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Distributed Microwave Pyrolysis of Domestic Organic Waste

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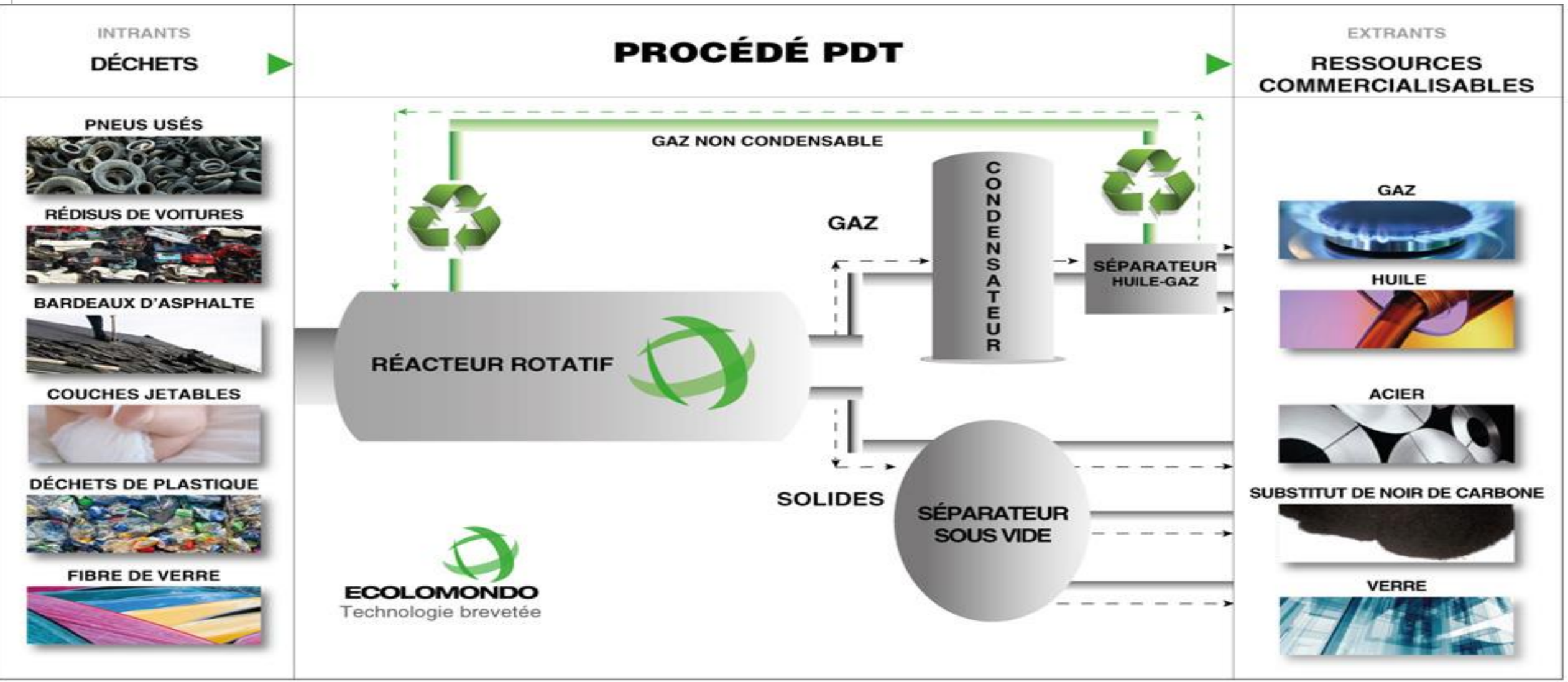
Pyrolysis: Ecolomondo … IPO

