



The University of
Nottingham

Can Chemistry be Green?

Martyn Poliakoff

www.nottingham.ac.uk/supercritical

China Cup



Paper Cup



Polystyrene Cup



Which is best for the Environment?



Paper



China



Polystyrene

Coffee Cups - Manufacture

China – most energy to
make

Polystyrene – made from oil

Paper – made from wood,
messy process

Cost of Energy varies

Coffee Cups- Use

Polystyrene – use once

Paper – use once

China – **multi-use**

BUT needs washing

(hot water, detergent)

Coffee Cups- Verdict

You have to use a china cup
1000 times before it is
environmentally better than
Polystyrene

Coffee Cups - Disposal

China – landfill

Polystyrene – landfill

(125 times better)

Paper – can be composted –

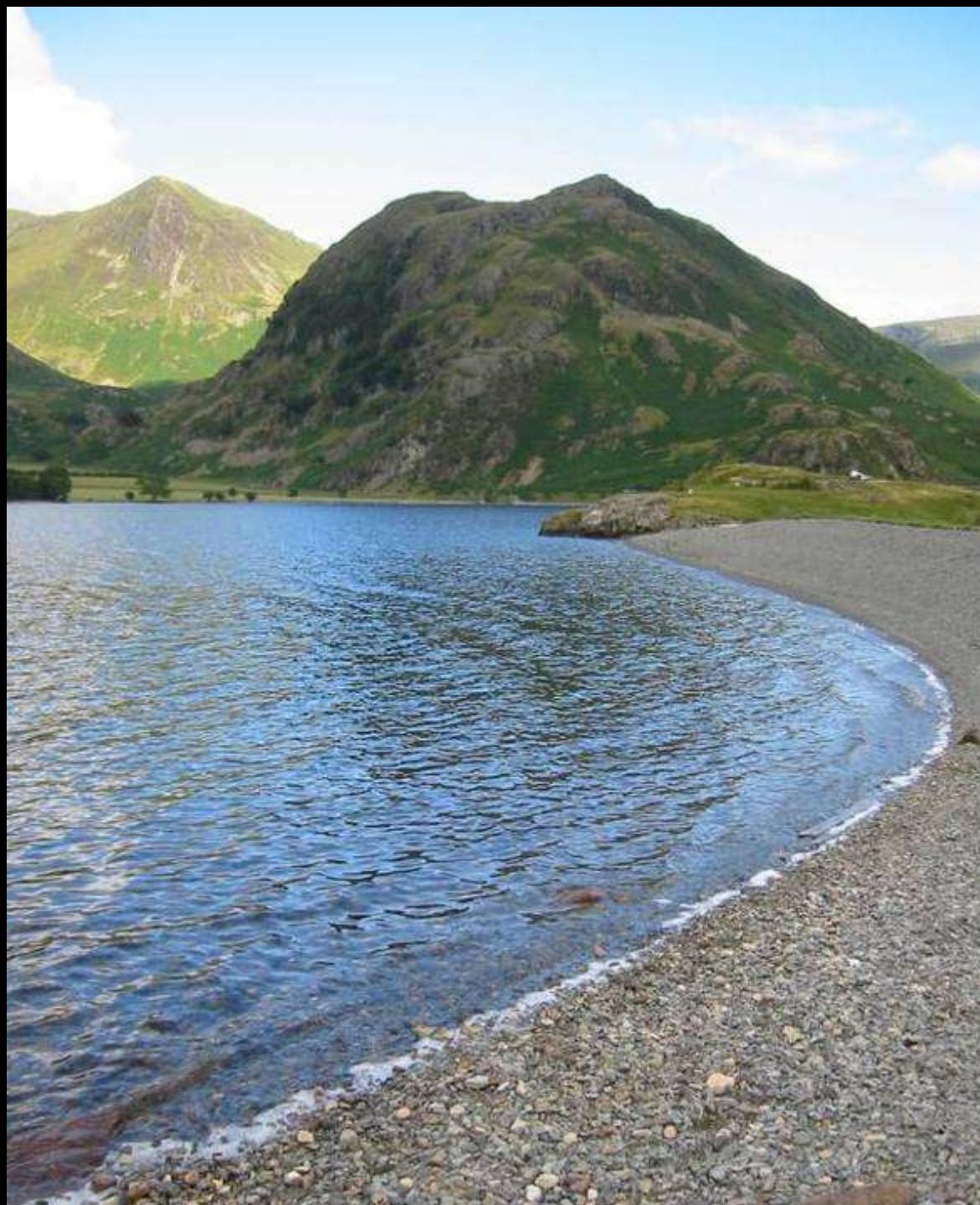
generates CH_4

(greenhouse effect)

