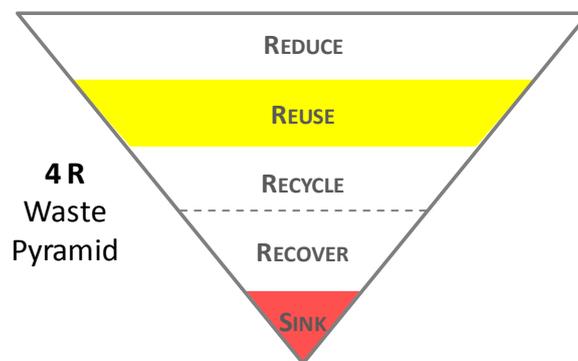


Fig. 3

It is not the highest achievable added value from abundant organic matter to just **RECOVER ENERGY** in forms of Combined Heat and Power [CHP].<sup>ix</sup> In spite of well proven Technologies available to decompose end-of-lifecycle Organic Matter into Energy (Hydrogen and/or Hydrocarbon)- rich gases, **WASTE MANAGEMENT** is still not **REUSING** or **RECYCLING CARBON** from MSW, organically loaded effluent sludge from edibles processing or industries like pulp & paper, etc. It has even been demonstrated already that appropriate treatment of decomposition gas allows downstream Chemical Synthesis for synthetic production of Hydrocarbon Energy Carriers,

Such thermo-chemical transformation of waste allows moving up to higher level planes in the Value Adding Pyramid from waste as a secondary resource, rather than instant consumption as a primary resource substitute, independently from synchronic need (accepting to lose what we can't use).<sup>x</sup>

At the Institute for Chemical Engineering in the University of Technology Vienna Fluidized Bed reactor systems for poor carbonaceous solid fuels have been being developed since 30 years. 20 years ago Vienna municipality installed an auto-thermal FB-Sewage Sludge combustion reactor. Since then the

Future Energy Technology department of the University Institute has focused on FB-gasification reactor Technologies and developed Fast Internal Circulating Dual Fluidized Bed from combining an air-driven FB-combustion reactor for pyrolysis char into a dual chemical loop system with a bubbling steam-driven gasification of poor carbonaceous solid fuel.

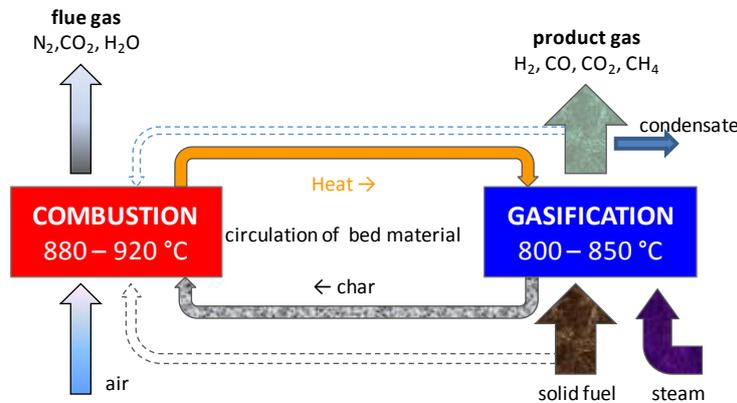


Fig.4<sup>xi</sup>

The process yields 2 separate gas streams - flue-gas from combustion & product-gas from gasification (transformation) of the feedstock in an anoxic atmosphere. This fast, elevated temperature pyrolysis & steam reformation of the solid carbonaceous fuel achieves an 80% carbon conversion, leaving the 20% unconverted carbon as pyrolysis char admixed into the circulating bed material, so it serves as auto-thermal fuel for the heating of the bed material in the combustion chamber. This system has been installed at the European Development Center for Renewable Energies in Austria more than 10 years ago and has been operated on biomass without pretreatment smoothly for the last five years.

