

Using anthropogenic Hydrocarbon stock to Capture nanoCarbon

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Keywords: Carbon Capture for Use, Synthesis Gas Platform, Municipal Solid Residue, Synthetic Fuel, nano Carbon, nano Carbon polymers and nano Carbon Composites, Stainless Steel, Ethylene, Hydrogen, Terra Preta, Carbon – Nitrogen Ratio [C:N], Green House Gas Emission [GHG], Prepreg, atmospheric Carbon Stock, electrolytic paint, Electro Magnetic Shielding, anti static, high purity graphite, nano-Graphene, Lithium Ion Battery, nano fluid, falling film heat exchanger, sewage sludge, biomass, secondary resource, Decomposition Gas, CHP Electricity, Utility scale Hydrogen Fuel Cell, back-up electricity, functional materials, IPSE Pro Process Simulation, building materials, nano Carbon Markets

Abstract

This paper summarizes our past achievements in thermo management material solutions' development, recently venturing into Capture of atmospheric Carbon for Re-Use applications. Climate Change is closely related to the CO₂ stock in atmosphere, nowadays at 550Gt. To stay within the +2°C scenario this atmospheric stock should never go beyond 800Gt^[1]. Therefore opportunities to Re-Use atmospheric Carbon stock in substitution of imported fossil Carbon from earlier ages should be explored. Hydrogen-Carbon Synthesis based materials can offer a great opportunity to achieve Carbon offsets > 100% of the feedstock's Carbon content if transformation efficiencies are favorable. Therefore shifting from mined to Captured Carbon resources could offer one of the greatest economic opportunities to mitigate Climate Change.

Introduction

In our Thermo-Catalytic Dissociation of Methane developments we had always been driven by the nanoCarbon materials. We needed them for Metal Matrix Composite developments. One of the merits achieved therein had been an Aluminum nanoCarbon Matrix, achieving conductivity values for electric and thermal currents equivalent to copper.

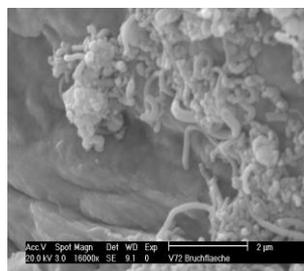


Fig. 1^[2]

Meanwhile one of our spin-offs had developed various nanoCarbon Polymer applications, covering a spectrum from anti static over mechanically enhanced to electromagnetic shielding polymers. Plastics with conductive surfaces further demonstrated primer-less electrostatic paint or electrolytic coating abilities. Further some of our nanoCarbon materials had been tested by paint makers and proved superior impact strength and corrosion resistivity, especially if the particles were Hydrogen loaded prior to admixture.

