Polyurethane Energy Recovery and Feedstock Recycling Technology

A Summary Overview of Latest European Technologies

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ABSTRACT

The implementation of the European waste sector regulations: packaging, automotive and electrical and electronic goods with specific targets for recycling and energy recovery warrant a summary overview of current installed and developing technologies for plastics in general and more specific for Polyurethane (PU). The quotas are very demanding and extremely ambitious with respect to the mile stones at 2006 and 2015. In addition landfill phase out regulations put additional pressure on the owners of PU waste to find a home.

There is a great lack of energy recovery capacities due to a phase out of landfill in most central European countries by the 2005 to 2007 time frame. Total capacity of WtE facilities in Europe is about 47 Million t in 2002. This is only 20 % of total municipal solid and other similar waste. The solution to bridge the gap between waste supply and waste treatment capacity is linked to the low cost approach building mechanical sorting plants and mechanical biological treatment plants. These plants do recover a mixed organic fraction to which the PU belongs after a mass reduction. Opportunities exist to do recover energy through fuel substitution in co-firing substituting traditional fuels in power, cement and lime production plants. This is due to the large substitution potential for solid recovered fuels (SRF). Economics of gate fees depend very much on incremental investment, new co incineration legislation and fuel characteristics of PU. PU specific combustion and energy recovery characteristics have been documented and analyzed to match up technological and operational requirements with fuel characteristics to such a degree that their fuel character is known to the market. Besides WtE and the classical thermal co-treatment routes selected few integrated facilities are available with limited capacity.

PU applications in the various market sectors are numerous. There are many feedstock recycling technologies specific to PU streams like glycolysis, which require a dismantling and separation of PU. The raw material and converting industry favors large scale operations to avoid high dismantling, logistics and recycling costs. The alternative to separated polymer streams is to treat shredder residue containing PU with the rest of non metallic materials either directly or after refinement depending on the user. A number of feedstock recycling technologies like traditional gasification, pyrolysis and new thermal or feedstock process developments are available and could be commercialized. But they require significant capital investment and carry the risk of scale up problems. Outlets for the produced gas are known and can be a feedstock for chemicals and plastics production. The investment cannot be paid through today's level of disposal cost or gate fees in the market. Metallurgical processes are also suitable when using the produced gas for reduction purpose. The amount of coal and heavy fuel oil which can to be substituted is favorably high.

INTRODUCTION

The areas of interest for a deeper understanding of PU energy recovery and feedstock recycling in Europe and other parts of the world are characterized through

1. Available treatment capacities
2. Technologies: PU specific or general to organic materials
3. Waste markets

The paper [1] summaries and analysis with special emphasis to the amount of PU waste arising, waste markets and gives an update on European regulations. But the paper did at that time not present the overview on the technology,it concentrated more on the waste characteristics description.

PU is one of the larger polymer product groups within the plastics family. The producers of PU are organized within ISOPA (www.isopa.org) , the Isocyanate Producers Association in Europe and API in North America www.polyurethane.org . Total production volume of PU in Europe is 2.5 Million tons per year. The European plastics producers association formerly APME and today PlasticsEurope does support the demonstration of existing technology for plastics and the development of new technology as part of their environmental program.

A general overview of the plastics family with the phases -production, life time use, inventory and end of life operations - can be seen in the Figure Nr. 1.

The plastics producer industry does advocate a position that many of the high efficiency energy recovery processes match up with the feedstock recycling process in terms of eco-efficiency. This has been shown in a number of studies done by PlasticsEurope for the market sectors packaging, automotive and electrical and electronic goods (2,3). A political hierarchy between high efficiency energy recovery and feedstock recycling processes can hence not be justified on environmental as well as economic arguments.