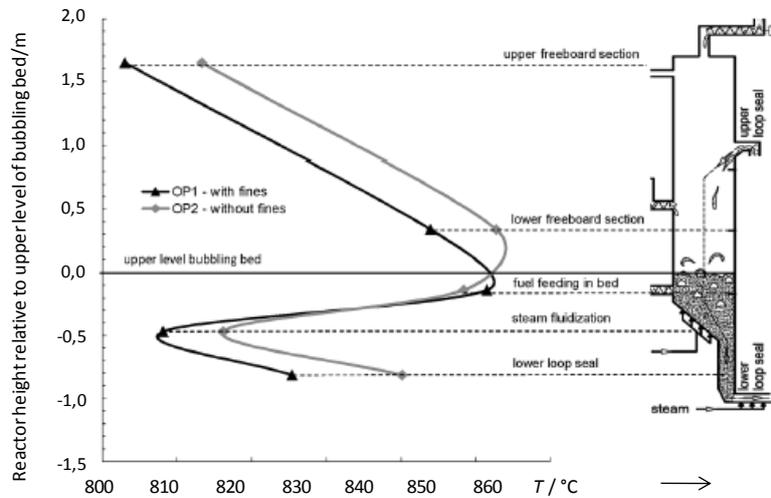


Fig.5<sup>xii</sup>

Reaction heat is indirectly provided through the bed material, looping between the combustion and gasification reactor. To catalyze steam reforming equilibrium reactions of tars an iron oxide mineral is used a bed material. By reintroducing the hot bed material in the upper free board zone and the solid fuel in the lower free board zone, the two intermingle in the splash zone of the bubbling bed, before the bed cools down by ~5% through the fluidization steam, entering at ~300°C.

There have been several initiatives around the world to transform waste hydrocarbons into fossil commodities' substitute hydrocarbons.<sup>xiii</sup> However, the upstream application of FICDFB gasification is quite uniquely an auto-thermal indirectly heated, anoxic transformation of the residues fed to the destruction chamber into membrane or adsorption cleanable product gas, pyrolysis char and ashes (nutrients). Lower melting ashes might clog with bed material, leading to a cyclone sensitive change in specific gravity, allowing a mechanical separation prior to resending to the gasification chamber, or in extreme cases, not rising anymore in the combustion chamber, allowing separation as bottom slag.

Typical oxide flue gas contaminants from incineration are substituted here by the formation of hydrate contaminants in the product gas, from where they can even be recuperated in re-usable aggregates.

This system has meanwhile been scaled up and rolled-out several times for woody biomass, currently operated at  $32\text{MWh}^{-1}_{\text{chem}}$  in Gothenburg at GoBi-Gas followed by a Methanation. A similar size system is currently under construction at Lyon by Gas de France – Suez for renewable public transportation fuel.

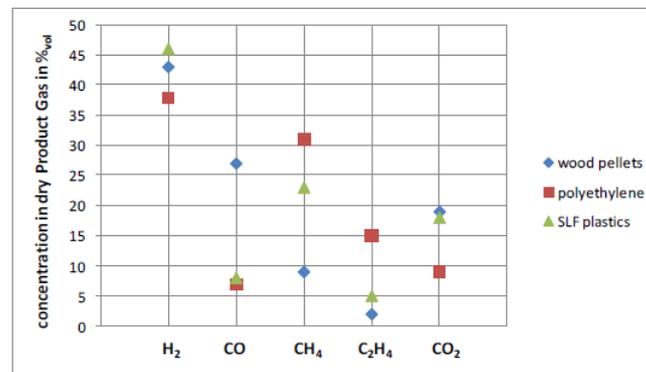


Fig. 6<sup>xiv</sup>

From numerous tests of various solid fuel types like poor coal, MSW, vegetable oil residues, bagasse, sewage sludge, etc. the system has been further optimized to deal even better with small particles and higher tar formation during volatilization.