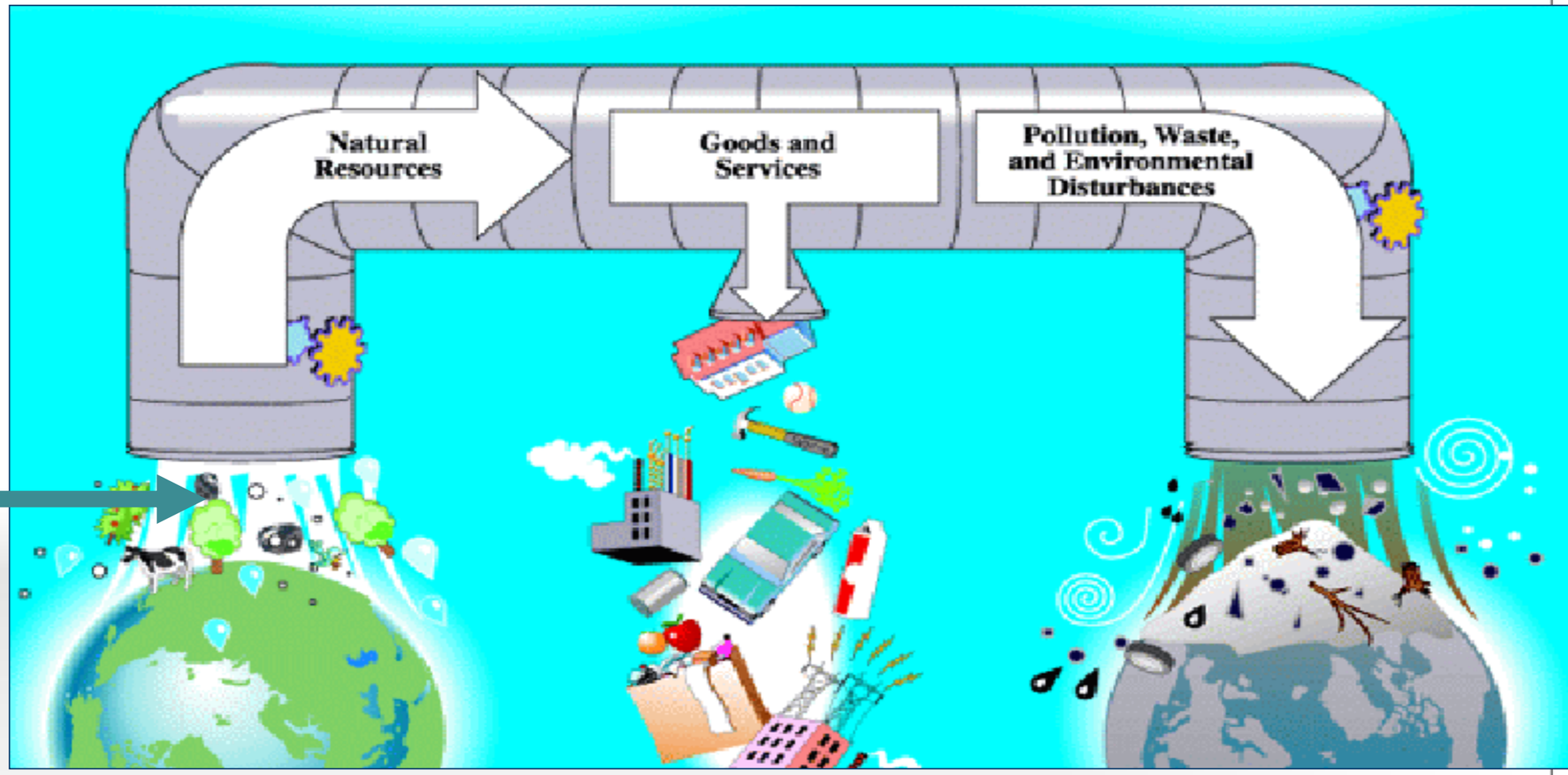


Semi-Batch Horizontal Rotary Reactor

Non-sustainable mankind

Only 25 wt% of what goes into the pipe comes out as goods and services

(Source: World Resource Institute)