Life Cycle Assessment







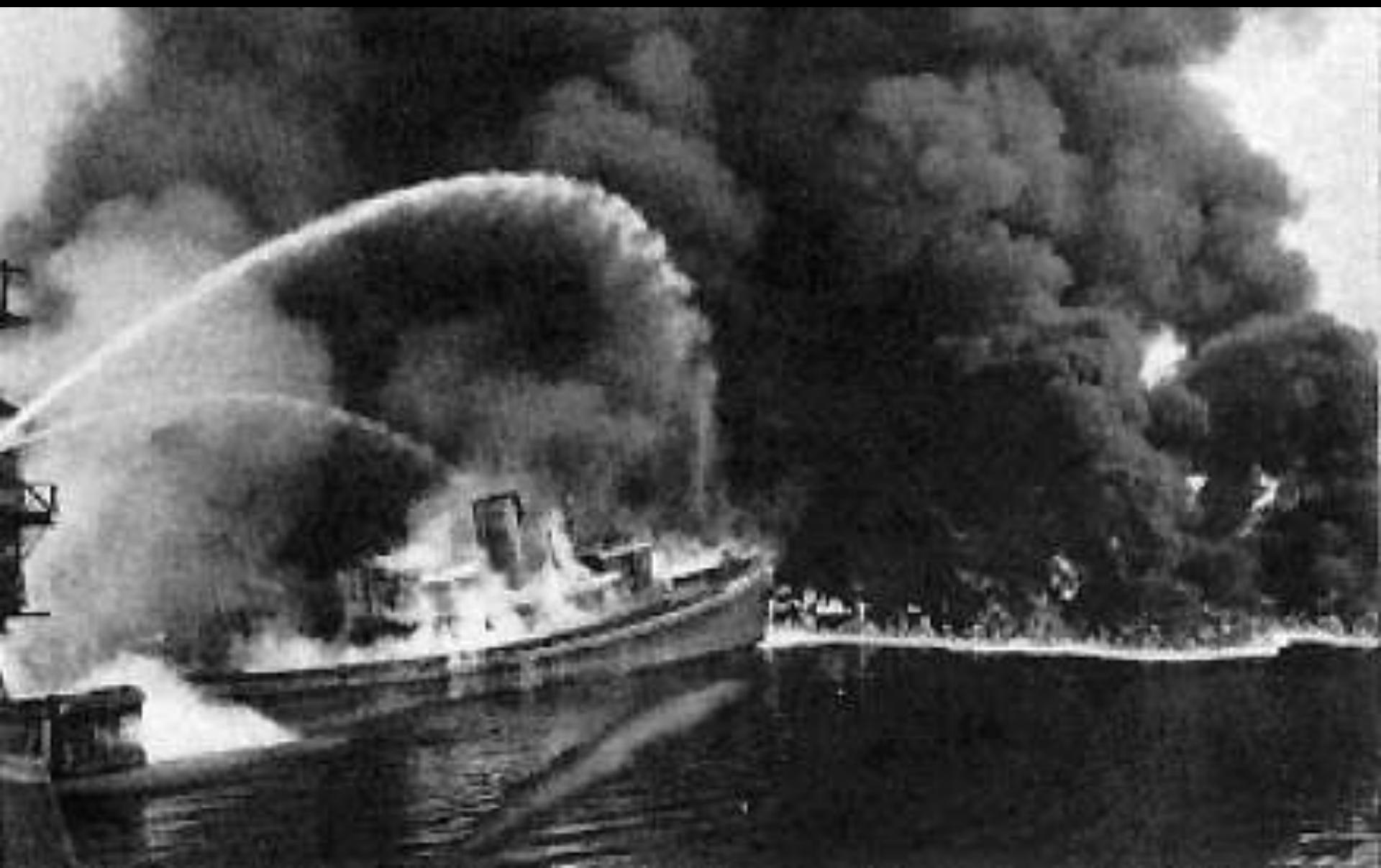




CAUTION
It's very hot

One of the main
problems in chemical
manufacture is the
generation/disposal of
(toxic) waste

Cuyahoga River 1969



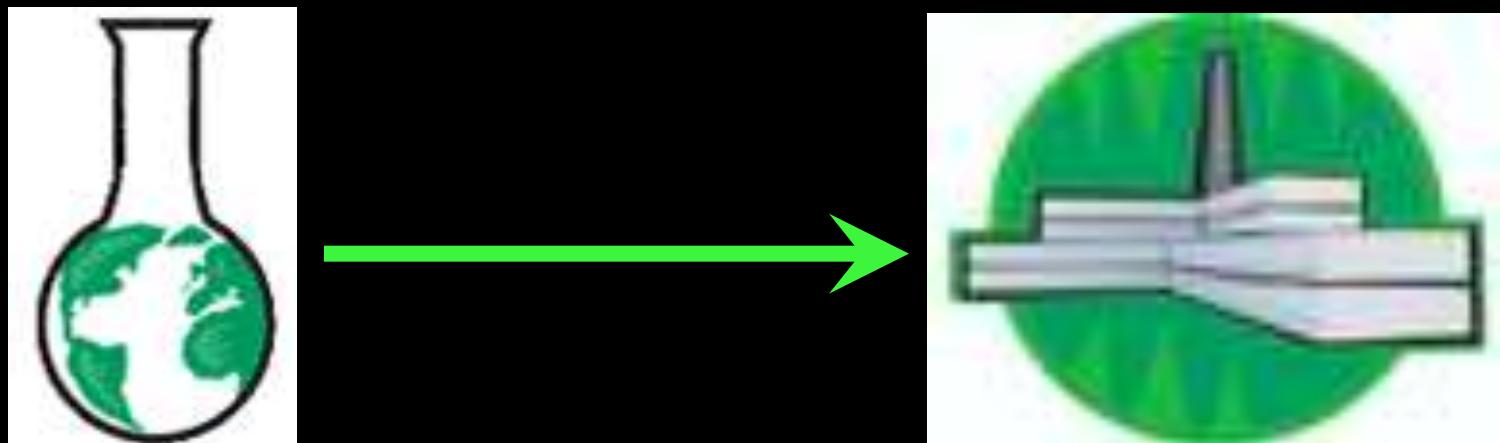


FLAMMABLE

CUYAHOGA
RIVER

Green Chemistry (early 1990s)

Cleaner approaches to
making and using chemicals
& materials



Assessing Risk

Risk = Hazard x Exposure

What we do now

Limit Exposure \Rightarrow Acceptable Risk

Green Chemistry

if Hazard = 0 \Rightarrow Risk = 0

Areas of Green Chemistry

- New reactions
- New catalysts
- Alternative Feedstocks
- **Safer Solvents**



Solvents: the problems

- Most solvents are
Volatile Organic Compounds
- **Fire / explosion hazards**
- **VOC emissions** →
atmospheric pollution
- **Disposal / recycle** →
environmental pollution

Fork Lift +Toluene → ‘Big Bang’