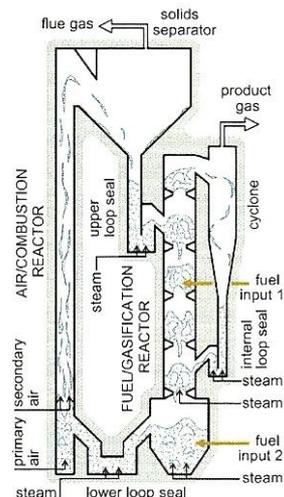


Fig. 7<sup>xv</sup>

Therefore we advocate decomposition of organic residues from MSW, food & feed-, vegetable oil-, pulp & paper- production or husbandry & slaughter waste in an accelerated way, by anoxic bio- & thermo- chemical processing into energy rich producer gas and process- waste heat.

Usually organic waste coincide  $\frac{1}{3}$  in the form of poor carbonaceous solid fuel plus  $\frac{2}{3}$  of fermentable mass-fraction. Energy wise it is rather the opposite way round. Therefore the total recyclable energy in the combined producer gases comprises of a significant Methane fraction already from the bio-gas yields. Methane is one of the most stable organic molecules and therefore received the name Natural Gas [NG] and has become a very competitive Primary Energy Carrier.

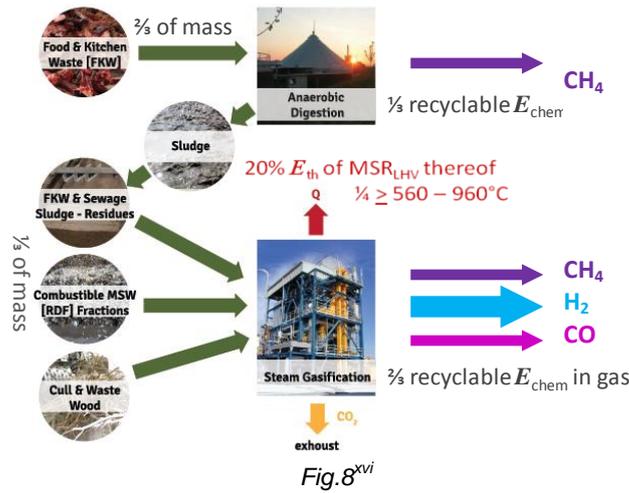


Fig.8<sup>xvi</sup>

By applying “THERMO- CATALYTIC DISSOCIATION” [TCD] of Hydrocarbon Gases, the CARBON content of Methane can be CAPTURED for Re-USE under the release of Hydrogen. As our pilot plant has shown, such Hydrogen can be yielded at 55% of the energy input per mol than is needed for SMR [Steam Methane Reforming]. TCD is a chemical catalytic process using a transition metal catalyst to co-produce H<sub>2</sub> and high surface area crystalline Carbon<sup>xvii</sup> We call it Catalytic Chemical Vapor Deposition [CCVD] method and have developed a continuous process for it.<sup>xviii</sup>

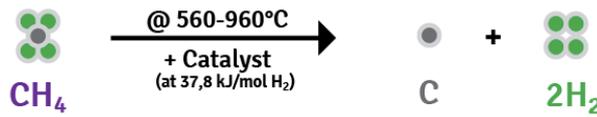


Fig. 9

This process can unlock highly energy efficient atmospheric Carbon stock Recycling and Reuse, for example under coinciding high temperature (flue gas) WASTE HEAT co-Recycling CO<sub>2</sub> decomposition gas fractions back into chemical energy in the form of CARBON monoxide – or as a C:N ratio enhancing additive to CARBON depleted compost substrates – or as a natural high purity graphite (e.g. 85% of Li-I batteries, stainless steel or refractory metals production, etc.) substitute.