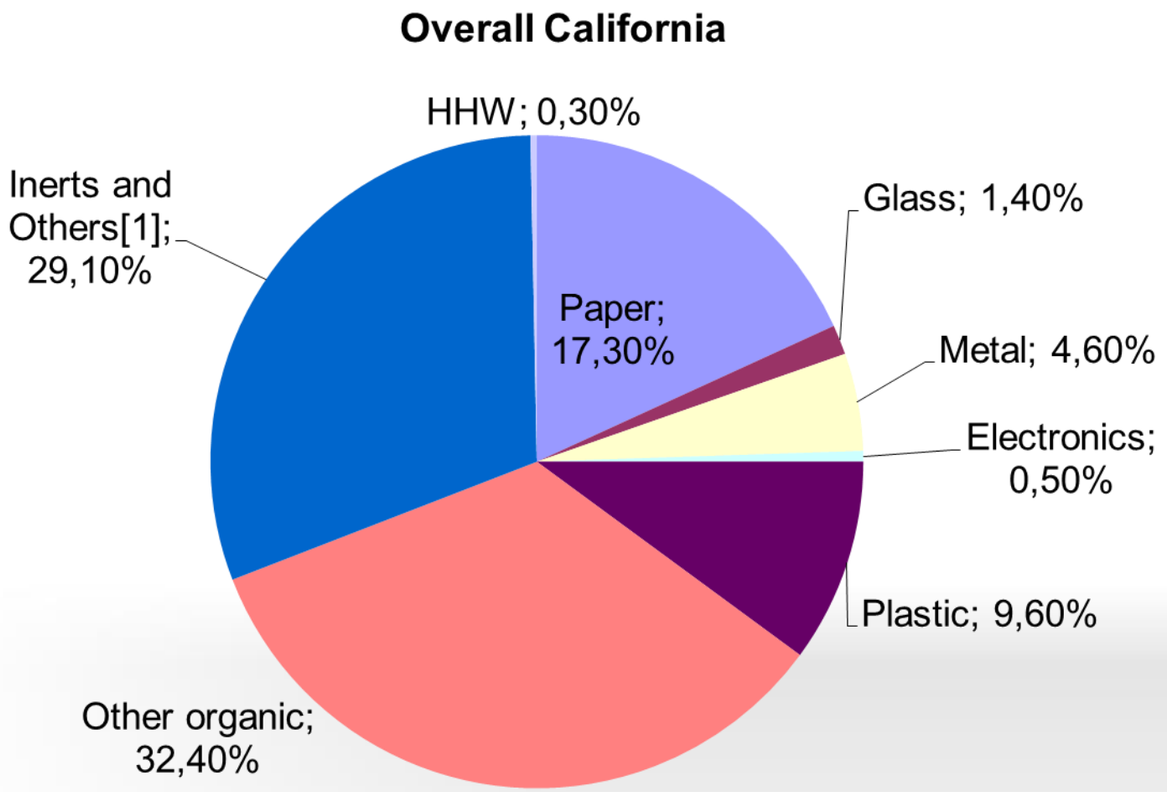
Yesterday, waste was a problem.
Today, it is a valuable resources