Solvents: Alternatives

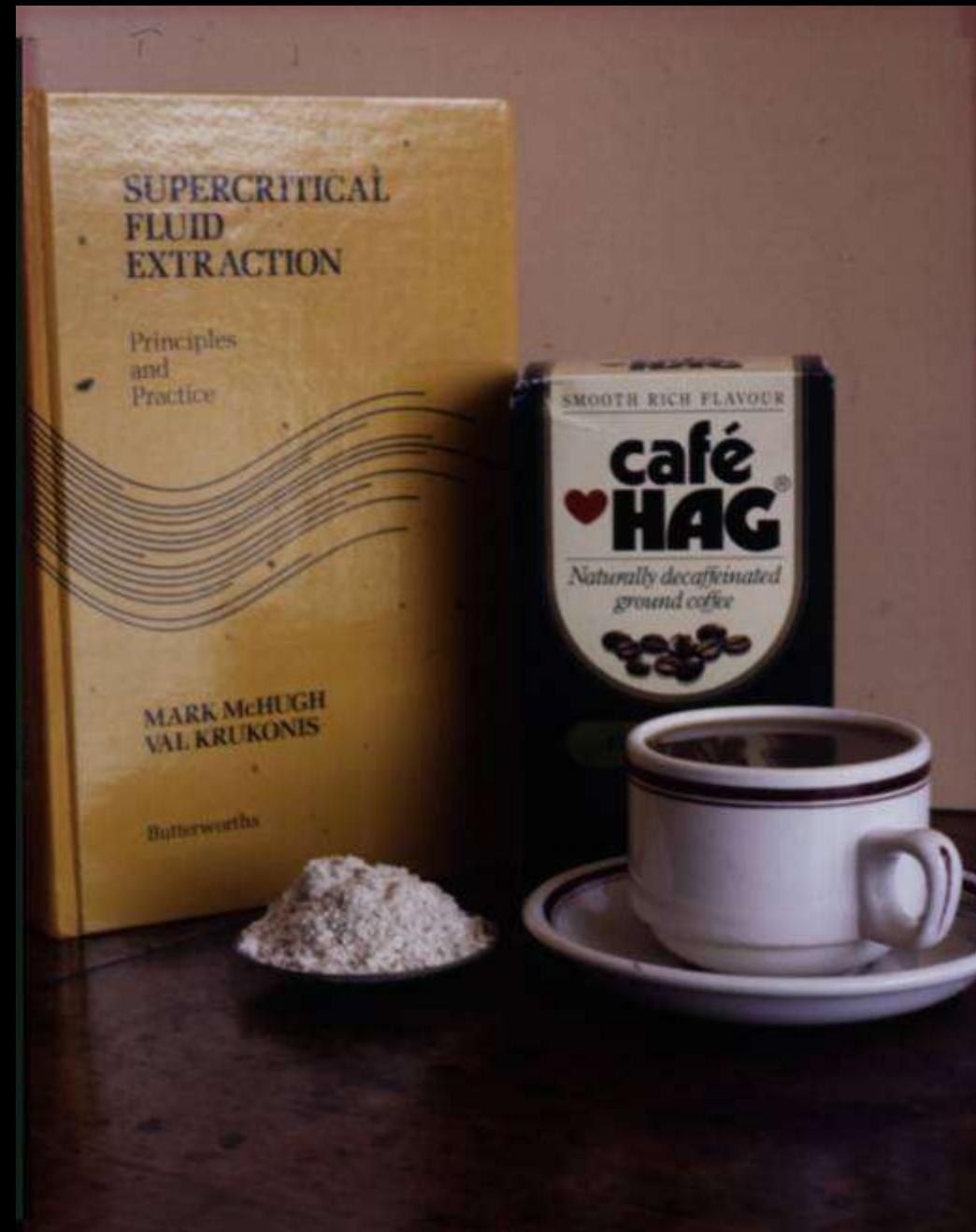
- No solvent
- Water
- Ionic Liquids
- **Supercritical Fluids**

Supercritical Fluids

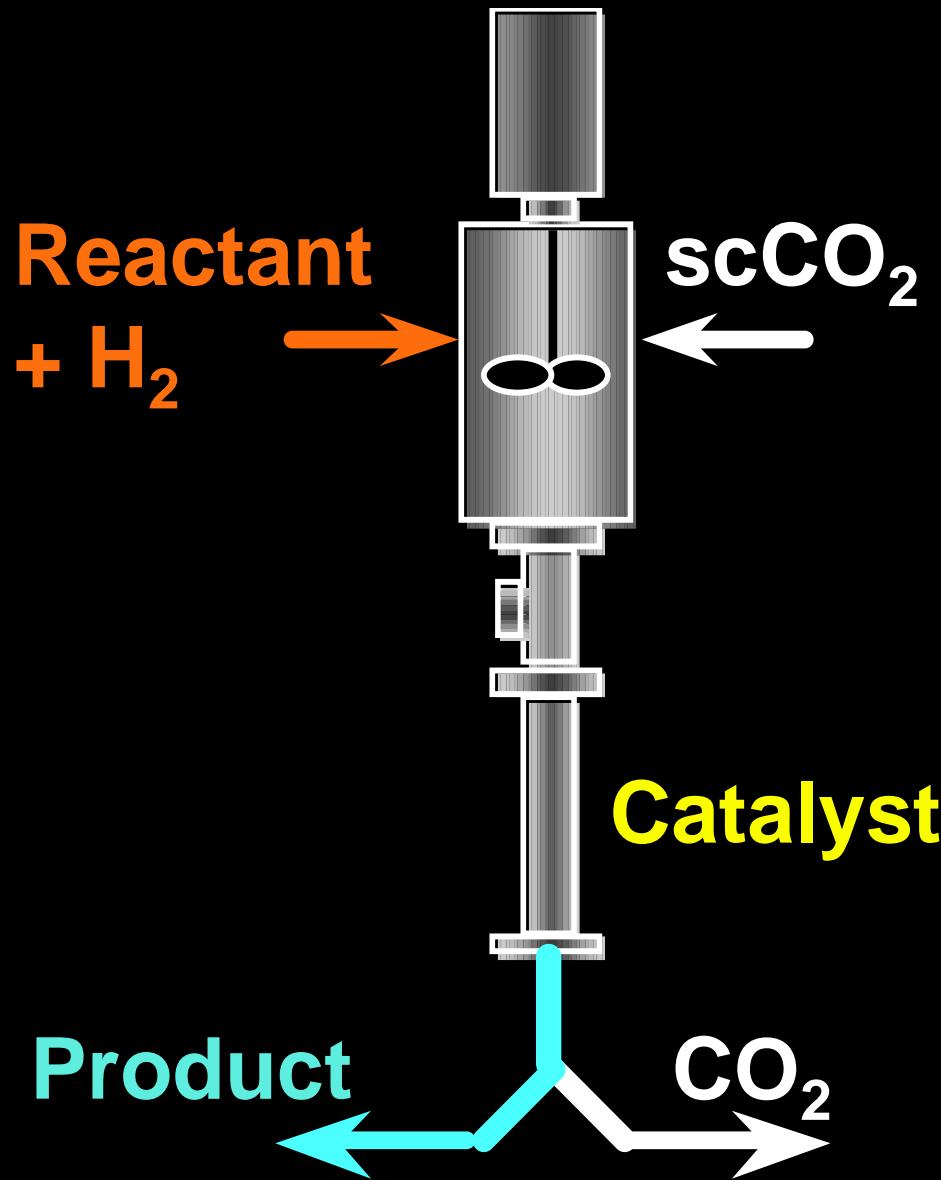
- Gases (e.g. CO_2) compressed until they are nearly as dense as liquids
- **SCFs can dissolve solids** solubility increases with density (applied pressure)