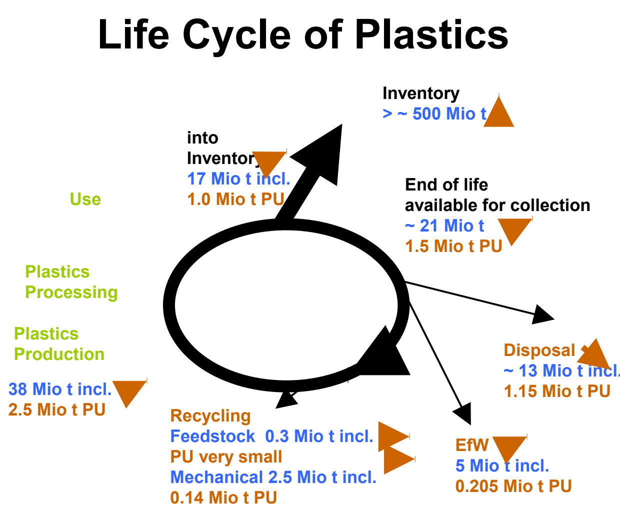

Figure Nr. 1 Life Cycle of Plastics

EUROPEAN LEGISLATIONS

The most important change in European waste sector regulations recently is the switch from specific waste sector regulations to the Thematic Strategies. The two important upcoming Thematic Strategies which influence PU industry at large are on

- Waste prevention and recycling and
- Natural resources use

It is expected that the EU commission will publish their first draft after the summer of 2005. Other important legislative developments are the modification of the waste frame work directive as well as the discussion about the recognition of waste to energy (WtE) as called in the USA or energy from waste abbreviated in Europe (EfW).

- potential reclassification of EfW as a disposal operation D and not recovery R
- potential reclassification of plastics recycling in steel plants as energy recovery
- pre treated waste plastics stays as a waste and cannot be classified as fuel substitute

The official classification and the understanding for Europe are shown in Figure Nr. 2 below.

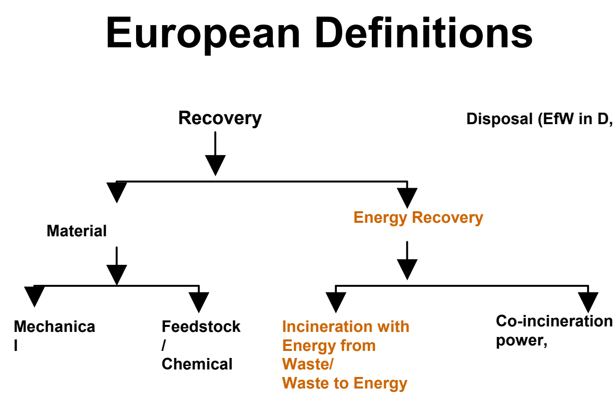

Figure Nr. 2 European Definitions

INTEGRATED WASTE MANAGEMENT

The current EU statistics for waste management from http://epp.eurostat.cec.eu.int does characterize the total of EU 15 through the following routes: 20 % to incineration with energy recovery, 47 % landfill and the rest recovery. The main technology routes are explained in the schematic diagram below. The classical WtE route technology is today advanced by specific combustion techniques such as the (I) post grate ash treatment to achieve a grate ash which is considered by all EPAs to be of no concern to the environment and beneficial use when land filled without protection against ground water contamination, the (II) oxygen enrichment to achieve higher throughput in existing plants and the (III) recovery of salt products from a WtE facility. Mechanical sorting (MS) of different depth, types and degrees can produce a residue with a very high quality solid recovered fuel (SRF) or a hydro carbon feedstock for metal reducing furnaces to achieve a reducing reaction to produce iron or other non ferrous metals such as zinc. The development of combined mechanical biological processes (MBA) can have different conditions:

aerobic, anaerobic, medium to low temperature or just a drying step to remove moisture. The product is also a type of SRF with product characteristics to be used in the same applications as mentioned before derived from the MS operation.
PU end of life article are in many cases part of the waste mixtures coming from the sector or sub sector application. Due to that mixture composition the physical form does not lead to critical processing issues as long as the amount of PU is lower than 20 %. In some applications such as bedding and furniture where PU articles become separated and have a larger market share the processing step to come from the waste stream to a SRF stream a PU specific densification is needed. Processing technologies for low density foams have been described in [1].

