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Aida Grga  
Master of Conservation-Restoration



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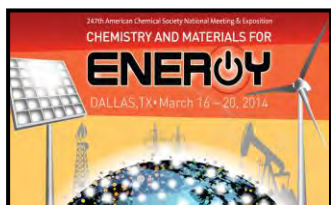
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Thursday, March 13, 2014

“Detecting Bioterrorism: Is Chemistry Enough?”

**Dr. Kristin Omberg**, Los Alamos National Laboratory  
**Dr. Darren Griffen**, University of Kent



Monday and Tuesday, March 17-18, 2014

“Exclusive Access to Experts from the ACS National Meeting”

**2pm ET:** The Chemistry of Solar Energy: Materials for Conversion of Light to Electricity

**5pm ET:** The Kavli Foundation Emerging Leader in Chemistry Lecture with Dr. Emily Weiss

**6pm ET:** The Fred Kavli Foundation Innovations in Chemistry Lecture with Dr. John A. Rodgers

**And much more....**

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Advancing Chemistry, Innovating for Sustainability

## 18th Annual Green Chemistry & Engineering Conference

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April 30, 2014  
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## From Waste to Wealth Using Green Chemistry

Dr. Joseph Fortunak  
Howard University

James Clark

Dr. Avtar Matharu

Dr. Andrew Hunt

Lucie Pfaltzgraff

\* All Speakers  
Green Chemistry Centre of  
Excellence, University of York

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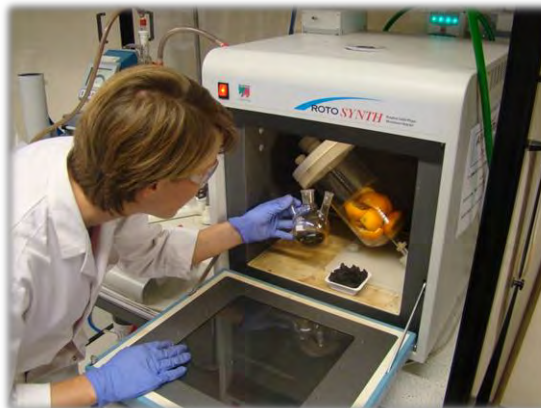
## From Waste to Wealth Using Green Chemistry

James Clark

Avtar Matharu

Andrew J. Hunt

Lucie A. Pfaltzgraff



Green Chemistry Centre of Excellence  
Department of Chemistry  
University of York, UK

[www.york.ac.uk/greenchemistry](http://www.york.ac.uk/greenchemistry)

## Who Are We?



**James Clark** is Professor of Chemistry and Director of the Green Chemistry Centre of Excellence at the University of York where he runs a large team researching bio-renewables, waste valorization and sustainable chemistry. He has distinctions including medals from the Royal Society of Chemistry, the Society of Chemical Industry and an honorary doctorate from the University of Gent. He has about 400 research articles and many edited books.

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## Who Are We?



**Dr. Avtar Matharu** is Deputy Director of the Green Chemistry Centre and Scientific Leader for Renewable Materials Technology Platform. His background is synthetic organic chemistry relevant to design, synthesis and characterisation of functional materials such as liquid crystals and ultra-high capacity optical data storage media. His research now focuses on technological innovations in green and sustainability chemistry.

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## Who Are We?



**Dr. Andrew J. Hunt** is scientific leader of the natural solvent technology platform at the Green Chemistry Centre. His research interests include elemental sustainability, solvents and supercritical fluids. His work on the recovery of polyvinyl alcohol from waste LCD's received significant attention including a press conference at the ASC green chemistry conference, Washington DC, June 2010. He has recently edited a book on "Elemental recovery and sustainability" as part of the RSC Green Chemistry book series.

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## Who Are We?



**Lucie A. Pfaltzgraff** is a PhD student at the Green Chemistry Centre under the supervision of Professor James Clark. Her research interests include the valorisation of food supply chain waste as a valuable biorefinery feedstock, mapping the availability and studying the cost effectiveness of this resource. Her project focuses on the use of low temperature microwave processes for the combined extraction of citrus peel compounds.

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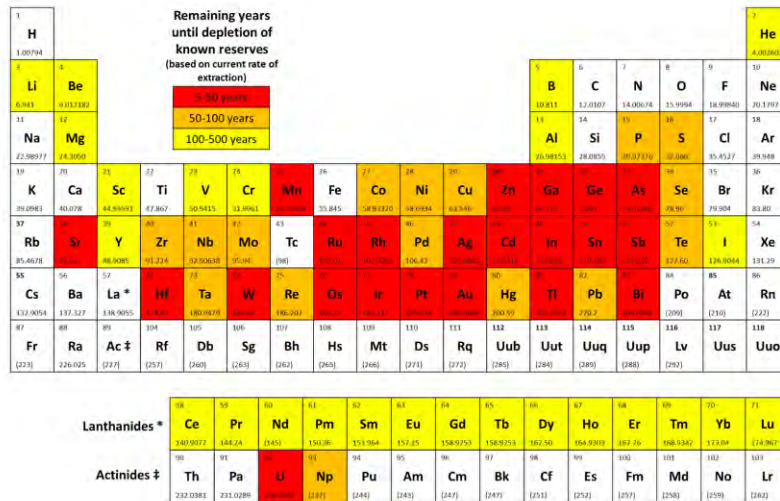
# Benefits of Chemicals - Everywhere!