Decaffeination in scCO₂

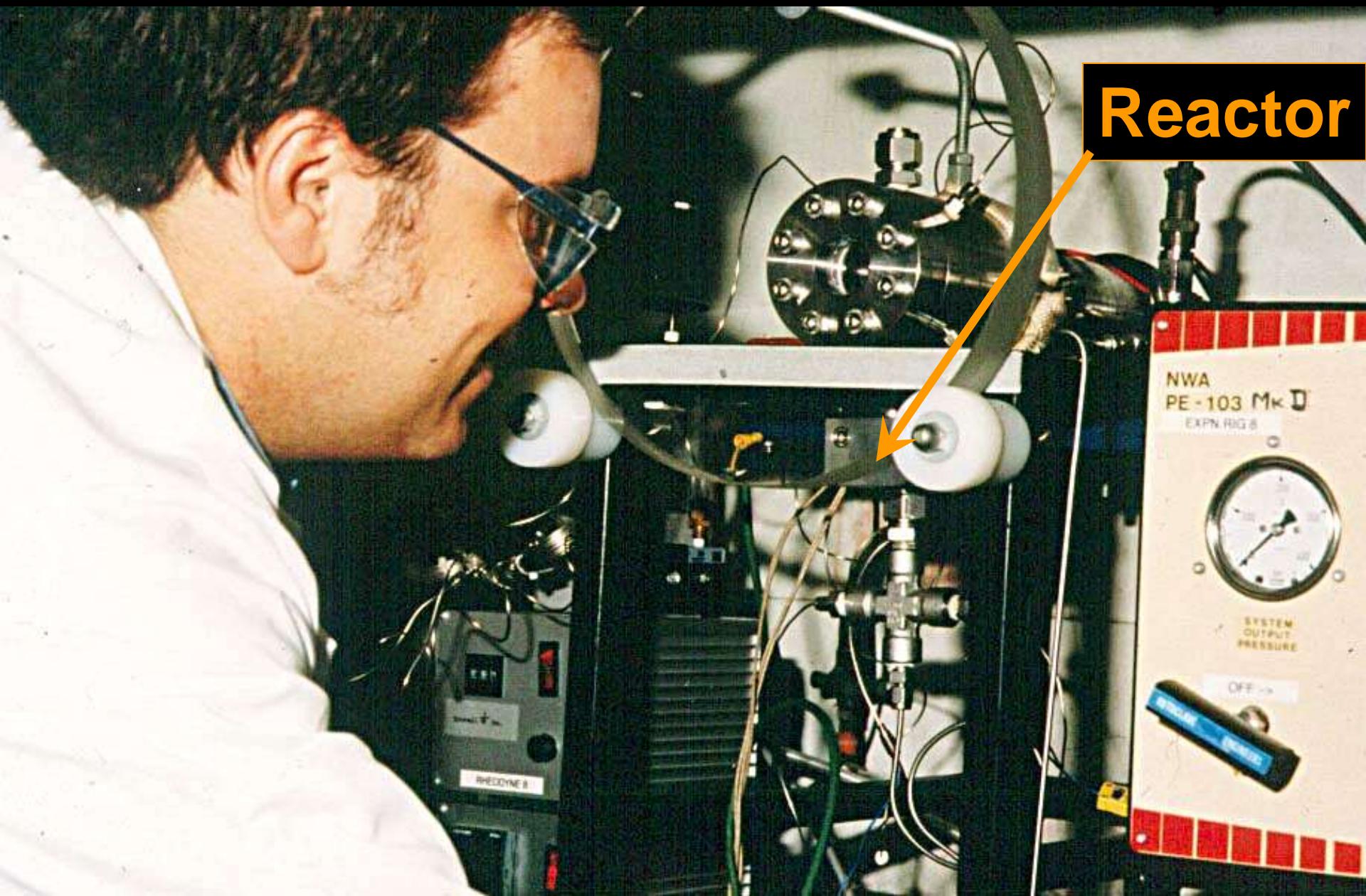
- Well established commercially



Greener Hydrogenation in scCO₂

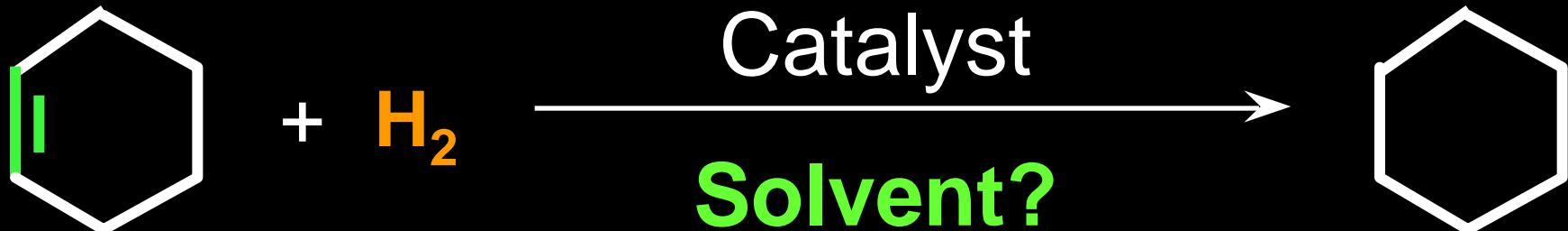


Lab Reactor



Reactor

Greener Hydrogenation



Use Supercritical CO₂

scCO₂ is completely miscible