Integrated Waste Mgt. Overview

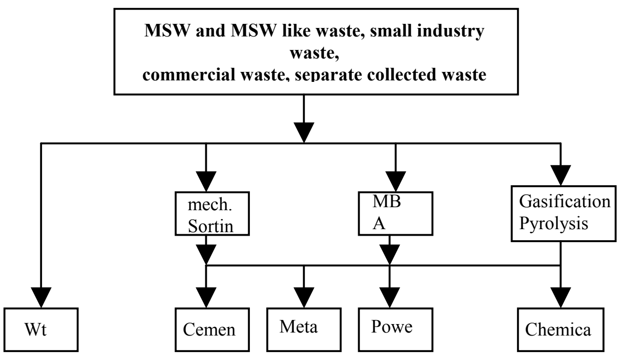

Figure Nr. 3 Integrated Waste Mgt. Overview

The advances standardization of SFR has made and the recognition it received within the last 4 years is [4] remarkable due to the official nature of the European standardization approach under the guidance of CEN. The amount SRF today produced in Europe is about 5 Million t/ 2004.

Technology	Mio t Plastics or SRF	Mio t product	Notes
	Treated or recoverable *	capacity	substitution
WtE	**5**	**47**	
MS	**n.a.**	**?**	**Only seperation**
MBA	**n.a.**	**?**	**No Plastics converted**
TPT	**0.2**		
Steel	**> 1.6 ***	**126**	**(3) , 30 % SRF**
Cement	**> 6.0 ***	**280**	**(4) , 20 %**
Power	**> 1.2 ***	**n.a.**	**(3) , 10 %**
Paper	**> 1.4 ***	**41**	**(6) , 20 %**
OTP	**0.16**	**0.35**	**(5)**

Tables Nr. 1 Technology Overview
Note: * means potential , n.a. not applicable

(3) World crude steel production in 2003, for EU (15) + rest of Europe, ISRI , replacement potential 0.03 ton SRF/ t pig iron
(4) Cembureau 2004 Activity report, 14 % of Global cement production , replacement potential 30 % of 0.12 t coal/ t clinker
(5) Eurolectric 200? Statistics,
(7) Cepi statistics 2001, Western Europe

Waste to Energy (WtE)

The WtE route does recover today in Europe around 0.2 to 0.3 Million tons of PU in the form of energy assuming that maximum 5 % of the plastics is PU and a 10 % plastics content in the various forms: shoe ware, household equipment, bedding, furniture and others which is found in the MSW and the MSW like waste collected from other waste owners.

Mechanical Separation (MS) & Mechanical Biological Treatment (MBA)

The plastic enriched residues coming out of the above mentioned plants MS or MBA are marketed today to a limited extent to the large energy intensity industries as mentioned in Table Nr.3. Large bulky PU items such as furniture, mattress and construction onsite debris residue and PU foam scrap or steel metal facings will enter in separately collected streams to the MS facilities. This is happening today already due to landfill avoidance or restriction regulations in countries such as Austria, Netherlands, Germany, Switzerland,… High PU rich mixed plastic streams have a need for a compacting step. Different densification technologies such as milling, pressing and others are known but need to be built and operated. A high enough demographic density is needed to avoid high transport costs from the MS and MBA facility to the final user such as the cement, power or steel plant.

Thermal Pre-Treatment (TPT)

Two types of thermal pre treatment processes (TPT) pyrolysis and gasification exists. The thermal pre treatment leads mostly to a gaseous product which is piped to the final user. The users could be in the following industries

- **Steel**
- **Cement**

- **Power**
- **Paper**

Large scale examples such as the Contherm process from RWE in Germany [4] with a two train arrangement of 50 kt /year each treatment capacity have been in operation for a number of years successfully, where selected SRF permit is used. The specification limits for the SRF are related to the emission limits of the European waste incinerator (WID) Directive. The first large scale successful gasifier for waste connected to an industrial user is in Ruedersdorf (D) [5] was developed by Lurgi. Specific criteria of SRFs ensure that the operation meets the environmental permit and the strict cement product quality requirement. The cement product quality is an important criteria as the product gas is fed without prior cleaning from impurities to the cement kiln. PU goes in very small and insignificant amounts to these users.