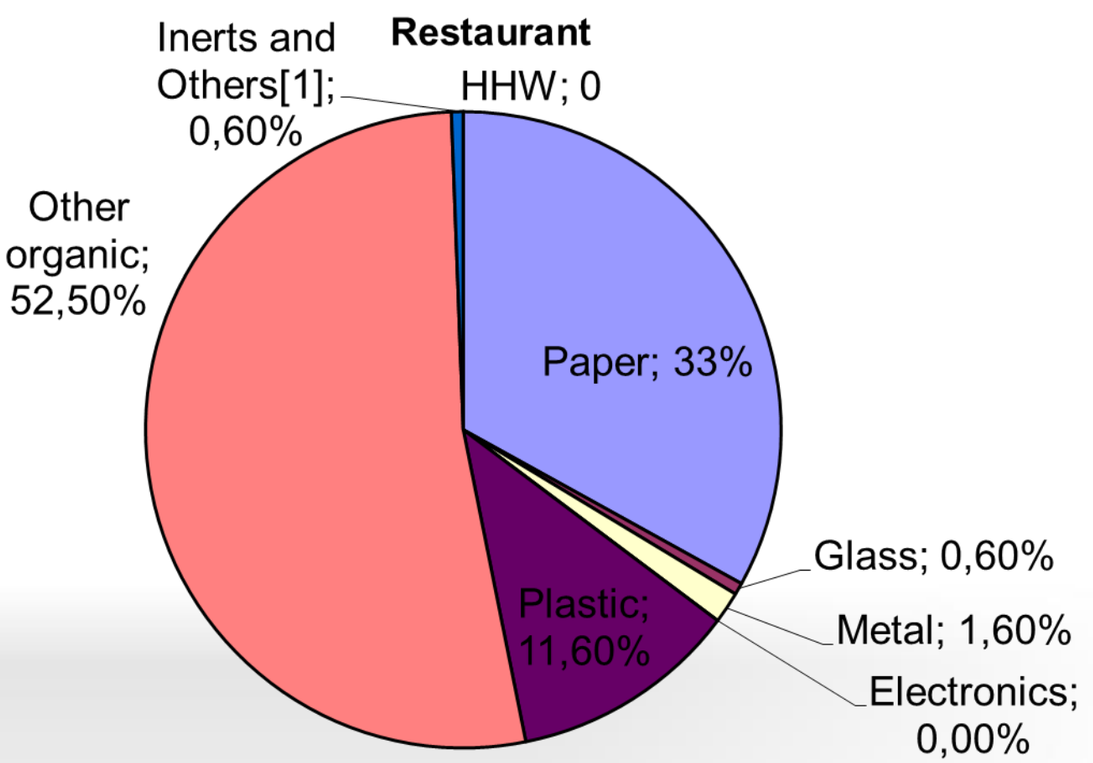
Waste deposit worldwide

Region	MSW Generation rate (Ton/cap/y)	Fraction of MSW disposed to SWDS	Fraction of MSW incinerated	Fraction composted	Fraction of other MSW management (e.g. recycling)
Asia					
Eastern Asia	0.37	0.55	0.26	0.01	0.18
South-Central Asia	0.21	0.74	-	0.05	0.21
South-East Asia	0.27	0.59	0.09	0.05	0.27
Africa	0.29	0.69	-	-	0.31
Europe					
Eastern Europe	0.38	0.90	0.04	0.01	0.02
Northern Europe	0.64	0.47	0.24	0.08	0.20
Southern Europe	0.52	0.85	0.05	0.05	0.05
Western Europe	0.56	0.47	0.22	0.15	0.15
America					
Caribbean	0.49	0.83	0.02	-	0.15
Central America	0.21	0.50	-	-	0.50
South America	0.26	0.54	0.01	0.003	0.46
North America	0.65	0.58	0.06	0.06	0.29
Oceania	0.69	0.85	-	-	0.15

Adapted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 2).

Some waste is poorly divertible





Waste disposal and Diversion Findings for Selected Industry Groups, 2006

Statistique SUR LES déchets alimentaires

Source

- 3,6 GTonnes/année (3,6 billions) de déchets alimentaires sont jetés chaque année à l'échelle mondiale
- 7% sont recyclé pour autre chose que l'enfouissement (composte)
- Le reste est enfoui dans des sites d'enfouissement (beaucoup de transport…)

- Et si tous ces déchets étaient convertis en énergie…
- Remplaceraient l'énergie utilisée par 31% des ménages aux États-Unis
- Réduirait l'équivalent d'émissions des gaz à effet de serre (carbon offset) de 61 millions d'automobiles