with H₂ – more efficient reactions



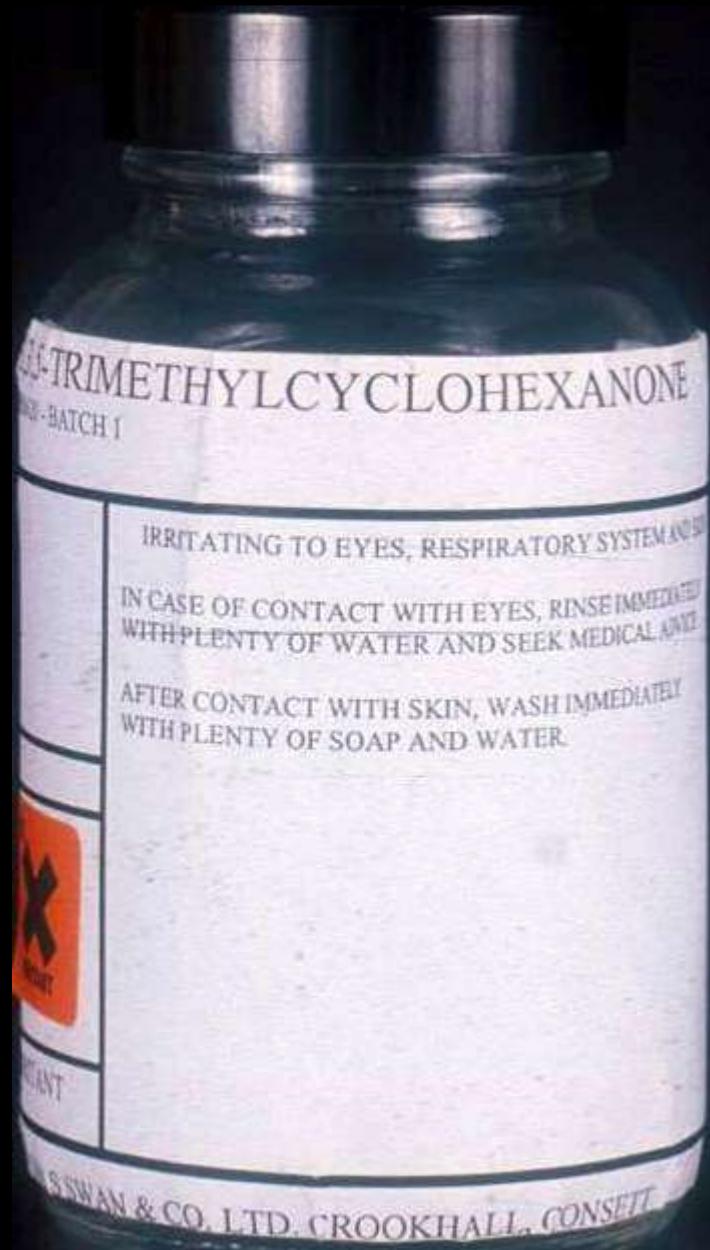
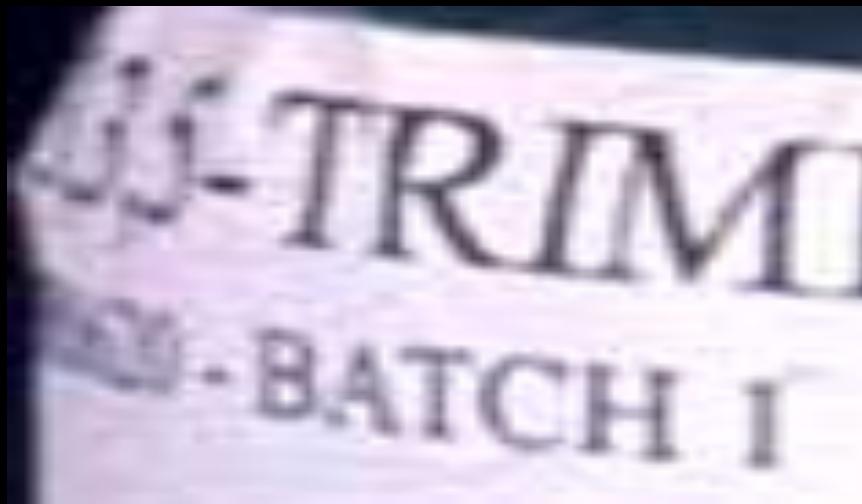
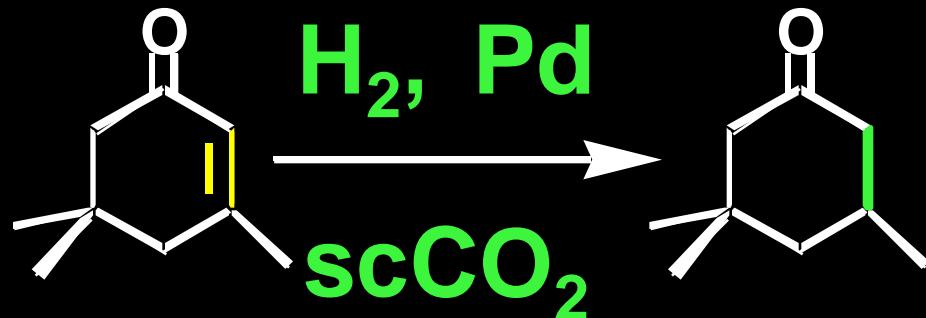
scCO₂ Chemical Plant opened July,2002

- continuous
- multipurpose
- 1000 ton p.a.

Thomas Swan & Co



The First Product!