The potential amount of plastics as SRF has been calculated based on practical experience and technical limitations. 20 % substitution potential is assumed for a cement kiln operation. Large differences exist with higher than 25 % for specific operations in Switzerland, Belgium, France and other countries. Differences are more due to company strategy and installed type of kilns. Non ferrous pyro metallurgical processes can also be considered as an outlet but the N-Fe industry. But it is rather difficult to characterize and assess through a simple approach. Experiences with fuel substitution have several companies such as Boliden, Sweden in their Zn- fuming and secondary Pb furnace, Umicore in their precious metal furnace in Belgium at Hobokken as well as others such as Noranda, Canada and Norddeutsche Affinerie, Germany. In the case of the iron/steel production, the substitution potential is based on the oil substitution ratio of 30 % through mixed plastics with some limited amounts of refined SR. For power production the substitution of the hard coal demand is considered at 10 %. In the case of the paper industry the available capacity from recycle paper has been accounted for to estimate the fuel substitution potential. This assessment procedure and the assumption used was based on the fact that non integrated paper mills and stand alone recycle paper mills are net consumer of fuels to supply the heat and electricity need. Additional fuel substitution potential in the paper and board industry would be available.

Other Thermal Processes (OTP)

The number of thermal processes which have been designed, piloted and promoted by engineering companies is rather large. The technical literature is full of positive company news which does support their claim that large scale reliable best available technology (BAT) facilities can be built. But the number of operating plants which have been designed and commissioned by these engineering companies is relatively small. The number of companies which have taken a considerable risk and tried to scale up thermal process unsuccessfully is rather large. The overview of technology will hence be divided into two groups:

I: pilot and small scale operating plants
and
II: commercial operations.

Examples of the group I are summarized in the attachments in table Nr. 6.

Good examples of best available waste technology for the OTP type of route are: High Temperature Gasification in Germany by SVZ, Circulating Fluidized Bed from Lurgi (CFB) in Austria by RVL, CFB from Foster Wheeler in Lahti Finland and the Ebara/UBE type CFBs in Ube, Yamaguchi, Japan as well as the specific gasifiers from Thermoselect in Japan.

Some of the original coal type gasifying equipment are currently being tested for specific types of plastic rich waste. This modification from feeding coal to waste is very time consuming. Demonstration of the fuel preparation step needs to be tested at large scale if the substitution waste type does not match the ignition, gasifying behaviour of coal and slag formation. Examples of large scale plants of this type are Demkolec, Buggenum, NL, Shell, Burlington/Ve, US, Batelle/Ferco and Puertollano, Spain, Krupp-Uhde/Prenflow

	plastics recovered	**capacity**	**Notes**
	Mio t	**Mio t, MW th**	
Demkolec Belgium			plastics investigated
Lathi Finland	0.025	0.05 *, 70 MW_{th}	SRF
SVZ Germany	0.12	0.35	All waste types
RVL Austria		110 MW th	
Citron			Mostly hazardous waste

Tables Nr. 2 Summary of OTP for Waste in Europe
Note: figures are best estimates from the author
* coal equivalent

RECOVERY IN PERSPECTIVE

It is important to note, that the total of 350 kt/year of recovered polyurethane cannot not be compared with the consumption of raw materials in 2004 (approximately 2.5 million t, sold into die business sectors discussed here), because long live applications of polyurethanes result in much smaller amounts of waste in the same year.

Total polyurethane waste is estimated to be about 1.5 million t in 2004, approximate half of which is not suitable for collection and subsequent recycling, because of small volume and/or wide distribution. This waste is best recovered by combustion (incineration with energy recovery) together with municipal solid waste.

The choice of the most suitable option(s) for recycling/recovery is governed by a number of factors that vary from case to case and also from location to location. Some of the most important ones are the properties of the polyurethane to start from, the intended application of the recyclates, and the capacity of the market to absorb die recycled material. Logistics are also frequently of key importance, especially with respect to economics.