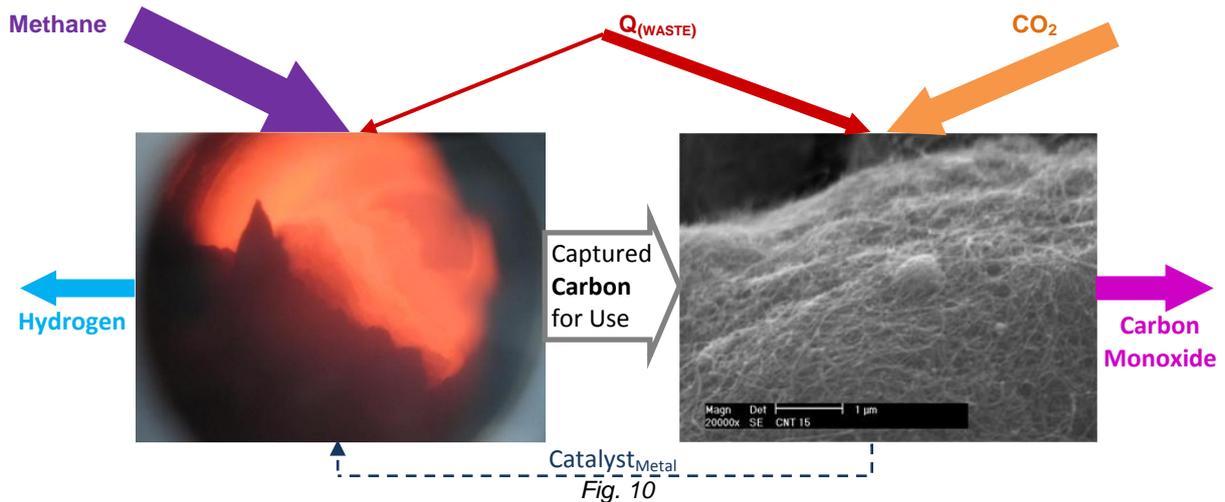


Fig. 10

Since TCD only consumes a part of the waste-heat available from the upstream thermo-chemical decomposition process, the quite demanding endothermic Boudoir reaction can be afforded for catalyst recycling under CO<sub>2</sub> & waste heat, transforming those two, otherwise “unused” outputs back into a calorific value<sup>xix</sup>

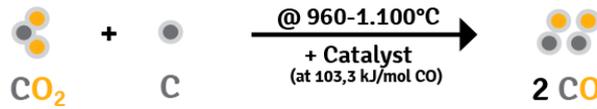


Fig. 11

With this addition the overall output/input chemical conversion efficiency into Chemical Synthesis gas can be further uplifted. GtL fuel synthesis had already been demonstrated from a Synthesis Gas slipstream at the European Development Center for Renewable Energies in Austria 6 years ago in the course of an EU project, for which all the necessary gas cleaning processes have been matured.