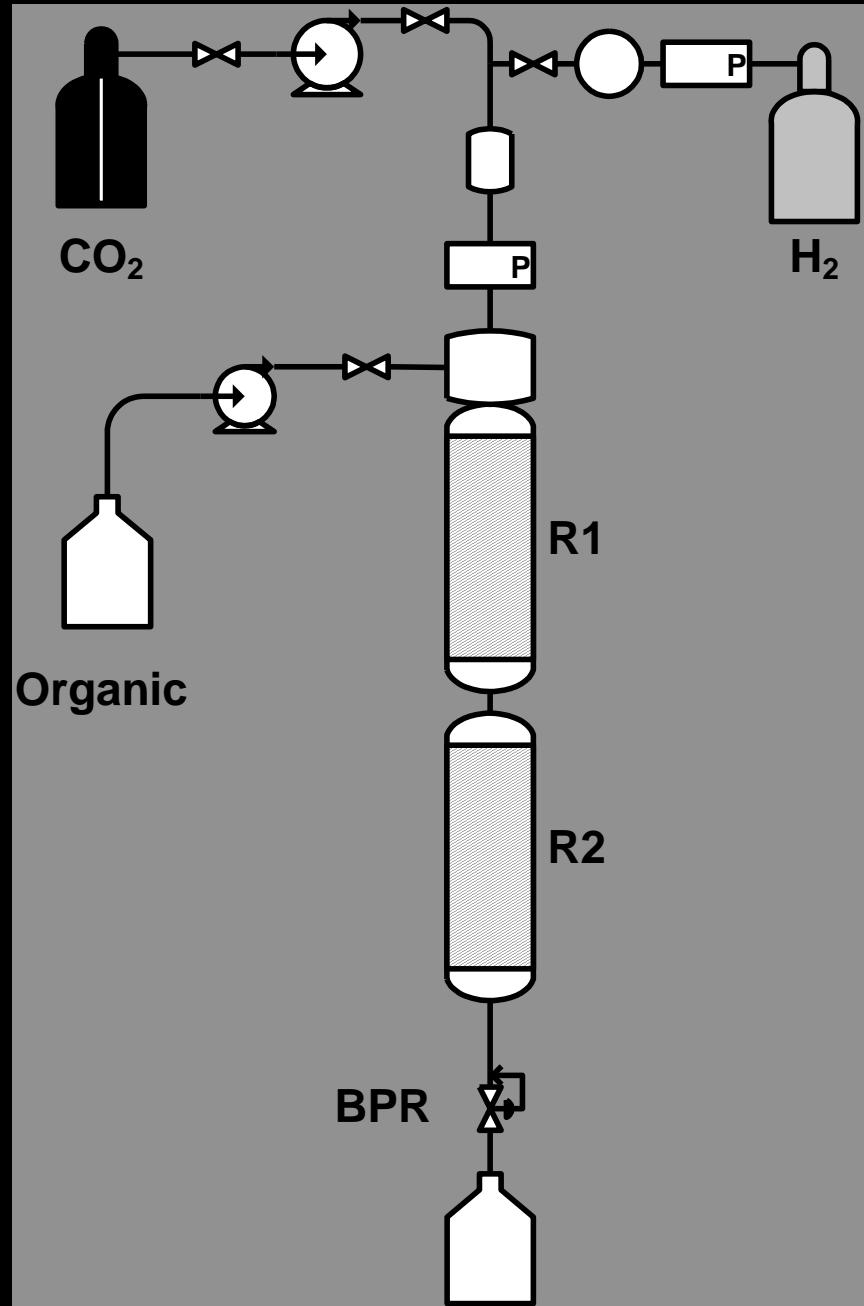
Green Chemistry 12 Principles

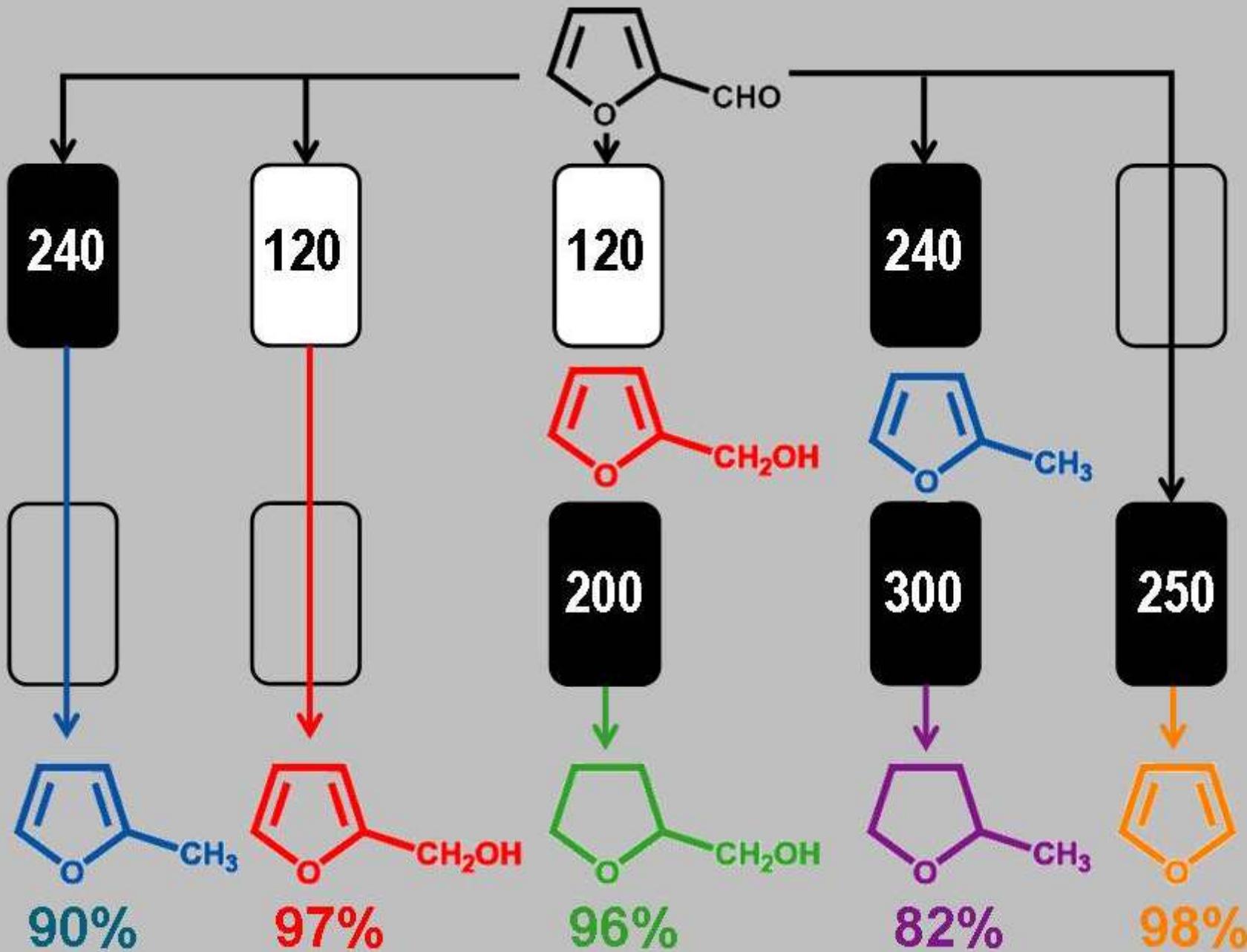
- P - Prevent wastes
- R - Renewable materials
- O - Omit derivatization steps
- D - Degradable chemical products
- U - Use safe synthetic methods
- C - Catalytic reagents
- T - Temperature, Pressure ambient
- I - In-Process Monitoring
- V - Very few auxiliary substances
- E - E-factor, maximize feed in product
- L - Low toxicity of chemical products
- Y - Yes it's safe

‘Chemical Vending Machine’

One precursor
several different
products?

Two reactors:
different catalysts
Vary reactor
temperatures





Supercritical Fluids: University Spin outs

- **Critical Pharmaceuticals:-**
Steve Howdle, scCO₂ drug delivery
www.criticalpharmaceuticals.com
- **Promethean Particles:-**
Ed Lester, scH₂O nanoparticles
www.prometheanparticles.co.uk/

Taking Green Chemistry to Developing Countries





Hossana, Ethiopia







First
OPTION
ANKA
CENTER

ACTION NOW
...THERE IS

Sugar Cane





Is it silly to make polymers out of sugar cane?