The criteria for the selection process can be classified as follows:

(A) Effects on
maintenance/
operation

(B) Existing Permit with respect to
gaseous emissions
feed composition

(C) Influence on
cost and
revenue

(D) Product Quality Influence
product, byproduct
residues for landfill

Table Nr. 3: Input specification limits

is attached and describes the relationship between A,B,C and D and the waste characteristics. An overview of the proposed recovery options for the main applications is shown in table Nr. 4 and as a schematic diagram in table Nr. 7.

This is the reason why maximum advantage for the environment is generally gained by a combination of options that depend strongly on the individual local conditions and may therefore differ from one place to another.

Table Nr. 5: **ESTIMATED TONNAGE OF RECYCLED AND RECOVERED POLYURETHANES (2004) IN W. EUROPE**

Flexible rebond and loose flocks	130 000 t/year*
Pressboards for roads/floors	7 000 t/year
Glycolysis	<1 000 *tlyear*
Powder (oil/chemical binder)	2 000 t/year
Powder in other applications	1 000 t/year
Flocks into insulation	3 000 t/year
Energy recovery in Municipal Solid Waste Combustors	200 000 t/year
In ASR to MSWI	2 000 t/year
Industrial Incineration	1 000 t/year
Industrial Gasification	2 000 t/year
Total appr.	**349 000 t/year**

*65 000 tons in Europe and 65 000 tons in North America

This estimate and the breakdown represent the best knowledge of ISOPA as of 2004. Polyurethane recyclers, collectors, exporters and other stakeholders are all welcome to make use of the ISOPA office for the confidential collection of actual data in the following years.

The estimated market and capacity figures have been given in the best understanding of the situation at present. Interested people and parties should contact the author in case of questions and concerns. The information is given in good faith to support the market and the industry at large.

Abbreviations

APME, in	Association of Plastics Manufacturers Europe
ASR,	automotive shredder residues
BIF	Boiler, Industrial furnaces
BCF	Building & Construction Foam
CEN	European Committee for Standardization
D	Disposal
ELV,	end of life vehicles
EfW	Energy from waste
EOL	End of Life Equipment
FF	Fridge Foam
FB	Fluidized Bed
FR	Flame Retardant Compound
FRH	Halogenated Flame Retardant
FBC	Fluidized Bed Combustor
FGC	Flue Gas Clean up
HM	Heavy Metals
HCF,	high calorific fraction
M	Metals
MPW	Mixed Plastic Waste
MSW	Municipal Solid Waste
PPC	Pulverized Power Plant
N-Fe,	Non ferrous
PCB,	Polychlorinated Biphenyls
SRF,	solid recovered fuel
SR	Shredder Residue
R	Recovery
WEEE,	Waste from Electrical and Electronic Equipment
WtE	Waste to Energy
C,H,N,O,P	Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorus
Br,Cl,F	Halogens
A,B,C,D	Criteria for Technology Selection

REFERENCES

[1] Frank E. Mark, 2002, PU Recovery fir for End of Life Waste Regulations in the European Union, API 2002 # 34

[2] APME Eco-efficiency Study on WEEE, contracted to TNO, Holland

[3] APME Eco efficiency Study on automotive Plastics, contracted to Oeko Institute , Germany

[4] CEN TC 343, Solid Recovered Fuels, Standardization Group

[4] RWE Contherm , Germany, www.rwe.com/generator

[5] Ruedersdorf Cement, Germany

[6] Boliden, Skelleftea, Sweden, www.boliden.com.

[7] Umicore, Hobokken , Belgium www.umicore.com

[8] SVZ, Black Pump, Germany, www.svz-gmbh.de/

[9] RVL, Austria, www.lenzing.com/group

[10]

BIOGRAPHIES

Dr. Frank E. Mark is currently a Research Associate with Dow Europe SA, working on Plastics Recycling related issues in the Environmental Technology Center. During his professional career with Dow he has held various positions: Technical Service for Automotive and Gas Conditioning Chemicals in Horgen, Switzerland and Process Research in Chlorohydrine, Epoxy and Chlorinated Hydrocarbons in Stade, Germany. During a one year assignment in Plaquemine, USA, he was responsible for the process and product research for Dow's Tyrin* Chlorinated Elastomer in Europe.