Large scale: pyrolysis/gasification/combustion

Statistique SUR LES déchets alimentaires

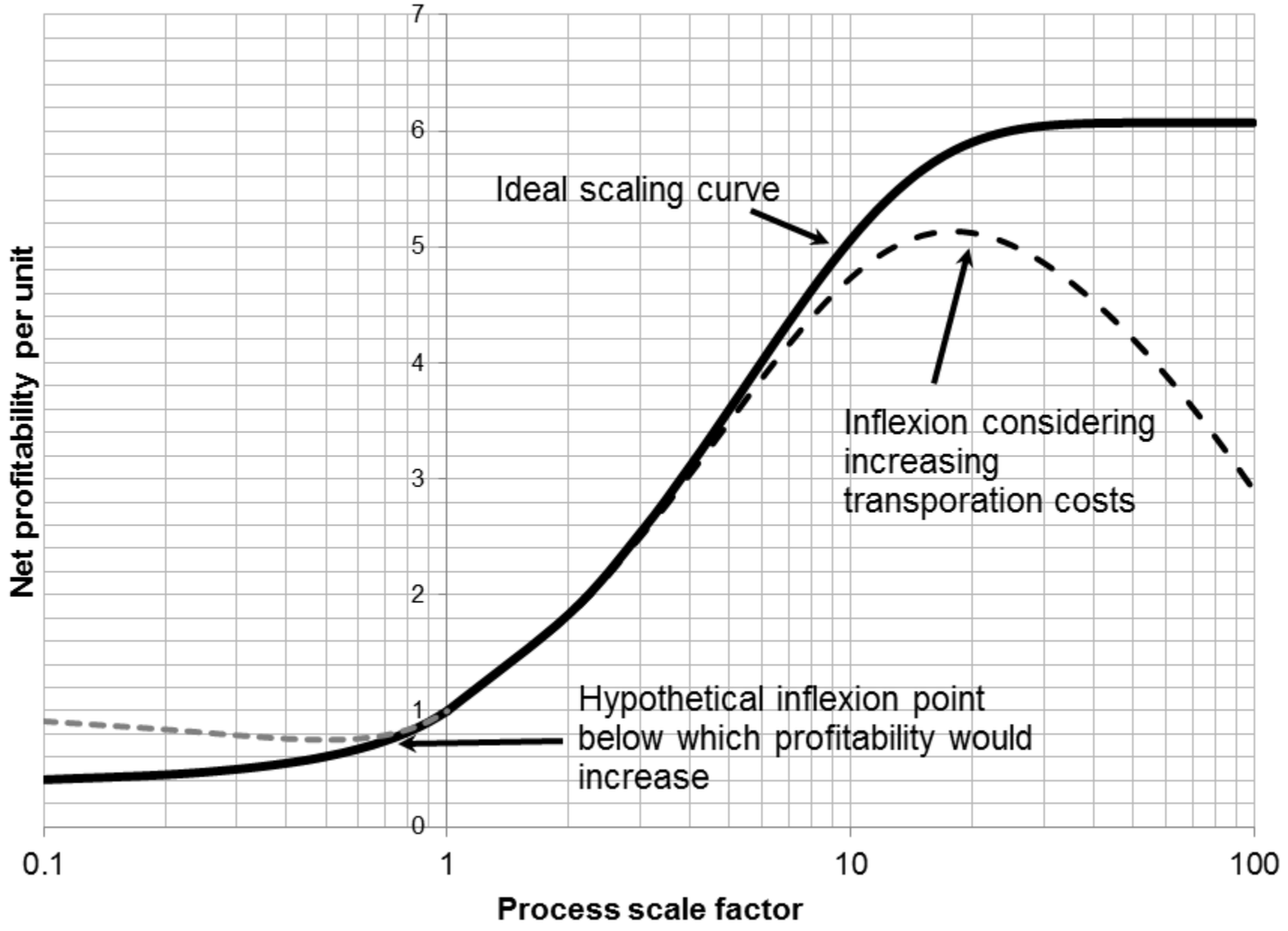
- **Transport**

- Les déchets sont déplacés mondialement pour l'équivalent de…

  - 1,5 millions de fois la distance aller-retour entre la Lune et la Terre
  - 10 000 fois la distance aller-retour entre Mars et la Terre chaque année (ne comprend pas les fausses septiques)

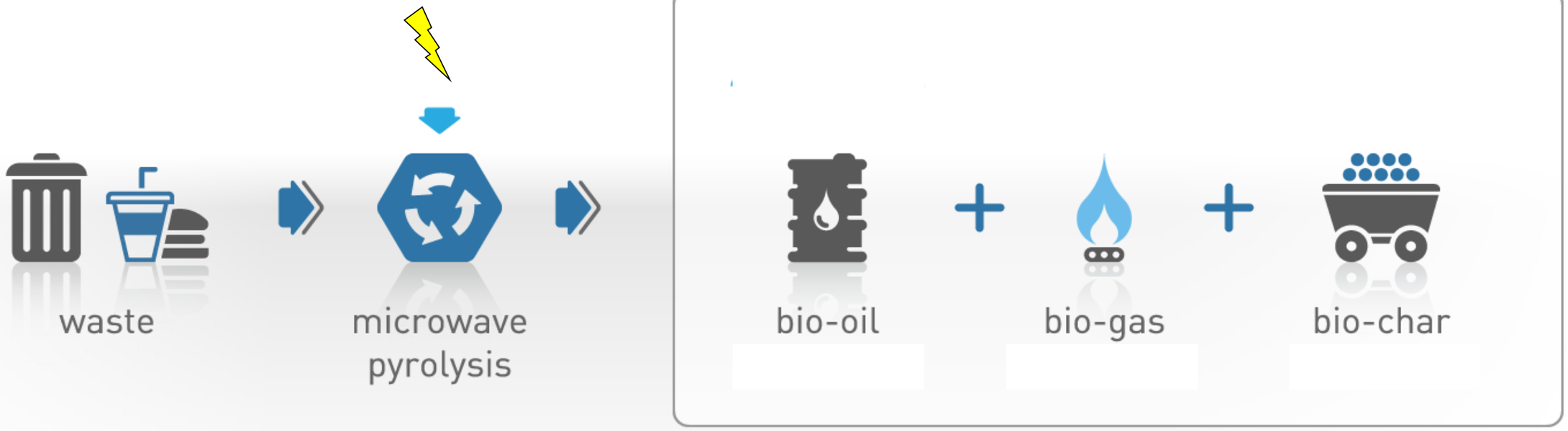
- 25% de la production mondiale d'essence est utilisée pour le transport des déchets alimentaires (ne comprend pas les fausses septiques)
- C'est l'équivalent d'environ 145 millions d'automobiles en gaz à effet de serre