No!!!

- Sugar cane is grown in huge amounts
- It grows where there is little oil
- There is a surplus
- The farmers cannot sell all of it

Sugar Cane



How to do it?

“To make a
bag from
sugar needs
new

Chemistry”
2nd July, 2003



Polymers from Carbohydrate

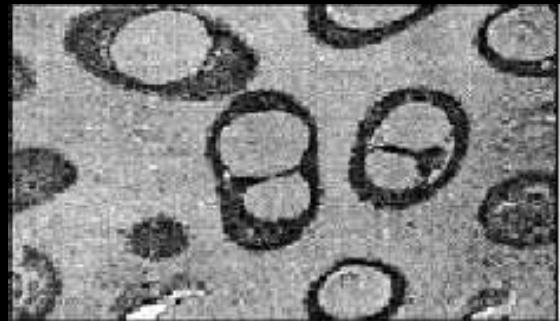
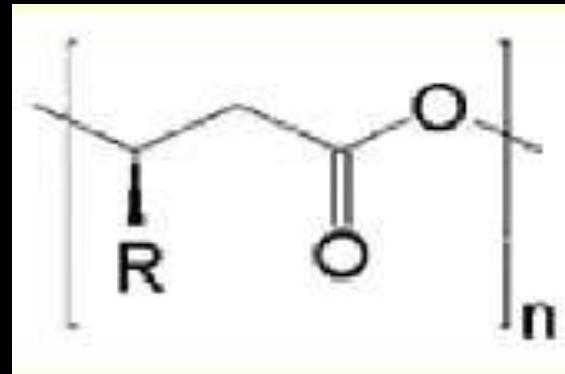
Dr Isao Noda, Procter & Gamble

Microorganisms eat carbohydrate

They store energy as a polymer

Polymer is easily harvested

Waste is recycled.



P & G NODAX™



Polymer from carbohydrate

Coffee Cups from Waste Carbohydrate

Cups for US Navy

Can be made on
existing machines

Composts in 2 days!





Dr Nigist in Washington 2005

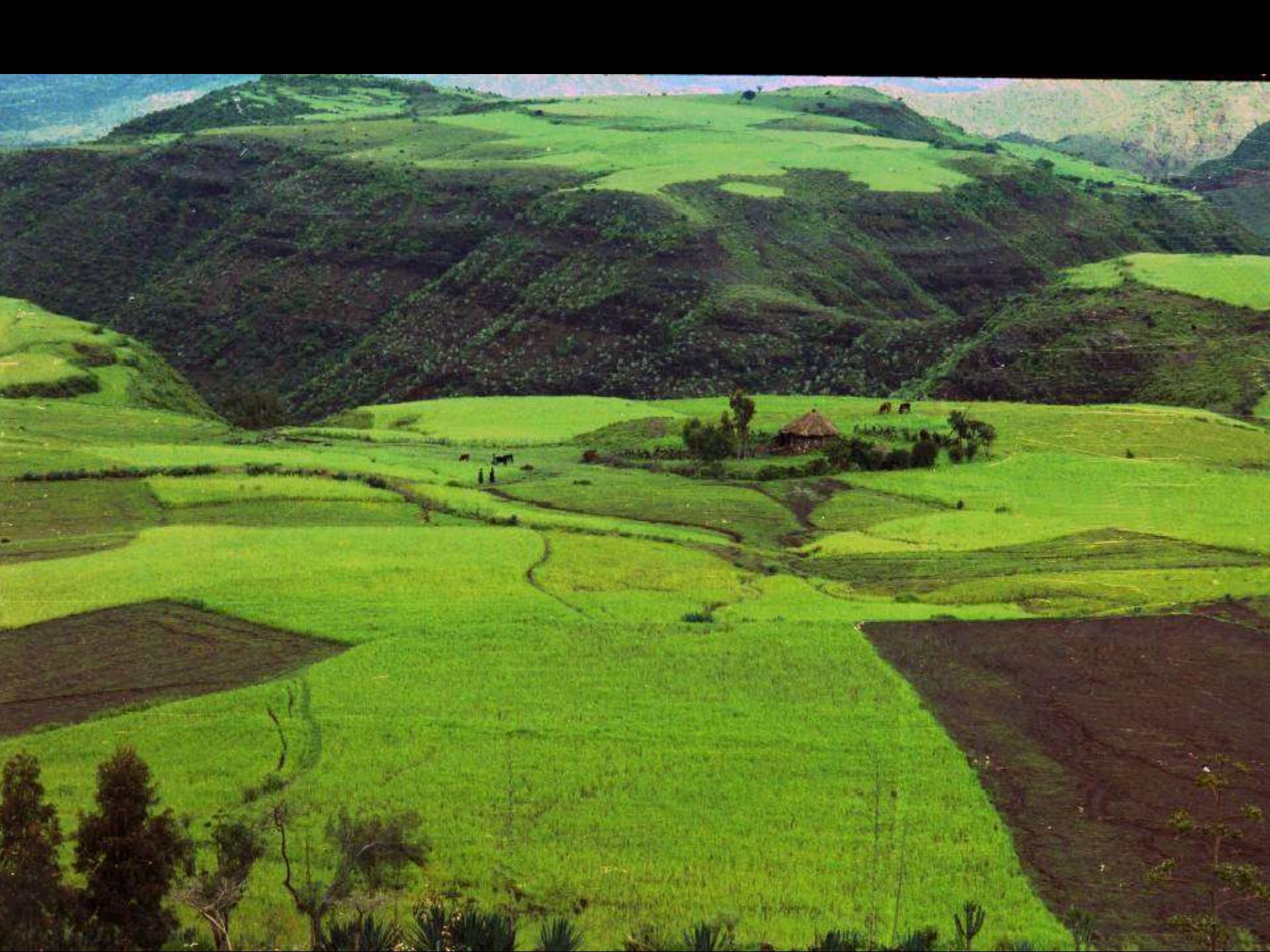
Jimma, Ethiopia 2007



Royal Society of Chemistry
PanAfrican
Chemistry Network
1st Green Chemistry Congress