Waste to Energy

In his present assignment with different industry associations he works on all forms of Plastic Recycling. Energy Recovery in different industries: power, cement , Non-Ferrous etc. and in Municipal Solid Waste combustion is one of his major areas of current activity.

Acknowledgements:

This paper would have not possible without the cooperation of other member company individuals from the associations ISOPA and PlasticsEurope and colleagues from DOW Chemical. A deep appreciation of their contributions cannot be valued enough.

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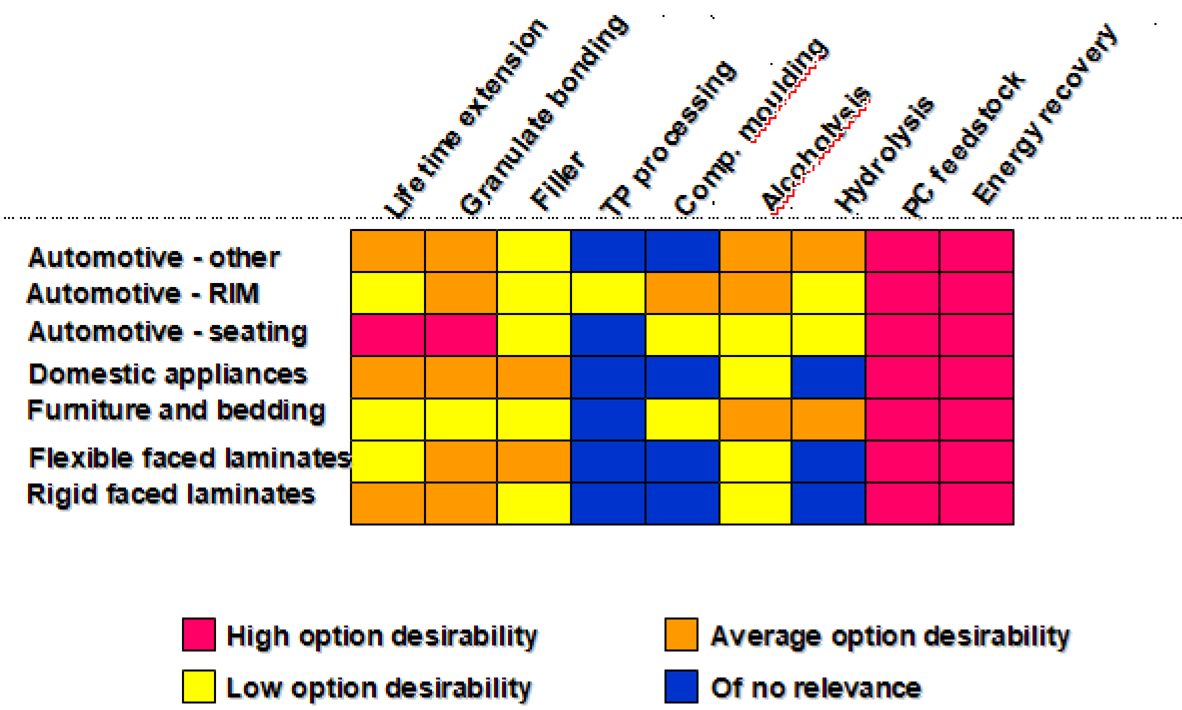
	Gasification	***Pyrolysis***	***MSW Incinerator***	***Cement***	***Power***	***Boilers***
Contents						
C + H	**C,D**	**A,C**				
Water	**A**	**A**				
Inert	**A,C**					
Halogens	**A,C**	**A,C**	**A,C**	**A,C**	**A,C**	**A,C**
Heavy Metals	**C,D**	**A,C,D**	**A,C,D**	**B,C,D**	**A,C,D**	**A,C.D**
Metals	**A,C**			**A,C,D**	**A,C,D**	**A,C,D**
Nitrogen	**??**					
Heat value			**A,C**	**C**	**C**	**C**
Ash						**C**

note: cont. = content

Table Nr. 3 Input specification limits and their influence on operational parameters