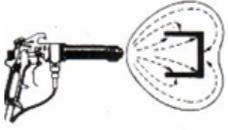
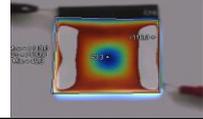
| Sample | Customer Benefit | Technical Data |
|---|--|---|
|  | Conductivity of nano Carbon Polymer replaces coupling resistance against electromagnetic noise → saving the extra component as well as it's assembly | Mat.: PBT+30%GF+6%CNF R _{el} : 150 kΩ Life: 7,000 hrs Temp: -40 - +140°C |
|  | Self-diagnostic cam belt elastic polymer-CNF composite with specific volume resistivity to detect micro cracks or defects in the material (by detection of sudden resistivity increase). Able to prevent expensive maintenance or engine damage | Mat.: TPE-U+5%CNF R _{el} : 100 kΩ Temp: -40 - +165°C |
|  | A mixture of CNT and glass bubbles can reduce the warp and cte of the injection molded part. By adding CNF surface resistivity can be designed to provide for EMI, allowing replacement of metal in electronic devices' housings | Mat.: PC +20%GB+8%CNF R _{el} : 10 kΩ Warp: < 1mm/m |
|  | To prepare thermoplastics for e-painting (eg. Mirror housings) a surface resistivity of 10 ⁵ Ohm or lower needs to be achieved. By compositing CNF into the plastic "priming" can be waived (eliminating an extra process step and environmentally hostile chemicals) at mechanical strengthening of the plastic part. | Mat.: ABS + 6%CNF R _{el} : 1 MΩ |
|  | For the Motorcycle Part HDT (high service temperatures); low warp and readiness for e-painting was the target ! To prepare thermoplastics for e-painting a surface resistivity of 10 ⁶ Ohm or lower needs to be achieved. | Mat.: PPS GF20+ 6%CNF R _{el} : 1 MΩ Low Warp High HDT |
|  | Conductive polymers allow to measure the level of fluid in a container, e.g. in a gasoline tank, saving component assembly, moving parts, etc. | Mat.: PP+9%CNF HDT: > 135°C E-Mod.: 2,000 MPa |
|  | Conductivity of nano Carbon Polymer replaces components in heater panels – a metal free alternative for uses indoor; e.g. in e-cars for floor and/or door panel heating | Mat.: ABS+20%GF+8%CNF R _{el} : 10 Ω Cycled Life-Time: > 10,000 hrs Temp: -RT - +110°C |
|  | Self-lubricant in case of a special additivated PA 12 with 4% CNT; reduces wear in the gear box and therefore temperature and qualifies the present gear for 6000 Cycles | Mat.: PA 12 +4%CNF R _{el} : 1 MΩ Temp: -30 - +65°C |
|  | Motor – Near Applications need to introduce CNT's for an improvement of the heat distortion temperatures (HDT) – long term behavior are improved for >15% | Mat.: PA6 +8%CNF R _{el} : 140 kΩ HDT- Improvement 15% |
|  | Fuel systems require a surface resistivity of 10 ⁶ Ohm to avoid sudden discharge during flow. By compositing CNF into the plastic chemical resistance, long life reliability (against wash out) and mechanical impact resistance (particularly in cold environment) coincide nicely with such conductivity achieved | Mat.: PA 12 + 6%CNF R _{el} : < 1 MΩ |
|  | Conductive polymers as a Multilayer Application for automotive fuel lines – less filler in case of CNT for the conductive Layer leads to better mechanical stiffness, long term behavior and best chemical resistance | Mat.: PA 12 Multilayer+5%CNF HDT: > 135°C E-Mod.: 2,000 MPa |
|  | 2 K- Injection Moulded Sensor Field (CNT filled PP had been the material of choice for the sensor application on the back side of the mounting. | Comp. 1 Conductive PP + 12 % CNT 10 Ohm Comp 2 TPE-Coat (Soft Touch) |

Fig. 2^[3]

Through appropriate functionalization of the nanoCarbon ink-like nano fluids could be created, for the enhancement of thermo conductivity and thermal capacitance of liquids, particularly of interest in heat exchangers. Actually adsorption/desorption systems sometimes may even want to use catalysts, which can be coated onto the nano particles, e.g.: nanoCarbon.

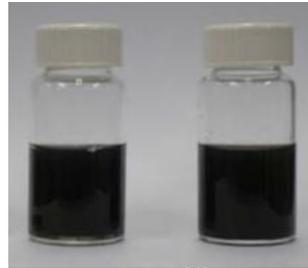


Fig. 3^[4]

nanoCarbon is a crystalline grapheme type of Carbon aggregate with very high tensile strength and electron emissivity, a surface of 140 – 350m²/Gramm and can replace natural high purity graphite, occurring at 6-7% of mined materials only, in many applications. One of the most dynamic fields are Lithium Ion Batteries, containing such graphite in the order of 85% of its weight.

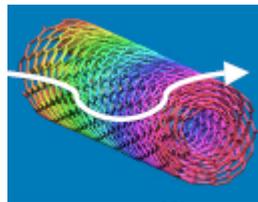


Fig. 4^[5]

Much feasibility had been undertaken for applications of our nanoCarbon. For example for pre-preg densification – showing almost 3 times the tensile strength of un-doped material. However, this is only achievable if the macro fibers’ coating can be mixed with the nanoCarbon, which is not in the interest of current suppliers, as it would cannibalize part of the capacities and ease bottleneck of supply, which is always a very price sensitive issue. But our material had even been tested successfully for the fabrication of Carbon disk brakes.