15-17 November 2010
Addis Ababa, Ethiopia

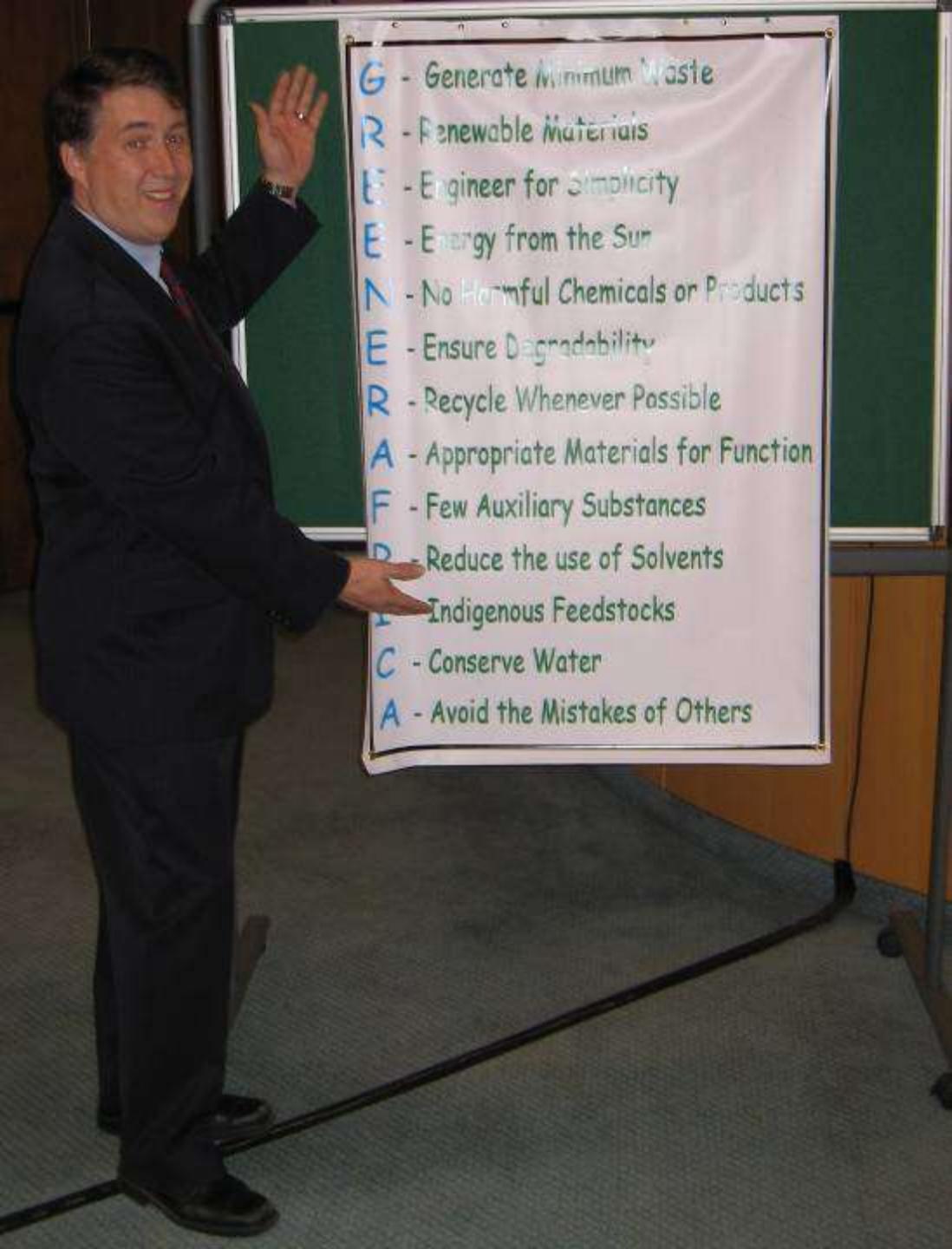






13 Principles of Green Chemistry for Africa

- G** - Generate Wealth not Waste
- R** - Regard for All Life & Human Health
- E** - Energy from the Sun
- E** - Ensure Degradability & No Hazards
- N** - New Ideas & Different Thinking
- E** - Engineer for Simplicity & Practicality
- R** - Recycle Whenever Possible
- A** - Appropriate Materials for Function
- F** - Fewer Auxiliary Substances & Solvents
- R** - Reactions using Catalysts
- I** - Indigenous Renewable Feedstocks
- C** - Cleaner Air & Water
- A** - Avoid the Mistakes of Others



Paul Anastas with the 13 principles at the PACN Congress, Nov 2010

PACN Lecture, Addis, 2010

- ▶ SPME has been successfully used to sample and extract volatiles from Morama milk
- ▶ Its simple to operate
- ▶ Portable
- ▶ solvent free

 SPME OFFERS POTENTIAL AS A 'GREEN' TOOL FOR SAMPLING AND EXTRACTION OF VOLATILE COMPOUNDS IN MORAMA MILK

Score on 13 principles of green chemistry = $10/13 = 78\%$)
GENRAFRICA

Influencing Policy Makers



**The Ethiopian
Minister for
Education
in Nottingham
Jan 13th 2011**

**The 13
Principles**

Green Chemistry: The Role of Government?

TONY
JUDT

*Ill fares the land to hastening ill prosperity,
Where wealth accumulates, and men decay.*

Oliver Goldsmith, *The Despised Village*, 1726

ILL FARES
THE LAND

III Fares the Land

- Some things are done better by the State

running the railways

The Role of Government?

- The success of Green Chemistry is vital for society
- UK chemical manufacturing is going offshore
- Huge opportunities for inventing new technologies

The Role of Government?

- Many of the key problems are long term
- **Government must support:**
Ambition in the research agenda
Chemistry + Engineering + Business
Academia + Industry

What's our University doing?

- **Leading centre of Green Chemistry**
- £4M DICE project: **Driving Innovation in Chemistry & Engineering**
- **SM Howdle, S Kingman, M Binks:**
development of Sustainable
Processing/Chemistry in Nottingham
- **GSK £14 M investment in Green
Chemistry at Nottingham**

“We've invested in Nottingham because it's one of the best universities in Britain, in fact the world, from a chemistry point of view

There's a great record of excellence in that school and they absolutely deserve that investment.”

Andrew Witty,
CEO GSK, BBC News

**Mike George, Steve Howdle,
Pete Licence, Sam Kingman
Sam Tang**

**All our Students,
Postdocs and Collaborators**

P. Fields, R. Wilson, M. Guyler

***INVISTA, Thomas Swan & Co, AstraZeneca
EPRSC, Royal Society, EU Marie Curie***

Green Chemistry: What Now?

- 19 years old – growing fast
- Spreading all over the world
- Increasing industrial interest
- **Is now part of A-Level!!**
- **Needs lots of new ideas**