But we are running out of key resources...

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## Elemental unsustainability



- Research
- Industry
- Networking
- Education

And it's getting worse

18

A. J. Hunt, T. J. Farmer, J. H. Clark, Elemental Sustainability and the Importance of Scarce Element Recovery, in Element Recovery and Sustainability, Edited by A. J. Hunt, RSC publishing, Cambridge (UK), 2013, 1–28.

**Because we turn elements  
from a resource to a product  
and then to a waste....**

Research

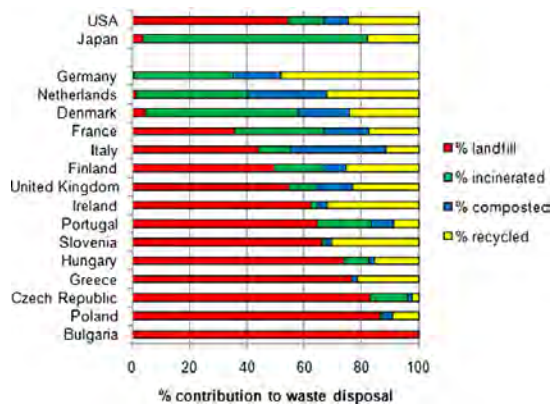
Industry

Networking

Education

19

**What do we do with our waste?**



**And this does not include the waste we don't "manage"  
that is destroying our environment...what a waste!**

Research

Industry

Networking

Education

20

J. R. Dodson, A. J. Hunt, H. L. Parker, Y. Yang and J. H. Clark, Elemental sustainability: Towards the total recovery of scarce metals, Chem. Eng. Process., 2012, 51, 69–78

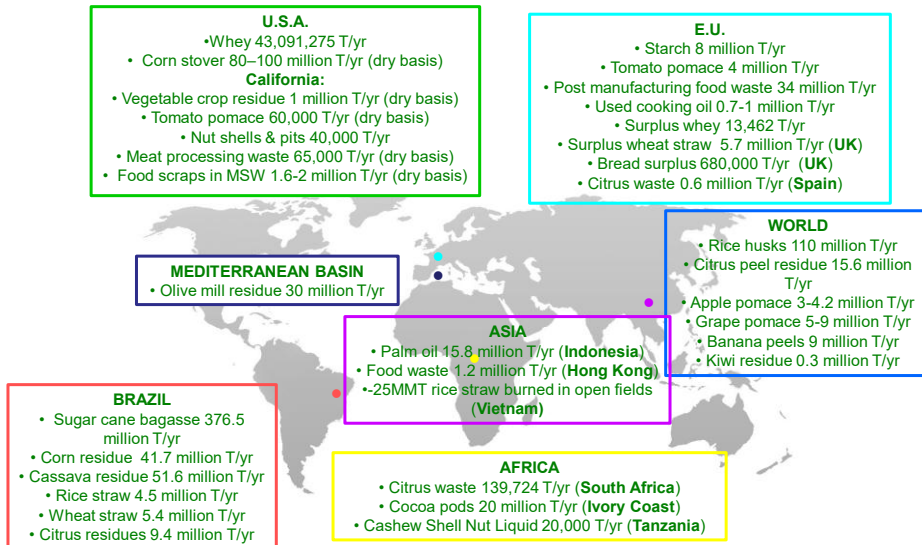
## Instead of a problem, waste can become tomorrow's resource



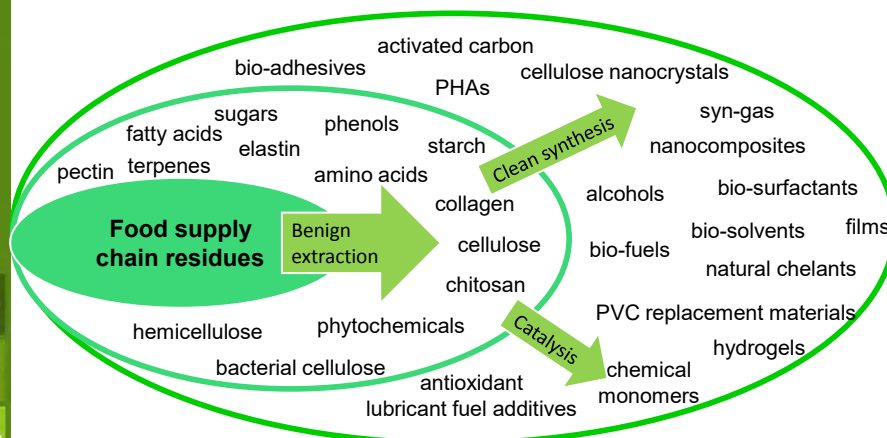
*But we must use green technologies*

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## 2014 = European Year of Food Waste



## Chemicals from Food Waste



S. K. C. Lin *et al.*, *Energy Environ. Sci.*, 2013, 6, 426-464.

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## Question for the Audience