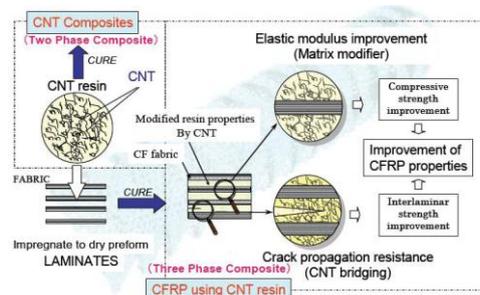


Fig. 5^[6]

Courtesy of Dr.Ishikawa and Dr.Iwahori (Jaxa)

Another application study had been conducted with a stainless steel smelting company, resulting in superior uniformity of carbonization and mitigation of impurities by using nanoCarbon instead of coal products for the Carbon doping of the steel.

However, market prices of nanoCarbon, usually produced in rather small scales and often by more scientific than industrial entities, never really allowed a breakthrough of any of these applications in larger scales. Therefore unfortunately none of the aforementioned proven applications are readily available today for any substantial off-take of nanoCarbon that could be captured from anthropogenic Methane or decomposition gas from abundant organic matter.

nano Carbon Application Markets

Table 1^[7]

| Field of Application | Annual Volume nano C (worldwide) | Price Entrance Barriere |
|--|----------------------------------|-------------------------|
| Lithium Battery Ion Spacer | 800 – 1.000 t | RM 300/kg |
| Thermoplastics/Elastomeric (Electrical conducting Composites) | ≤ 6.000 t | RM 120,-/kg |
| Thermoplastics/Elastomeric (light weight materials) | ~ 10.000 t | RM 65,-/kg |
| Thermoplastic Metal Substitution (at full EMI Shielding) | ≤ 30.000 t | RM 35,00/kg |
| Substitution of Carbon Black (Car tires, color dies, graphite) | ≥ 100.000 t | RM 13,00/kg |
| FiT Refinery Intermediary (CO ₂ Splitting for CO – H ₂ ratio) | 7.000.000 t | RM 9,00/kg |
| Terra Preta (Black Soil) | 300.000 t | RM 4,00/kg |
| (Foam-) concrete filler | 100.000.000 t | RM 0,45/kg |

Since time to market in materials is a very unpredictable parameter, we have simulated a model where TCD of Methane from thermo- and bio- chemically decomposed end of life cycle organic matter delivers Hydrogen and nano Carbon as refining intermediaries towards a 100% Synthesis Gas platform, enabled through some CO₂ Recycling over the high temperature flue gas waste heat of the upstream gasification, consuming the nano Carbon to return the catalyst for further TCD of Methane.

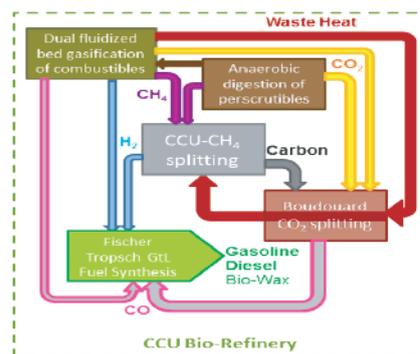


Fig. 6^[8]

Chemical synthesis from Hydrogen and Carbon Monoxide slip streams of decomposition gas from biomass gasification has been demonstrated at the Research Center for Renewable Energy in Austria and showed the so far highest added value from poor carbonaceous solid fuels at unsubsidized arms' length market prices.^[9] Just the aviation industry, demanding 150 million tons of GTL would already represent a market for such a usage path from organic residues' transformation by Captured Carbon for Re-Use refining. The big advantage of GTL is that it burns very cleanly.

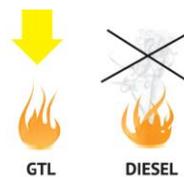


Fig. 7^[10]

However, in a Hydrogen economy such Captured Carbon should be used in material applications and will be affordable for most of the examples cited above at the cost going into the CO₂ recycling calculation. In contrary, at natural high purity graphite substitute prices that Carbon would actually increase the achievable total added value, if it was used in material applications.

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.^[11] 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.