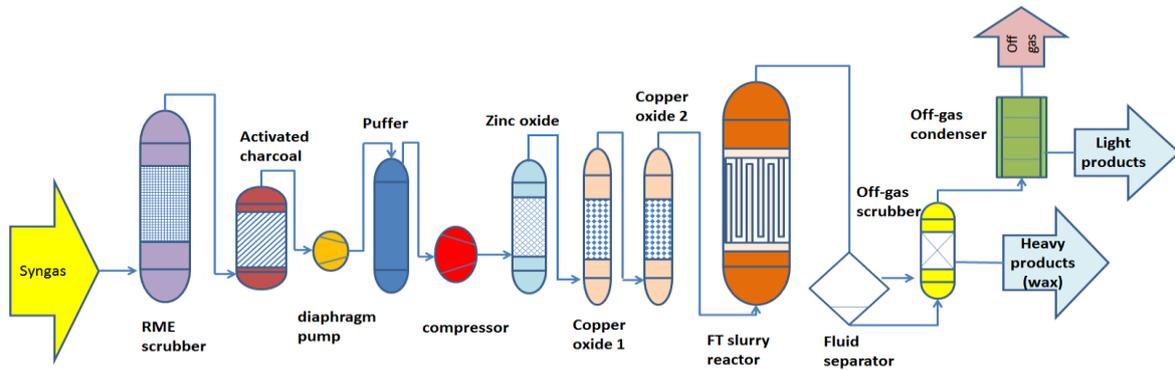


Fig. 12<sup>xx</sup>

## Results

guo – Business Development has been contracting out several feasibilities to TU-Vienna on different kinds of feedstock. An ideal environment for a pilot installation could be provided by the palm oil industry. There is 62million tons of Crude Palm Oil [CPO] production in the world, generating organic waste and effluents in the order of 17GJ/ton CPO.<sup>xxi</sup> Readily aggregated on the mills' sites, but causing significant environmental impact today, due to insufficient or inappropriate treatment. In primary energy equivalents this represents about 3 barrels [bbl] of crude oil.

1 ton Municipal Solid Organic Residue [MSR] may vary between 1 – 2bbl crude oil equivalent in energy content, depending on demography and living standard. Also logistics and governance may vary from country to country and most often is scattered across many different authorities within each country. Therefore it may be the most challenging area for early implementations, but could actually contribute a solution to one of the least resolved problems of our civilization.

Recent adoptions of bio-fuel mandates by increasing number of governments have created new demands for energy plants like sugar cane, etc. We have seen bagasse waste streams attract pulp and paper industries to set up their plants adjacent to those agricultural debris for their cellulose productions. However, remaining residues from such activities have been being used for CHP energy recovery only so far, but could potentially also contribute to Re-Use of Captured Carbon.

Therefore we have benchmarked different usage path options per 1GJ Lower Heating Value of the organic feedstock mix (fermentable & combustible) in the standard ratio as follows:

Table 1: Output Options per 1GJ LHV feedstock

OUTPUT/GJ <sup>*)</sup>	CHP	GtL Fuel	CCU Hydrogen	LGHG Hydrogen	Ethylene
Product	89kW <sub>el</sub>	12.5 ltr Diesel	4kg Hydrogen	5.4kg Hydrogen	4.4kg Ethylene
By-Product	175kW <sub>th</sub>	3.2 kg wax	5kg <sub>nano</sub> Carbon	53 kg CO <sub>2</sub>	3.1kg Hydrogen
CO <sub>2</sub> offset	42.7kg	44.5kg	105.3kg	65.5kg	156.0kg

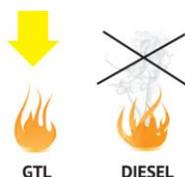
\*) for example Palm Oil Mills generate Organic Waste at  $E_{chem}$  of 17GJ/t CPO (combined MCF, EFB & POME) MSW varies from 6.5GJ/t (CN - scavengers), 8.5GJ/t (AUT – recycling ratio) to up to 13GJ/t (IT – no plants) According to Jaakko Pöyry there seem to be 4GJ/t Paper produced (combined liquor, coke, bark, etc.)

Depending on the price structures for electricity, fuel and Hydrogen the achievable added values from waste can differ significantly. If we take a utility provider's spot market purchase price of € 40/MWhel and € 0.56/ltr Diesel and € 1.15/kg wax, we are talking about factor 2.5. Green Hydrogen is currently being discussed at € 2.5 – 3.5/kg wholesale price for a potential Hydrogen mobility future, where distributed generation would be quite welcome, would even factor 4 of CHP. Alternatively in the case of Carbon Use as a natural high purity graphite substitute material, at 50% of today's long term price projections (€ 3.0/kg) from the relevant mining industry<sup>xxii</sup>, the achievable added value from waste would even 5-fold today's CHP recovery practice at arms' length market prices.

There are about 30billion GJ of urban MSR, expected to more than double due to rapid urbanization and emerging economies increase in standards of living until 2050. Today MSR is contemplated to contribute 2.5 GtCO<sub>2</sub>eq / yr, representing almost 40% of annual atmospheric carbon stock build-up.