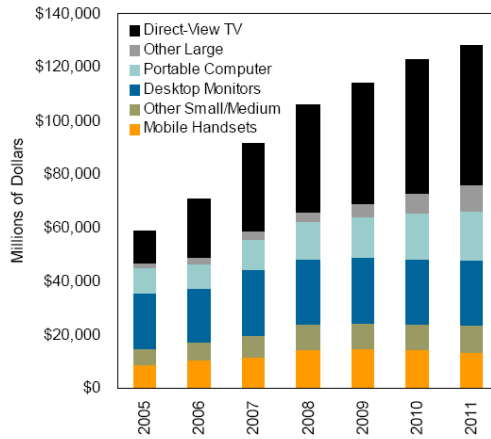
### Making Metals Sustainable

**What is the best option to ensure the sustainability of key processes and products that depend on metals we are running out of?**

- Improve recycling
- Find new virgin sources of the metals
- Develop replacements
- Another solution?

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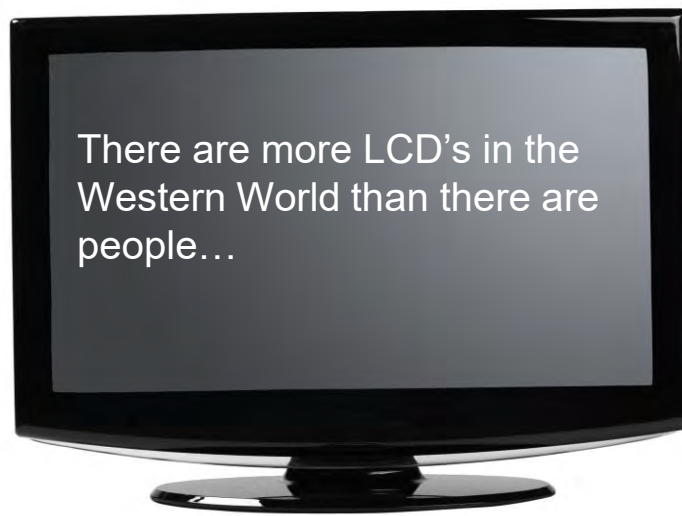
## LCD E-WASTE



- Sales revenue >\$100 billion (2011)
- >100 Mill. LCD TV's sold 2011/12
- LCD TV largest growth area
- >220 million m<sup>2</sup> LCD glass sold (2012)

25

## LCD E-WASTE



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## LCD E-WASTE

- Research
- Industry
- Networking
- Education



WEEE DIRECTIVE (2002/96/EC)  
 "LCD containing WEEE with a surface area greater than **100 cm<sup>2</sup>** and those with **Hg containing** backlights must be isolated..."

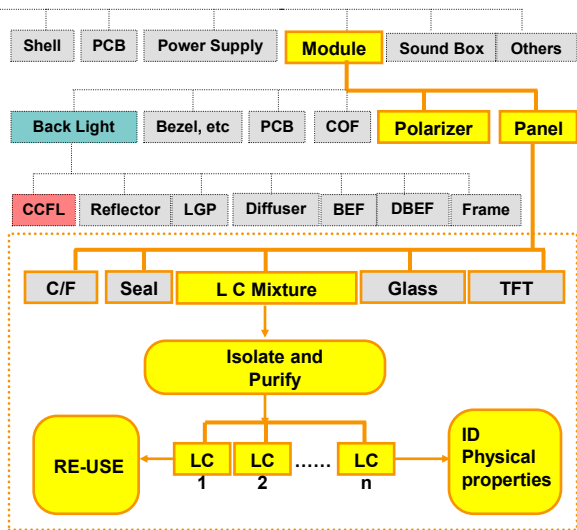
LCD CONTAINING WEEE IS THE **FASTEST GROWING** WASTE SOURCE IN THE EU

LCs classified as non-hazardous (waste code number 16 02 16)

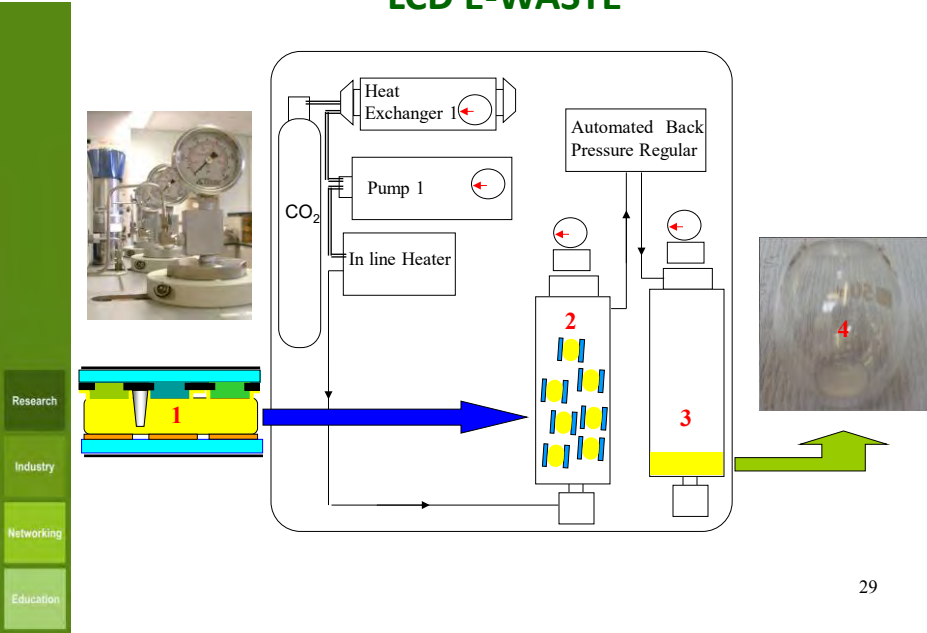
**CURRENT PRACTICE: Remove Hg Lamp and shred the rest**