Orders of Magnitude

Our planet possesses a CO₂ metabolism of 190Gtpy, 120 by vegetation and 70 by waters. Our civilization currently emits ~50Gtpy CO₂eq Green House Gases, which is ~115% of the planet’s metabolism’s contingency headroom. Therefore atmospheric Carbon stock keeps building up by 6.5Gtpy.^[12]

Global Anthropogenic CO₂ Equivalent emitted

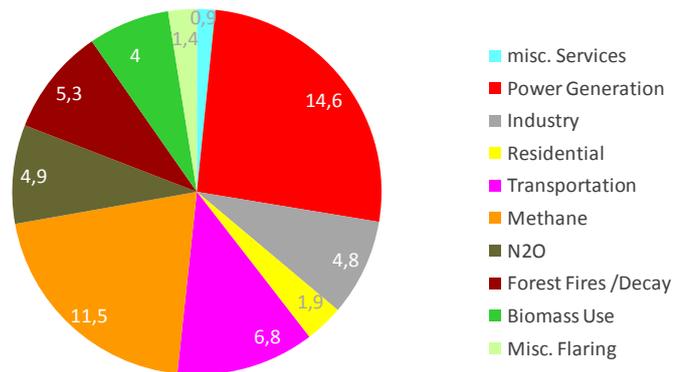


Fig. 8^[13]

The Methane actually ranks #2 and is the most stable Hydrocarbon molecule. Actually it is very likely to even surpass Power Generation, where a lot of efforts in decarburization and reductions through Energy Efficiency improvements are on their good way. But one of the major root causes of anthropogenic Methane – “urban waste” – is increasing exponentially over increasing urbanization, growing population and improving standards of living (all coinciding in developing countries and/or emerging economies). Actually urban waste is expected to double in the next 25-30 years. Without a game change in urban waste treatment practices urban waste will become one of the biggest problems for our civilization.^[14]

At today’s rate we are actually talking about ~400bill m³ Methane a year, representing a potential for nanoCarbon Capture yielding ~200million tons. Since mined graphite usually only occurs in crystalline morphology at 6-7% of recovered volumes, this could substitute mined products at a multiple of ~14.^[15]

Urban Waste currently is contemplated to contribute 5% of the Green House Gas Emissions, namely 2.5Gtpy. Although some high income countries developed Waste to Energy Recovery concepts, meanwhile quite sophisticatedly, they don’t work without strong subsidies on the CHP output and amortize only within regimes, setting out very high dipping fees for landfills.

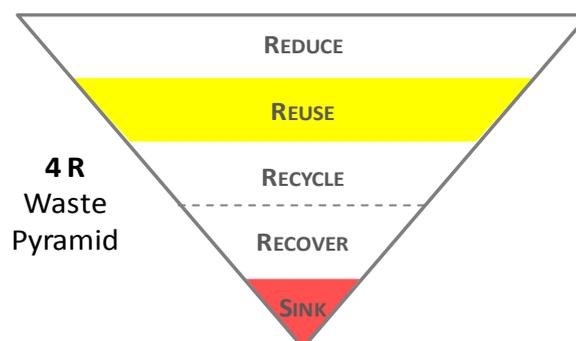


Fig.9^[16]

There were times where Carbon trading schemes allowed foreign direct investor models for flaring landfill gas in poorer countries, but didn't sustain within expectations. The only chance to achieve self sustaining cost performance of proper waste treatment therefore is to move upwards in the value adding pyramid with so called Best Available Technology [BAT] from Recovery to Re-Use.^[17] CHP Recovery is still considered BAT in spite of well proven Technologies available to decompose end-of-lifecycle Organic Matter into Energy (Hydrogen and/or Hydrocarbon)- rich gases.^[18] There is no apparent reason why Waste Management does still not REUSE or RECYCLE CARBON from MSW, organically loaded effluent sludge from edibles processing or industries like pulp & paper, etc.