Towards a distributed small scale conversion approach



$$I_1 / I_2 = (Cap_1 / Cap_2)^f$$

Local conversion



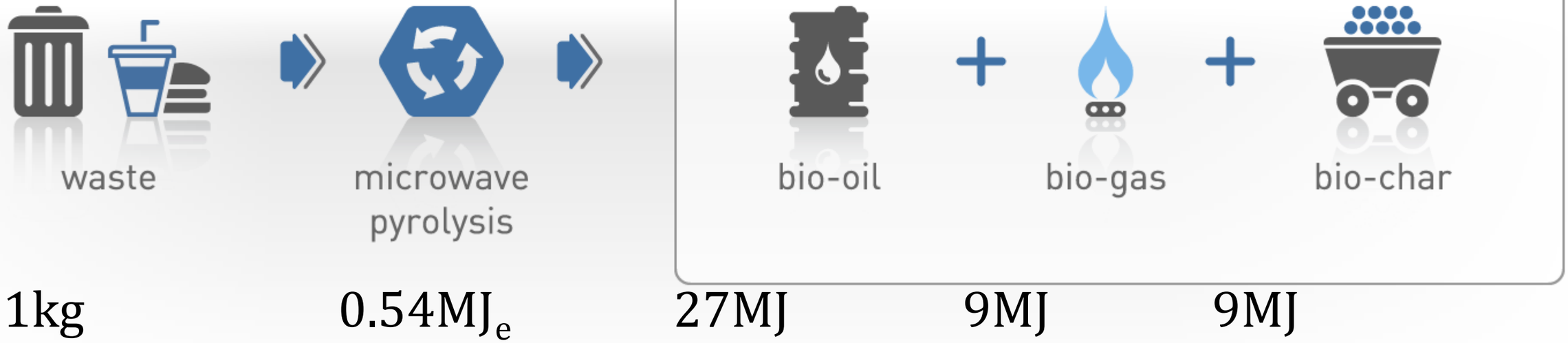
PYROWAVE Apparatus

Segment of waste addressed

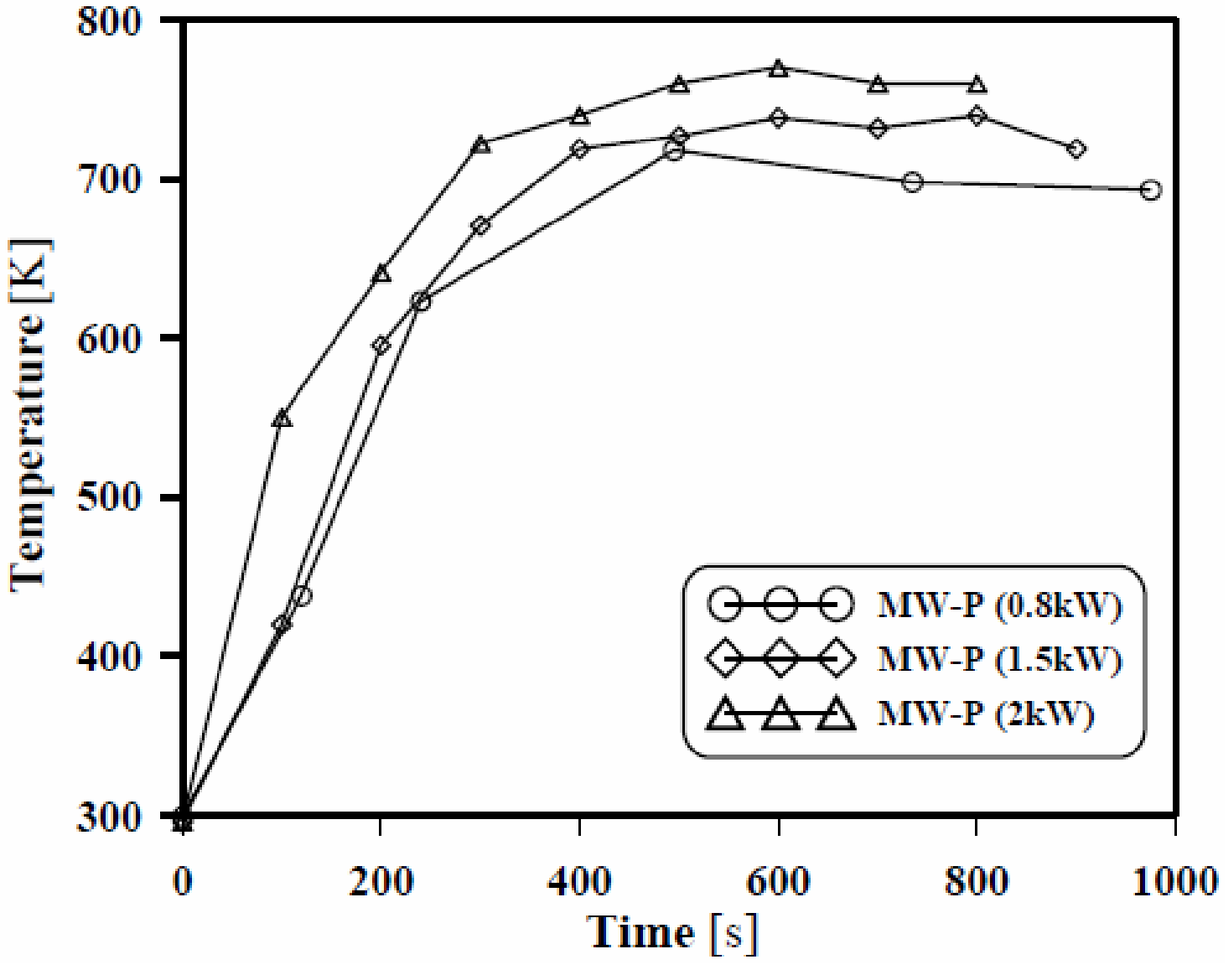
- Typical restaurant disposes 26 tons/year
- Poorly diverted
  - Around 31%-33%
- Long term availability

/ waste converting process

the quantities:



Experimental results



By products

Table 3: Pyrolysis products distribution

Materials	Number of experiments	Product distribution (wt%) within 90% confidence interval		
		Solid	Liquid	*Gas*
Polystyrene	6	19 ± 2	71 ± 3	*9 ± 4*
Paper	6	28 ± 7	19 ± 6	*53 ± 5*
Meat	6	15 ± 9	57 ± 7	*28 ± 10*
Equal mix	2	21 ± 13	57 ± 8	*22 ± 5*
Restaurant mix	2	11 ± 9	66 ± 35	*23 ± 45*

By products

Table 5: Liquid product water content

Materials	Water content in oil [wt%]	Water content due to feedstock	Fraction of water in oil due to feedstock
Polystyrene	4.80	4.9% ± 0.1%	100% ± 4%
Paper	55.35	14% ± 3%	26% ± 12%
Meat	77.75	50% ± 1%	60% ± 30%
Equal mix – oil 1	84.00		
Equal mix – oil 2	39.25		
Restaurant mix – oil 1	83.30		
Restaurant mix – oil 2	32.60		