## LCD E-WASTE

- Research
- Industry
- Networking
- Education



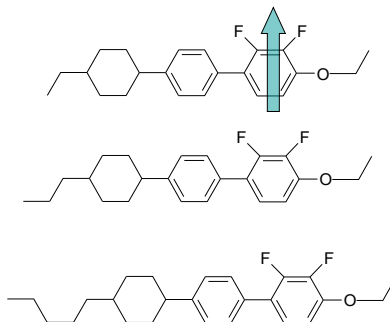
## LCD E-WASTE



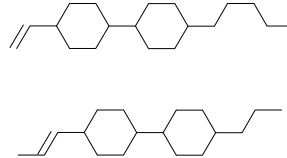
29

## LCD E-WASTE

### VAN LCDTV



### VAN and IPS LCDTV

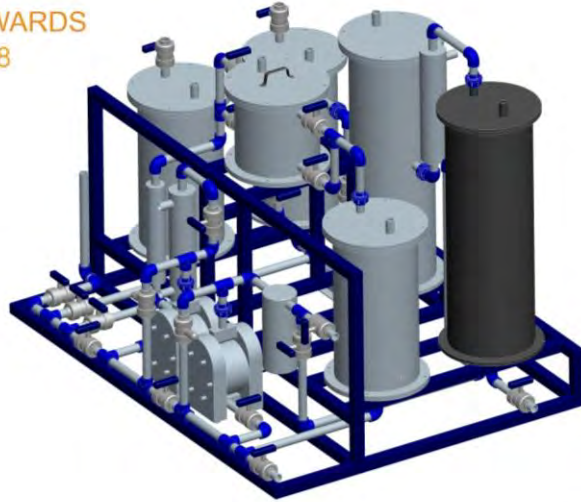


30



# LCD E-WASTE

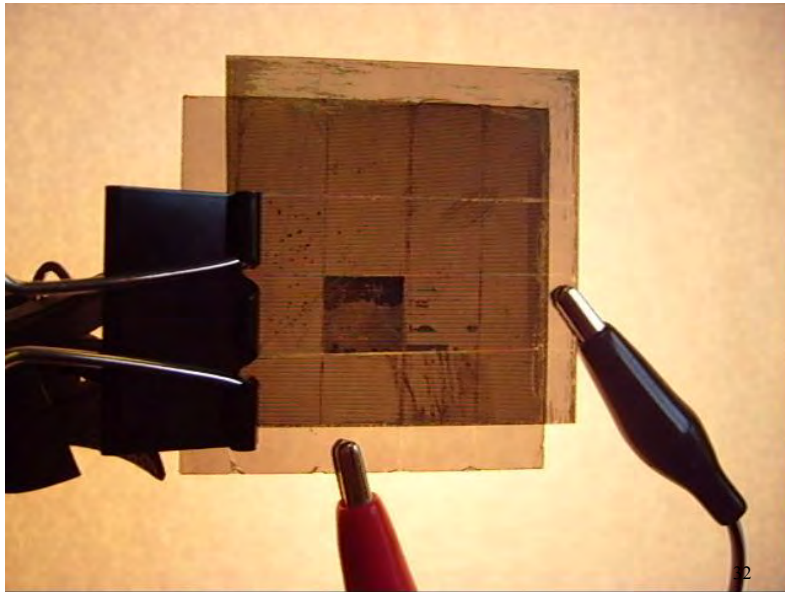
**RUSHLIGHT AWARDS**  
WINNER 2008



31 -XXX+0.1  
-XXX+0.01  
-XXX+0.001  
ANG. +0.5

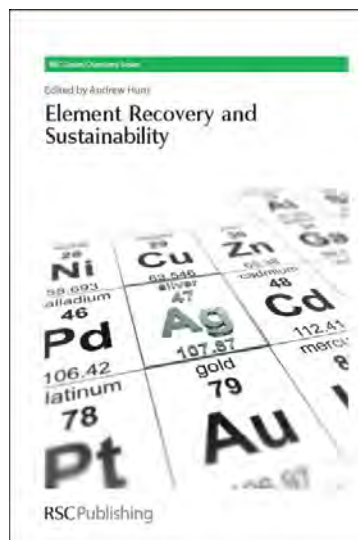
- Research
- Industry
- Networking
- Education

# LCD E-WASTE



- Research
- Industry
- Networking
- Education

## Elemental Sustainability



• Elemental sustainability is a concept whereby the sustainability of each element in the periodic table is guaranteed.