HSBC : "some day Energy & Waste will be the same" <sup>xxiii</sup>

Today's demand for synthetic kerosene is contemplated to stand at 150million tons per year. This could be satisfied by processing 50% of today's urban MSR by CCU-Refineries. At 250,000 ton/yr MSR facility capacity and an average of 10GJ/t MSR this would be 6,000 plants. (GTL burns soot-free)



Further world Hydrogen production amounts to 80million tons per year today (whereof 25% are consumed onsite for fossil Diesel desulfurization). Hydrogen mobility would need 70million tons per year, giving a total of 130million tons per year. This could be supplied by processing 40% of 2050's urban MSR by CCU-Refineries. Today 98% of the Hydrogen produced yields from NG SMR, contributing 0.5 GtCO<sub>2</sub>eq / yr.

2012 Ethylene production had been in the order of 143million tons per year. This could be potentially covered by 100% of today's urban MSR or 12,000 standard size (250,000 tpy for 10GJ/t MSR) plants. Given the fact of MSW even 2050 representing less than 1/3 of feedstock potential outlined in Fig. 1, there would be enough room for fossil resource substitution by organic waste carbon recycling and re-Use.

#### Benchmarking against BAT Incineration Practice:

Latest state of the art incineration combined with anaerobic digestion of commercial food and kitchen waste, delivering bio-gas as an auxiliary fuel source to compensate for the wet fractions of regular MSW, costs about € 54/t in operations, allowing WtE revenues for CHP of € 20/t at local arms length tariffs. That leaves € 34/t "social cost" <sup>xxiv</sup>.

Table 2: Waste to Energy Benchmarking (at US\$ 100/bbl crude oil)

260,000t/a	WtE 90's	WtE now	SDI-FICFB + ADOS-CHP	SDI-FICFB + ADOS+CCU
aux. fuel	800,000GJ	0GJ	0GJ	0GJ
Electricity (€44/MWh)	40,000MWh	67,600MWh	105,900-210,000MWh	0-210,000MWh
Heat (€15/MWh)	470,000MWh	426,400MWh	324,400-405,000MWh	192,750-405,000MWh
Synth. Fuel (+ Paraffin)	0bbl	0bbl	78,400- 0bbl + 2,500- 0ton	205,000 – 0bbl + 6,500- 0ton
€ <sub>PROFIT</sub> /t MSR	-75.00	-34.00	-4.00 – -12.00	+27.00 – -12.00

The cost of MSR CCU-refining shows the following structure:

- Feedstock remuneration to sorted waste free of Recyclable and Reusables € 2.28/GJ
- Cost of Personnel for 24/7 operations on site € 4.00/t
- General Expenses of plant operation (incl. maintenance, sundries, catalysts) € 14.00/t
- Engineering and Logistics € 7.10/t
- Overhead € 2.50/t
- Depreciation of capital equipment € 28.00/t
- **Total cost of 250,000tpy operation (8.5GJ/t MSR . . . Vienna Recycling Rate) € 75.00/t**

For a 250,000tpy MSR-refining plant a 25 headcount on site employment is needed. At ~100 €/t revenues each such installation could generate € 25million turnover from locally available waste residue, that in most non fossil resource countries would replace imports. A macroeconomic study for such a local closed loop economy practice showed indirect employment effects of almost twice the plants' headcount and an induced employment effect from money staying in the region of 20% on top of this combined direct and indirect headcount, totaling at close to 100 full time equivalent jobs.<sup>xxv</sup>

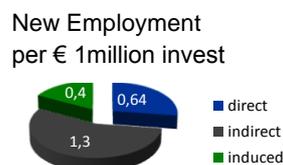


Fig. 13

The perspective of a global need for urban MSR CCU-refining 250,000tpy plants by 2050 in an order of 25,000 allows a comparison with aircraft industry for the respective plant and equipment makers. Today's World Jet aircraft inventory amounts to the same order of magnitude.