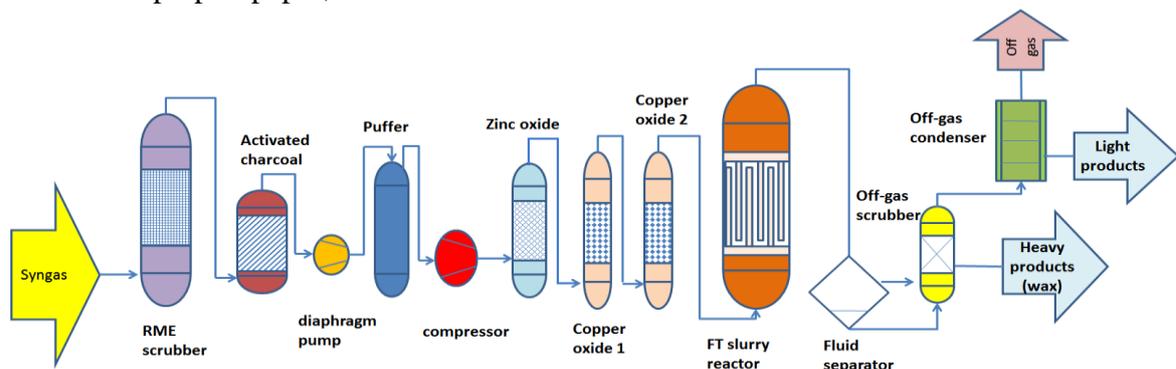


Fig. 10^[9]

It has even been demonstrated already in an EU Project at the Research Center for Renewable Energies in Austria, that appropriate treatment of decomposition gas allows profitable downstream Chemical Synthesis for synthetic production of drop-in Hydrocarbon Energy Carriers.^[9] Actually Urban Waste is just close to 30% of all organic waste accrued in the world.^[19] But it is the most complex challenge, compared to the remaining 70%. Therefore any Technology able to transform urban waste into fossil substitute products, will work for the rest as well.

State of the Art

Thermo-chemical transformation of abundant or end of life cycle organic matter into Energy-rich gas offers alternatives to instant consumption as a primary resource substitute, independently from synchronic demand (accepting to lose what we can't use). But such accelerated decomposition will never be able to compete against Natural Gas,^[20] without receiving subsidies, market preference terms and conditions or Green Certificates, now popular in the UK and France.

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.^[21] 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 [FICDFB] 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.

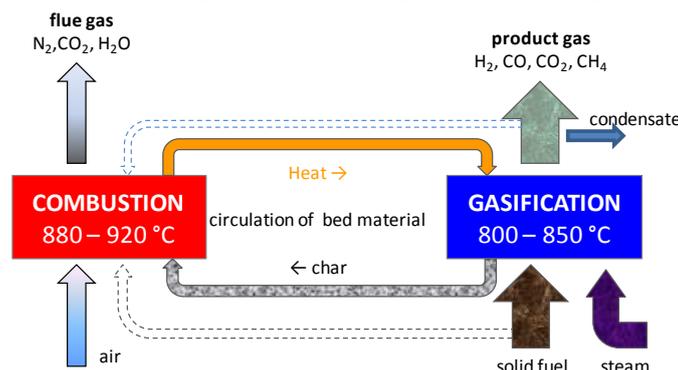


Fig. 11^[22]

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. That way 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.^[23]

Therefore FICDFB gasification is quite uniquely an auto-thermal indirectly heated, anoxic transformation of residues fed to the destruction chamber into cleanable product gas, pyrolysis char and ashes (nutrients). Typical oxide flue gas contaminants of incineration are substituted here by the formation of hydrate contaminants in the product gas, from where they can even be recuperated by membrane or adsorption as re-usable aggregates.^[24]

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

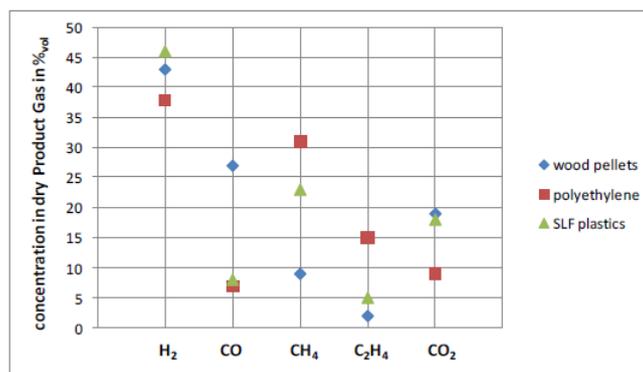


Fig. 12^[25]

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.