• For an element to be sustainable, its use by this current generation should not impair or restrict future generations from also utilising that same element.

• **Exciting new book now available!**

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## Elemental Sustainability

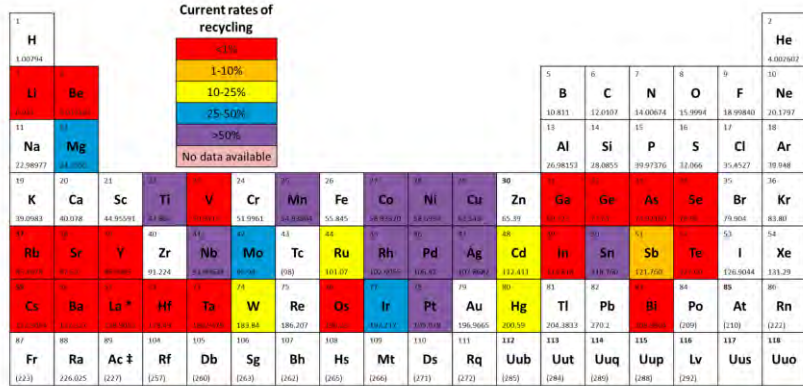
Remaining years until depletion of known reserves (based on current rate of extraction)

1																	2				
H																	He				
1.00714																	4.002602				
3	4															6	7	8	9	10	
Li	Be															B	C	N	O	F	Ne
6.941	9.012182															10.811	12.0107	14.00674	15.9994	18.99840	20.1797
11	12															13	14	15	16	17	18
Na	Mg															Al	Si	P	S	Cl	Ar
22.98977	24.3050															26.98153	28.0855	30.97376	32.066	35.4527	39.948
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36				
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
39.0983	40.078	44.95591	47.867	50.9415	51.9961	54.93804	55.845	58.93320	58.93324	63.546	65.38	69.723	72.6305	74.9216	78.96	79.904	83.80				
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54				
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe				
85.4678	87.62	88.90625	91.224	92.90638	95.94	(98)	101.07	(101.07)	106.42	(107.8682)	(112.411)	(114.818)	(118.710)	(127.6)	(127.604)	(131.29)	(131.29)				
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72				
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
132.9054	137.327	138.9055	178.49	180.9479	183.84	186.207	190.23	192.225	195.084	196.967	200.59	204.384	207.2	208.9804	(209)	(210)	(222)				
87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104				
Fr	Ra	Ac ‡	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Lv	Uus	Uuo				
(223)	(226.025)	(227)	(261)	(262)	(263)	(264)	(265)	(266)	(267)	(268)	(269)	(270)	(271)	(272)	(273)	(274)	(275)				
58	59	60	61	62	63	64	65	66	67	68	69	70	71								
Lanthanides*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu							
	140.9077	144.24	(145)	150.36	151.964	157.25	158.9254	158.9254	162.50	164.9303	167.26	168.9342	173.04	174.967							
90	91	92	93	94	95	96	97	98	99	100	101	102	103								
Actinides ‡	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr							
	232.0381	231.0369	(238)	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)							

34

A. J. Hunt, T. J. Farmer, J. H. Clark, Elemental Sustainability and the Importance of Scarce Element Recovery, in Element Recovery and Sustainability, Edited by A. J. Hunt, RSC publishing, Cambridge (UK), 2013, 1–28.

# Elemental Recycling



- Research
- Industry
- Networking
- Education

**Lanthanides\***

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
140.12	140.907	144.24	144.9126	150.36	151.964	157.25	158.9253	162.50	164.9303	167.259	168.9304	173.054	174.967

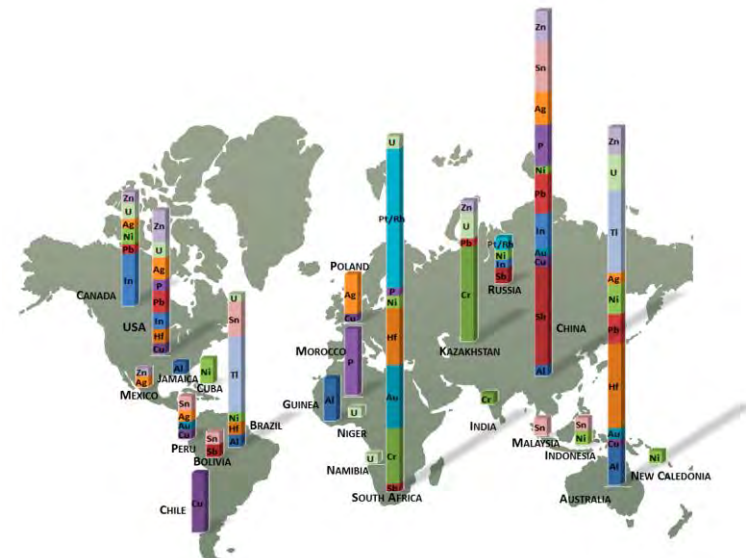
**Actinides‡**

Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.0377	231.0369	238.0289	237	244	243	247	247	251	252	257	258	259	262

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A. J. Hunt, T. J. Farmer, J. H. Clark, Elemental Sustainability and the Importance of Scarce Element Recovery, in Element Recovery and Sustainability, Edited by A. J. Hunt, RSC publishing, Cambridge (UK), 2013, 1–28.