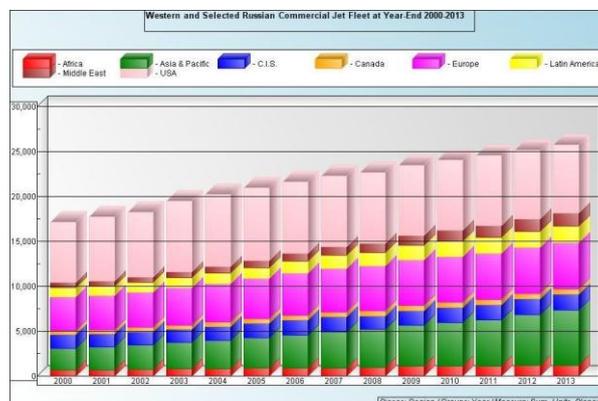


Fig. 14<sup>xxvi</sup>

According to the macroeconomic study for local end of life cycle organic residue CCU-refining plants the one time annual employment effect per plant built within a local economy with suitable domestic industrial and demographic characteristics amounts to about 5 times the total employment effects of a plant's operation. At a building rate for plants from 2020 – 2050, equivalent to new airplane launches 300,000 new jobs could be created in the global plant and equipment industry, achieving a 75% penetration rate in MSR, or 25% of the total potential illustrated in Fig.1 herein. Operation of such an amount of plants would have to grow to 5-6 times that potential of new jobs by then.

Depending on fiscal and social security regimes of the locations for these new employments the fiscal self financing effects can be quite significant. In the example of Austria these fiscal effects only could amortize an installation within 7 years, even if the operation was run on a non-profit basis. For the plant building sector this effect is about 10% of the equipment value built in Austria.

## Conclusions

Each GJ<sub>LHV</sub> in MSR contributes ~0.08 tCO<sub>2</sub>eq GHG emissions. Thereof CHP can neutralize ~50% (times actual utilization rate). CCU GtL plus wax refining Re-Uses 15% and neutralizes 55% CO<sub>2</sub>eq, is storable and burns without aerosol formations. Carbon Use in materials, substituting fossil origin commodities can actually achieve a higher Carbon fixation than MSR's CO<sub>2</sub>eq over the lifecycle of such materials.

Carbon Capture for (Re-)Use Refineries for end of lifecycle or abundant organic matter therefore offers a tremendous opportunity for environmental improvements. But also new employment opportunities and more captive energy independence of economies who may choose this Technology in lieu of energy recovery by incineration or Anaerobic Digestion for CHP only. Something the most dynamically urbanizing and growing population countries can't afford today anyhow and continue land filling. Depending on future price trends for fossil primary energy investments in such installations might even become more lucrative than assumed in our economic analysis. Since energy prices have always been a strong inflation driver, this sector could provide a good hedge in long term investments of institutional or private family office portfolios.

Oil and Gas Industry so far has broadly denied interest in such renewable and repeatable feedstock exploration paths due to their much larger scale of economy thinking, incompatible with organic MSR or other abundant organic matter. However, a larger number of distributed smaller scale installations will in addition to the aforementioned merits also reduce logistic complexity, particularly of interest in conjunction with potential emergence of Hydrogen as an energy commodity.

CCU-Refineries work best in a continuous operation mode. But in local combinations with New Renewable Electricity and Electrolysis of their excess production Hybrid grid configurations could ease the storage challenge by flexible modulation of the downstream chemical synthesis from the available gas. Particularly in conjunction with utility scale Fuel Cell electricity generation peak or back-up electricity could be secured locally.<sup>xxvii</sup>

Our Thermo-Catalytic Dissociation of Methane, driven by upstream high temperature flue gas waste heat of an adjacent thermo chemical process' Hydrogen output would still produce 90% of a Methane gas generator's electricity output, if used for fueling a  $\eta = 60\%$  Hydrogen Fuel Cell, but CO<sub>2</sub> free. Therefore such hybrid NRE – CCU-Refinery back-up grid configurations could become a clean energy solution without idling cost for the back-up capacities.<sup>xxviii</sup>

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