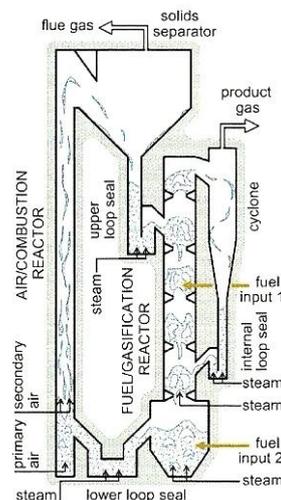


Fig. 13^[26]

Organic Municipal Solid Residue.

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.

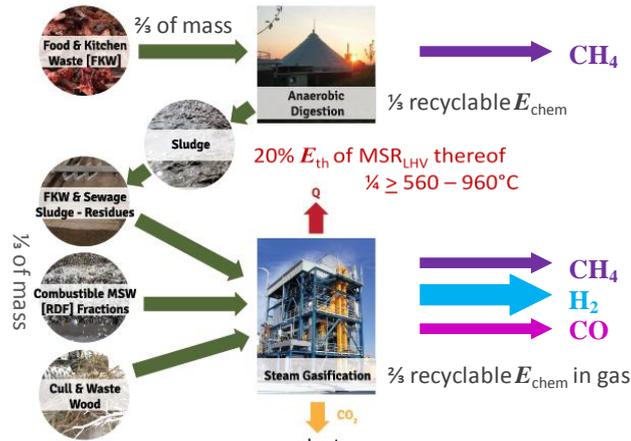


Fig. 14^[27]

Thermo-Catalytic Dissociation of Methane [TCD]

TCD of Hydrocarbon Gases, the CARBON content of Methane can be CAPTURED for Re-USE under the release of HYDROGEN. TCD is a chemical catalytic process using a transition metal catalyst to co-produce H₂ and high surface area crystalline Carbon.^[28] We also call it Catalytic Chemical Vapor Deposition [CCVD] method and have developed a continuous process for distributed Hydrogen production, as our pilot plant has shown such Carbon emission free Hydrogen being yielded at 55% of the energy input per mol than is needed for SMR [Steam Methane Reforming].^[29]

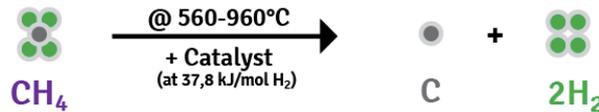


Fig. 15

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 CO₂ 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. Li-I batteries, stainless steel or refractory metals production, etc.) substitute.

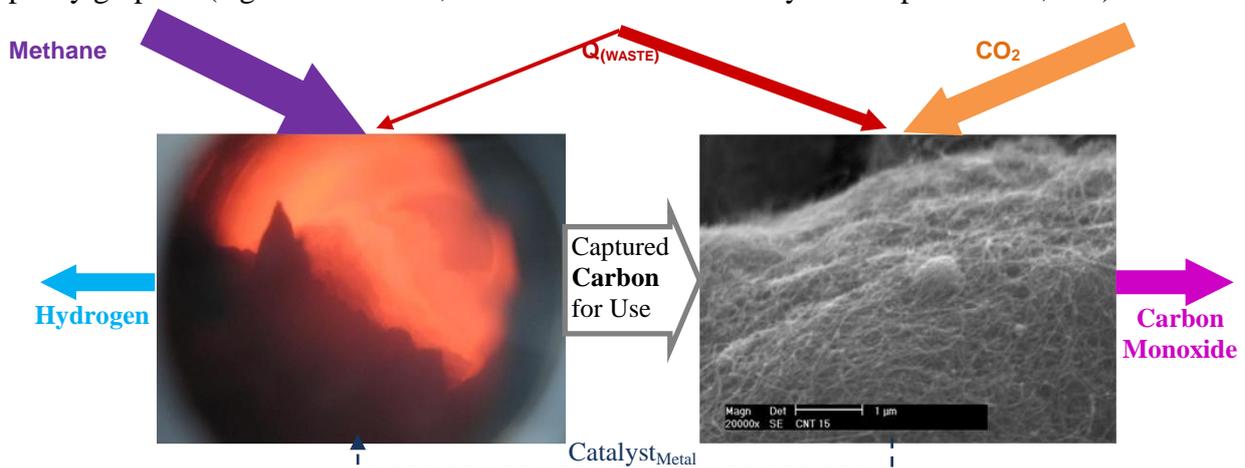


Fig. 16

Recycling E_{chem} from CO₂ and Waste Heat.