# Elemental Sustainability



- Research
- Industry
- Networking
- Education

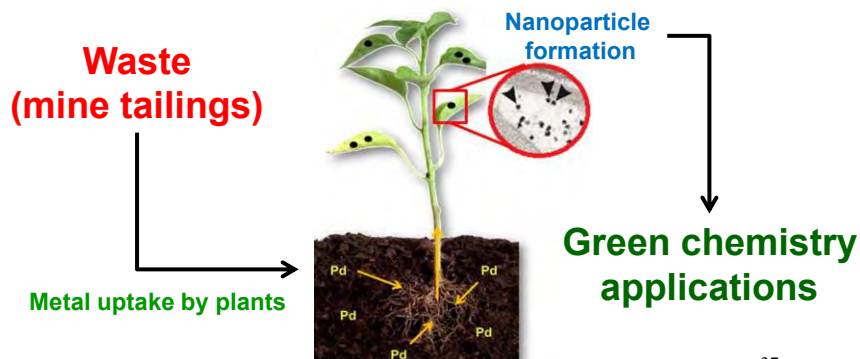
36

A. J. Hunt, T. J. Farmer, J. H. Clark, Elemental Sustainability and the Importance of Scarce Element Recovery, in Element Recovery and Sustainability, Edited by A. J. Hunt, RSC publishing, Cambridge (UK), 2013, 1–28.

# PHYTOCAT

Catalysing the Growth in  
Metal Recovery

**AIM:** Capture metals in plants via **phytoremediation** and utilise this trapped metal **insitu** for catalysis, focusing on the platinum group metals.



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A. J. Hunt, C. W. N. Anderson, N. Bruce, A. Muñoz García, T. E. Graedel, M. Hodson, J. A. Meech, N. T. Nassar, H. L. Parker, E. L. Rylott, K. Sotiriou, Q. Zhang and J. H. Clark, Phytoremediation as a tool for green chemistry, *Green Process Synth.*, 2014, 3, 3–22

## PHYTOCAT Project

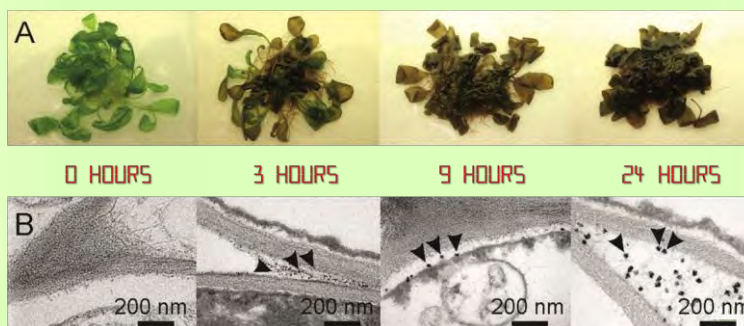
### Metal uptake:

*Arabidopsis thaliana* plants grown hydroponically until 3 weeks old...



### Nanoparticle formation:

...plants were dosed with aqueous solution of  $K_2PdCl_4$  & monitored over 24 hours...



38

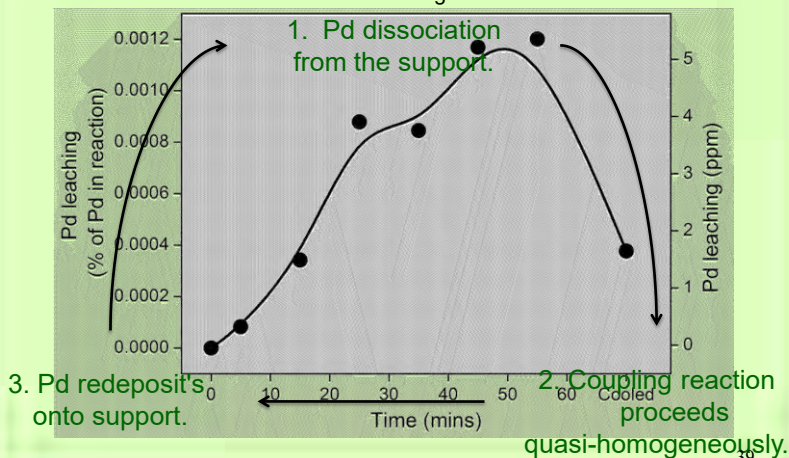
H. L. Parker, E. L. Rylott, A. J. Hunt, J. R. Dodson, A. F. Taylor, N. C. Bruce and J. H. Clark, *Plos One*, 2014, DOI: 10.1371/journal.pone.0087192



## PHYTOCAT Project

### Pd leaching & mechanism of activity:

...an investigation into the catalyst mechanism was carried out by monitoring Pd leaching...