Materials	Liquid product (native)				Liquid product (water removed)				
	N	C	H	S	N	C	H	S	O^2
Polystyrene	0.55	86.64	8.44	0.00	0.58	91.01	8.87	0.00	*-0.45*
Paper	0.1	19.02	9.79	0.00	0.22	42.60	21.93	0.00	*35.25*
Meat	0.9	4.21	11.16	0.00	4.04	18.92	50.16	0.00	*26.88*
Equal mix – oil 1	0.4	3.43	11.05	0.00	2.50	21.44	69.06	0.00	*7.00*
Equal mix – oil 2	0.11	6.07	11.16	0.00	0.18	9.99	18.37	0.00	*71.46*
Restaurant mix – oil 1	0.74	3.94	11.24	0.00	4.43	23.59	67.31	0.00	*4.67*
Restaurant mix – oil 2	1.57	57.54	10.46	0.00	2.33	85.37	15.52	0.00	*-3.22*

Chemical identification

Table 9: Liquid product chemical composition (water removed)

Species	Composition (mg/L) Polystyrene	Paper	Meat
Acetic acid	1050 - 1489	3509-28288	<400-2451
Toluene	8857 - 17376	<9	396-3785
Propionic acid	525	3121-6195	<200-2821
Ethylbenzene	2871 - 12089	<15-202	388-2046
Styrene	267836 - 389634	1162-1376	5356-30744
Butyric acid	525 - 525	<90	<200-1431
Furfural	n.d.	15305-38172	532-1077
Isopropylbenzene	n.d.	n.d.	n.d.
Cyclopropylbenzene	437 - 846	n.d.	28-308
α -Methylstyrene	10492 - 20408	n.d.	728-4405
Propenylbenzene	481 - 1066	n.d.	n.d.-56
3-Butylbenzene	143 - 321	n.d.	n.d.
5-Methylfurfural	n.d.	3562-4847	n.d.
α-Ethylstyrene	106 - 232	n.d.	n.d.-32
Styrene dimer	43379 - 45586	n.d.	180-4031
Levoglucosan	n.d.	5299-9550	256-444
Oleic acid	n.d.	n.d.	n.d.-841
Styrene trimer	33650 - 30661	n.d.	72-1815

	Equal mix - oil 1	Equal mix - oil 2	Restaurant mix - oil 1	Restaurant mix - oil 2
Acetic acid	34688-39949	1361-1767	12542-17563	< 1792
Toluene	<35-10546	46542- 55001	n.d. <37	18281-25976
Propionic acid	4424-7898	n.d. <531	3337-4688	n.d. <896
Ethylbenzene	<35-3852	96158- 112056	n.d. <37	35832-60015
Styrene	1368-26852	631039- 631788	840-884	159337-199973
Butyric acid	<347-983	6059- 7867	574-847	955-1273
Furfural	4701-6733	n.d.	316-681	n.d.
Isopropylbenzene	n.d.	4247- 4510	n.d.	1957-3439
Cyclopropylbenzene	n.d.-102	1980- 2690	32-49	1169-1629
□-Methylstyrene	n.d.-1949	47705- 48614	49-53	15364-20844
Propenylbenzene	n.d.	2677- 3337	n.d.	1212-1638
3-Butylbenzene	n.d.	872- 1320	n.d.	1269-1873
□-Ethylstyrene	n.d.-216	492- 695	95-125	328-447
Styrene dimer	n.d.-2102	54739- 88983	83-95	17360-19846
Levoglucosan	6097-8108	n.d.	3758-5715	n.d.
Oleic acid	n.d.	n.d.	n.d.	n.d.
Styrene trimer	n.d.-489	45796- 71001	n.d.	23982-24240

Table 10: Nitrogen based compounds found in meat derived bio-oil

Chemical	ppm
propanamide	390
3-methylbutanamide	462
benzènenitrile	477
hexadecanenitrile	944
9-octadecenamide	959
octadecanamide	262
indole	1190
4-méthylpentanamide	528
benzènepropanenitrile	364

Conclusion

- We presented the rationale behind distributed waste pyrolysis
  - Transportation costs, other economies of scale
- We demonstrated that microwave pyrolysis is a suitable candidate technology for distbuted treatment of waste

the sum of small contributions provides
the foundation of a profitable business