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 CO₂ & waste heat, transforming those two, otherwise “unused” outputs back into a calorific value.

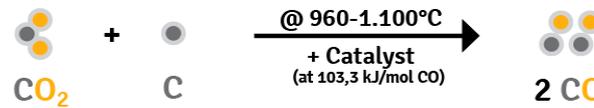


Fig. 17^[30]

Results

guo – Business Development has been contracting out several feasibilities to TU-Vienna on different kinds of feedstock. 1 ton Municipal Solid Organic Residue [MSR] may vary between 1 – 2bbl crude oil equivalent in energy content, depending on demography and living standard.

HSBC : “some day Energy & Waste will be the same” ^[31]

Today’s MSR amounts to 5billion bbl crude equivalent, ~17% of the world’s crude production^[32] and is predicted to double until 2050. Due to logistics and governance models varying from country to country and most often being even scattered across many different authorities within each country, the MSR sector may be the most challenging area for early implementation of our CCU integration.^[33] Hong Kong actually would appeal to us as an ideal location for this innovation, as it can provide all the downstream design and innovation potentials for a swift market penetration of all the usage paths for the Captured Carbon. And the approach would resolve Hong Kong’s most controversial topic^[34] by taking it to a completely new level. With China’s roll-out potential in the back financing should not be a show stopper. Particularly if we look at benchmarked different usage path options per 1GJ Lower Heating Value of the organic feedstock mix (fermentable & combustible in the standard ratio):

Table 2

| OUTPUT/GJ ^{*)} | CHP | GtL Fuel | CCU Hydrogen | LGHG Hydrogen | Ethylene |
|-------------------------|---------------------|-----------------|-----------------|-----------------------|----------------|
| Product | 89kW _{el} | 12.5 ltr Diesel | 4kg Hydrogen | 5.4kg Hydrogen | 4.5kg Ethylene |
| By-Product | 175kW _{th} | 3.2 kg wax | 5kg nano Carbon | 53 kg CO ₂ | 3.5kg Hydrogen |
| CO ₂ offset | 42.7kg | 44.5kg | 105.3kg | 65.5kg | 206.0kg |

*) for example Palm Oil Mills generate Organic Waste at Echem of 17GJ/t CPO (combined MCF, EFB & POME)^[35]
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/MWh_{el} 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.^[36] 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, the achievable added value from waste would even 5-fold today’s CHP recovery practice at arms’ length market prices.^[15]

Today’s demand for synthetic kerosene is contemplated to stand at 150million tons per year.^[37] 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.

Further world Hydrogen production is predicted to grow to 80million tons per year by 2020 (whereof 25% are consumed onsite for fossil Diesel desulfurization).^[38] 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 96% of the Hydrogen produced yields from NG (50%), oil (30%) or Coal (16%) – SMR,^[39] contributing 0.5 GtCO₂eq / yr.

2012 Ethylene production had been in the order of 143million tons per year.^[40] 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.

Climate Change Mitigation

Each GJ_{LHV} in MSR contributes ~0.08 tCO₂eq GHG emissions. So called BAT CHP can neutralize ~50% (times actual utilization rate) thereof only. If all Ethylene demand was produced by CCU-MSR refining, 6.2Gtpy CO₂eq fossil imports from previous ages could be substituted. By covering growing Hydrogen demand for hopefully emerging Hydrogen mobility through distributed CCU-Hydrogen reforming plants from the growth of MSR, this could be increased by another ~3.1Gtpy CO₂eq fossil substitution and create headroom for any natural force majeure incidents to be absorbed by our planet's metabolism.

Hydrogen mobility would actually improve today's energy efficiency in transportation from ~7% well-to-wheel to ~25%, making the CO₂eq emissions purely a function of Hydrogen production.^[41] Apart from these highlights, new Carbon based material developments will of course further add to improved energy economics, manifested in lower consumptions. For instance EMI shielding nanoCarbon - Polyethylene Composites will very likely substitute metals in many applications. Or compacted nanoCarbon Prepreg brake disks that could replace steel disks, decreasing unsuspended weight, enabling new electric power train concepts.