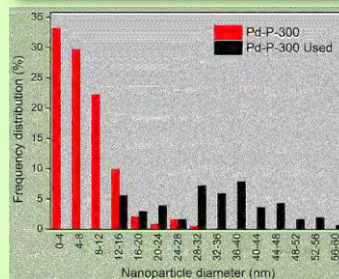
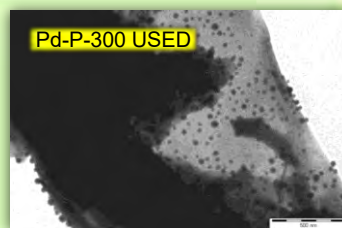
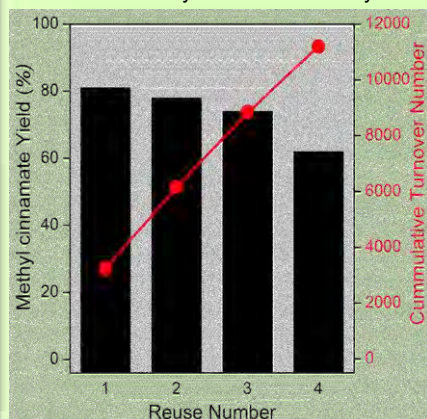


H. L. Parker, E. L. Rylott, A. J. Hunt, J. R. Dodson, A. F. Taylor, N. C. Bruce and J. H. Clark, Plos One, 2014, DOI: 10.1371/journal.pone.0087192

## PHYTOCAT Project

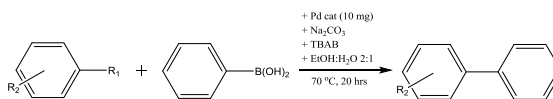
### Reuse of catalyst:

...catalyst was successfully reused...



H. L. Parker, E. L. Rylott, A. J. Hunt, J. R. Dodson, A. F. Taylor, N. C. Bruce and J. H. Clark, Plos One, 2014, DOI: 10.1371/journal.pone.0087192

## Suzuki-Miyaura Reactions



Entry	Aryl halide	Yield <sup>b</sup> (%)	Entry	Aryl halide	Yield <sup>b</sup> (%)
1		100	7		79
2		98	8		100
3		99	9		99
4		93	10		99
5		98	11		99
6		94	12		81 <sup>41</sup>

<sup>b</sup> Yield isolated by column chromatography

## Question for the Audience

### Food for Thought

**Food supply chain waste is available in very large quantities worldwide. How do you think it is best exploited?**

- Traditional uses such as feed and animal bedding
- Anaerobic digestion
- Extraction of high value chemicals
- Conversion to commodity chemicals
- Other uses

## The OPEC project



- **D-limonene 3.8% w/w**
- **flavonoids 4.5%**
- **pectin 20-30%**
- **cellulose 37.08%**
- **hemicellulose 11.04%**
- **sugars 9.57%**

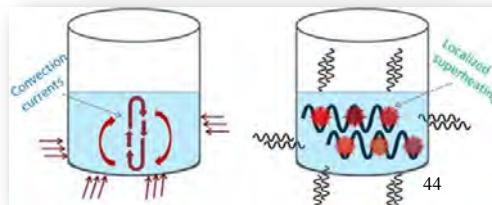
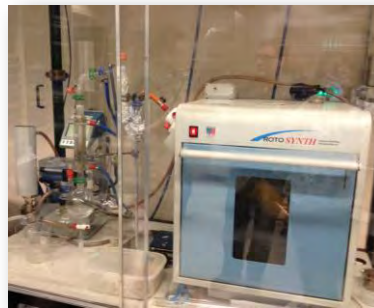
F. R. Marin *et al.*, Food Chemistry, 2007, 100, 736-741.  
M. Pourbafrani *et al.*, Bioresource Technology, 2010, 101, 4246-4250.

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## Why microwave technology?

Desirables for the design of an integrated conversion process:

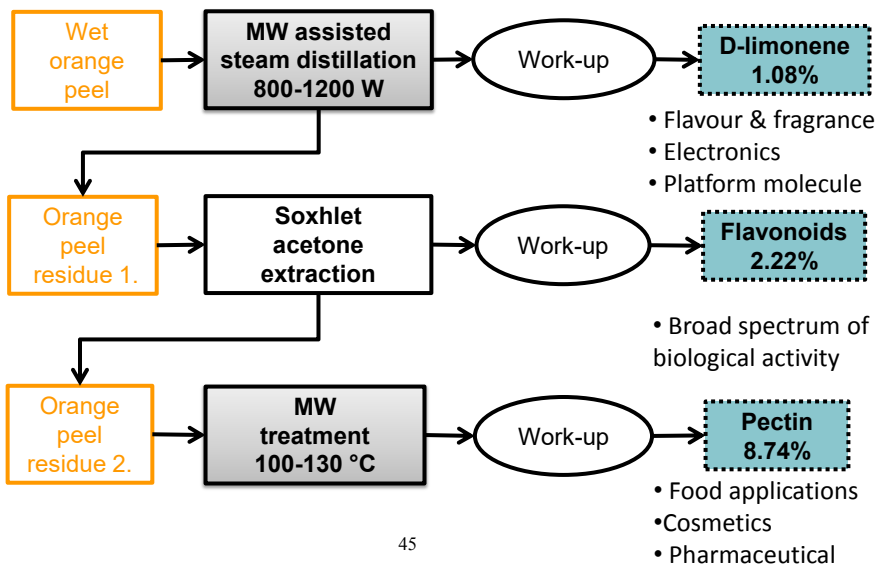
- ✓ volumetric heating
- ✓ Scalable
- ✓ flexible
- ✓ allows continuous processing
- ✓ feedstock agnostic
- ✓ allows the use of wet feedstocks