Table Nr. 4: Recovery Options for various applications



GASIFICATION	**Company**	**comments**
TwinRec	EBARA www.ebara.co.jp www.ebara.ch	Own gasification development
PreCon	Krupp Uhde Gmbh Sumitomo Heavy Industries Ltd.	Earlier work on Winkler gasifier
Thermoselect	Thermoselect S.A www.thermoselect.com Japan Kawasaki Steel Corporation (now JFE Holdings) http://www.jfe-holdings.co.jp/en/index.html	gasification
TiRec	Alcyon www.alcyon.ch	
Compact Power	Compact Power Limited www.compactpower.co.uk	Bubbling bed type gasification technology
Biosyn	Enerkem www.enerkem.com	
Carbo-V CarboCompact	Choren Industries GmbH www.choren.de	Gasifier
KSK		
Future Energy	Future Energy	Gasifier for liquid/gas dilute phase type
Reshment	Stiftung Autorecycling Schweiz www.stiftung-autorecycling.ch	In pilot phase gasification Voest-Alpine Industrieanlagenbau (VAI) www.vai.at
DM2-Der Blaue Turm	D.M.2 Verwertungstechnologien Dr. Mühlen GmbH & Co. KG www.dm1-2.de DMT	Gasification Bottrop , IPV Pilot phase gasification FH Siegen
PYROLYSIS		
FZK-Verfahren BTL	Forschungszentrum Karlsruhe www.fzk.de	
Recycle 21	www.mitsuibabcock.com	Based on Siemens/KWU 12 plants in operation in JA pyrolysis
PKA	PKA	Siemens/KWU pyrolysis development
BKMI-BABCOCK Krauss Maffei Industrieanlagen	Technip Germany GmbH Babcock Krauss-Maffei Industrieanlagen	Reference plant was Burgau pyrolysis
Techtrade (earlier PLEQ)	Technip www.technip.com www.brz-herne.de	Supplied pyrolysis technology to Contherm
SWERF	Brightstar Environmental	Similar as Compact , still mini plant size
HP-POX	TU Bergakademie Freiberg u. Lurgi Oel-Gas-Chemie GmbH	

Table Nr. 6 OTP examples and in development

Table 7: Options for Polyurethane Recycling and Recovery

PUR

Repair and re-use	typical long life products, e.g. building panels, can be re-used. Upholstery furniture can be refurbished
Mechanical Recycling	
Rebonding	*see Fact Sheet: "Densification/Grinding"* *see Fact Sheet: "Rebonded Flexible Foam"* many applications in various sectors
Compression moulding	*see Fact Sheet: "Compression Moulding"* Many application in automotive Moulded panels from up to 100% Recyclate
Regrind/Powdering	*see Fact Sheet: "Regrind/Powdering"* Powder to be added in new formulations Applicable for soft and rigid powders.
Thermoplastic reprocessing	for all thermoplastic polyurethane grades.
Chemical Recycling	*see Fact Sheet: "Chemolysis"* Hydrolysis Aminolysis Glycolysis To produce regenerated polyols
Feedstock Recycling	*see Fact Sheet:" Feedstock Recycling"* Polymer to be broken down to Hydrocarbon units or constituent monomers, raw materials for petrochemical processes.
Pyrolysis	→ Hydrocarbons, fuels
Blast Furnace	→ Iron
Gasification	→ Methanol, raw materials
Hydrogenation	→ Syncrude
Energy Recovery	*see Fact Sheet :"Energy Recovery"* *see Fact Sheet: "Energy Recovery from Flexible PU Foams"* Most appropriate waste management option Versatile industrial sized technologies Recovering "parked energy"- content (Replacing fossil fuels) Municipal solid waste incinerators Power stations Process energy