We had also demonstrated Carbon coating of Fe powders, allowing preparation of desired alloy volume fractions in a pre-alloy smelting step, leading to enhanced stainless steel qualities under reduced CO₂ emissions.

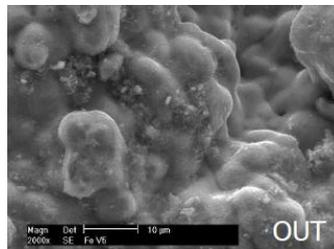


Fig. 18^[42]

Another steel substitution application we had tried out for rapid prototyping moulds. Phenolic nanoCarbon Composite Cast Resin enable mechanically and thermally Steel- equivalent moulds, with a tool-life of about 2.000 cycles

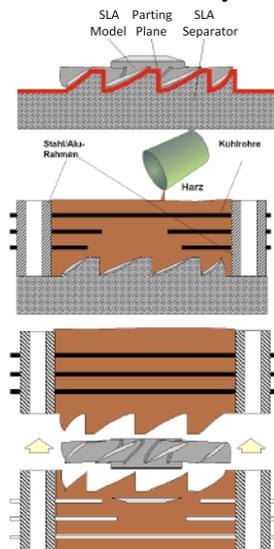


Fig. 19^[43]

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.^[44]

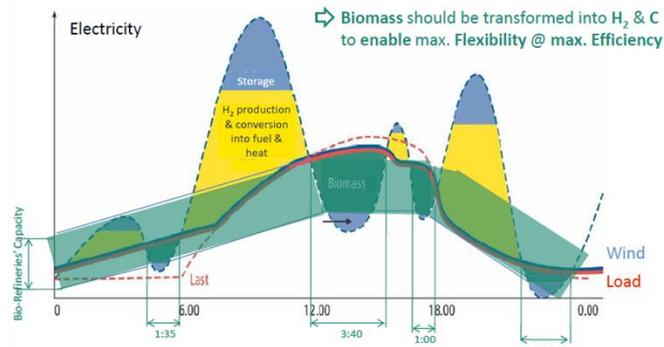


Fig. 20^[45]

TCD 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 CO₂ free. Therefore such hybrid NRE – CCU-Refinery back-up grid configurations could become a clean energy solution without idling cost and CO₂eq for the back-up capacities.

Today's practice of bringing stabilized (Carbon depleted) anaerobic digestion sludge out into fields, triggers N₂O until a balanced C:N ratio is reached again. By adding nanoCarbon into nutrients for wormy composting, these effects could potentially be reversed, as the carbon tends to hold nutrients from premature wash out by rain. Therefore less energy fertilizer could be applied, saving energy and emissions at the refinery and less nitrification of ground waters would happen.

Economics of CCU-Refining

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.^[46] That leaves € 34/t "social cost". Benchmarking CCU Refining against BAT Incineration Practice in Austria comes to following results:

Table 3: Waste to Energy Benchmarking (at US\$ 100/bbl crude oil)

| 260,000t/a | WtE 90's | WtE now | SDI-FICDFB + ADOS-CHP | SDI-FICDFB + 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 |
| € _{PROFIT} /t MSR | -75.00 | -34.00 | -4.00 – -12.00 | +27.00 – -12.00 |

The ranges indicated in the FICDFB columns should show the downstream use flexibility the system can provide. Following HSBC's slogan of putting Energy and Waste into the same category, we consequently have included it as a feedstock purchase into our cost model for CCU Refining and 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) € 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.^[47]

New Employment
per € 1million



Fig. 21

Summary

nanoCarbon 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. 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.^[48]

Future price trends for fossil primary energy might make investments in CCU installations even more lucrative than assumed in our economic analysis. Since energy prices have always been a strong inflation driver, this investment target could provide a good hedge in long term investments of institutional or private family office portfolios.

If one tempted to meet global demand for urban MSR CCU-refining through 250,000tpy each plants an order of 25,000 would be needed by 2050. This allows a comparison with aircraft industry for the respective plant and equipment makers.^[49] 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 of organic waste.

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