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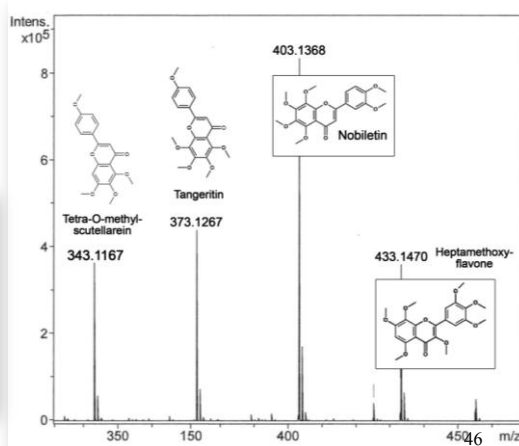
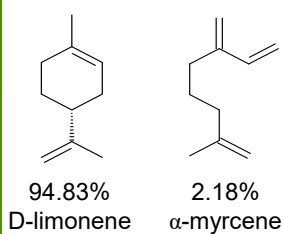


## Integrated process used



45

## Product range obtained



L. Pfaltzgraff *et al.*, *Green Chem.*, 2013, 15, 307-314.

## Summary of Food Waste Valorisation

- ✓ A low temperature hydrothermal microwave process separating pectin from cellulose in the cell wall **without any acid or other additive** has been developed.
- ✓ The process releases pectin, D-limonene, flavonoids, sugars, furans & cellulose.
- ✓ Product work-up done with food grade accepted solvents only.
- ✓ D-limonene and pectin meet standard quality requirements.
- ✓ The process potentially could be run in one step.
- ✓ Techno-economic evaluation currently underway.

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## Conclusion

- **We cannot afford** to continue to throw away such large amounts of valuable chemicals especially as **many traditional resources are liable to run out** in a matter of years
- What we **currently consider** to be waste streams are actually a **rich source of chemicals**
- **Valorising current process wastes** or by-products can give new business opportunities to companies and strengthen the overall business model for the process
- **Food supply chain wastes** are available worldwide and are a **rich source of valuable chemicals and materials**
- **Citrus** is a good example of a **high volume widely distributed food waste** that can be converted to chemicals and materials using green chemical technologies
- **E-waste** is an increasingly large volume waste that is a **good source** of waste organics and waste metals
- **Phytomining is a green technology** that can be used to capture valuable metals from mining and other waste streams

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## Further Info...

Find us on the web at  
[www.york.ac.uk/greenchemistry](http://www.york.ac.uk/greenchemistry)



**You Tube** Green Chemistry at York Youtube Channel  
[www.youtube.com/user/greenchemistryyork](https://www.youtube.com/user/greenchemistryyork)

**Twitter** Follow us on Twitter [@GreenChemYork](https://twitter.com/GreenChemYork)

Green Gown Award Video Case Study  
<https://www.youtube.com/watch?v=iCZwsoSv63Q>



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[www.phytocat.org](http://www.phytocat.org)



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Research

Industry

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## From Waste to Wealth Using Green Chemistry

**Dr. Joseph Fortunak**  
Howard University

**James Clark**

**Dr. Avtar Matharu**

**Dr. Andrew Hunt**

**Lucie Pfaltzgraff**

**\* All Speakers**  
Green Chemistry Centre of Excellence, University of York

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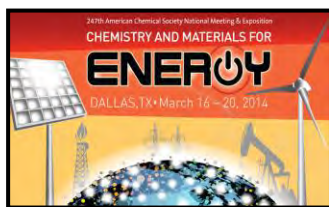
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Thursday, March 13, 2014

“Detecting Bioterrorism: Is Chemistry Enough?”

**Dr. Kristin Omberg**, Los Alamos National Laboratory  
**Dr. Darren Griffen**, University of Kent



Monday and Tuesday, March 17-18, 2014

“Exclusive Access to Experts from the ACS National Meeting”

**2pm ET:** The Chemistry of Solar Energy: Materials for Conversion of Light to Electricity

**5pm ET:** The Kavli Foundation Emerging Leader in Chemistry Lecture with Dr. Emily Weiss

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## From Waste to Wealth Using Green Chemistry

A world map is shown with red lines connecting to four speaker portraits. The speakers are:

- Dr. Joseph Fortunak (Howard University) - located in North America
- James Clark - located in Europe
- Dr. Avtar Matharu - located in Asia
- Dr. Andrew Hunt - located in North America
- Lucie Pfaltzgraff - located in North America

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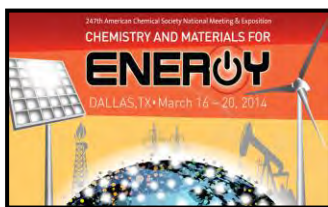
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