Bulk goods as an imperfect abstraction of the physical world

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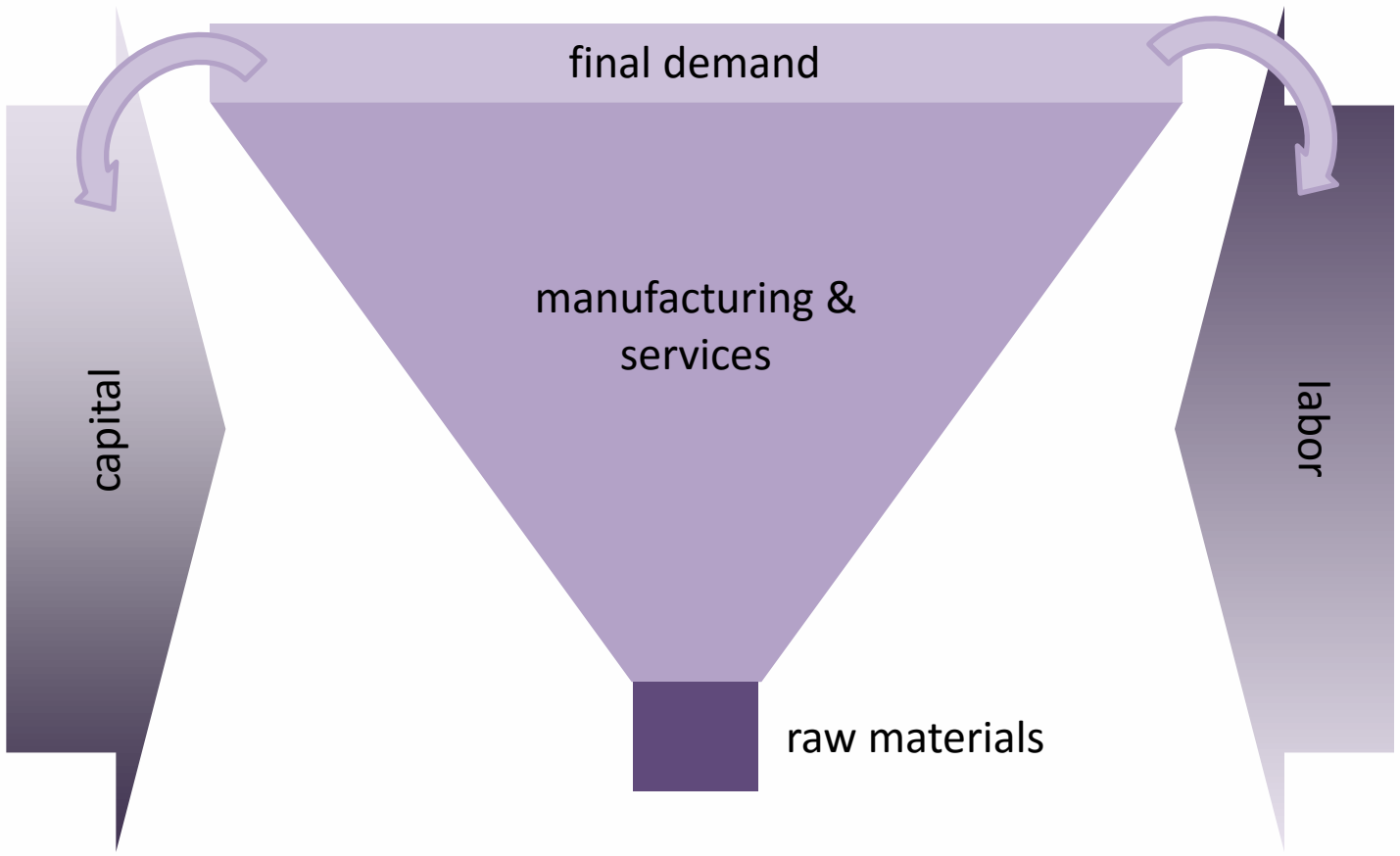
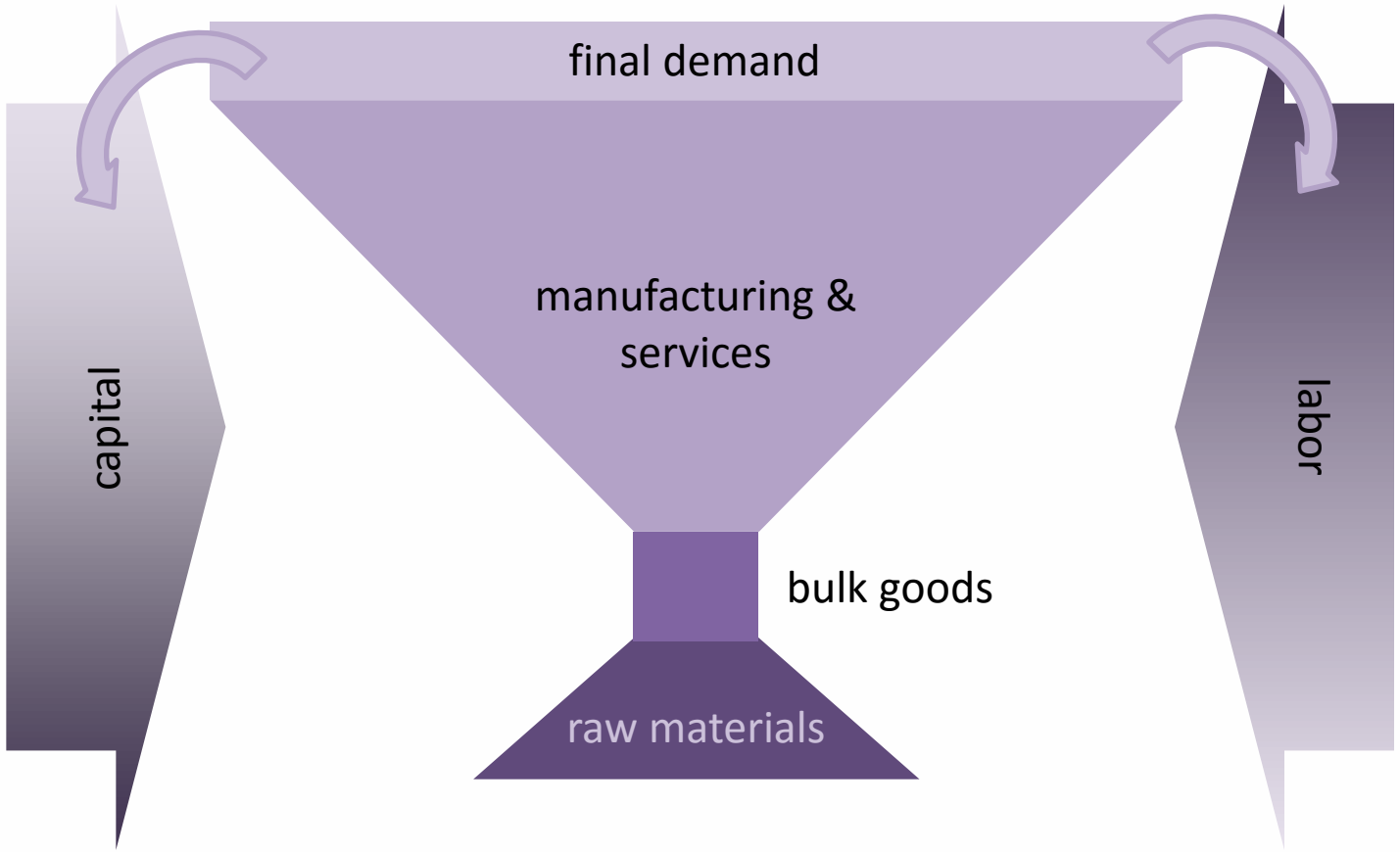
SEI STOCKHOLM ENVIRONMENT INSTITUTE

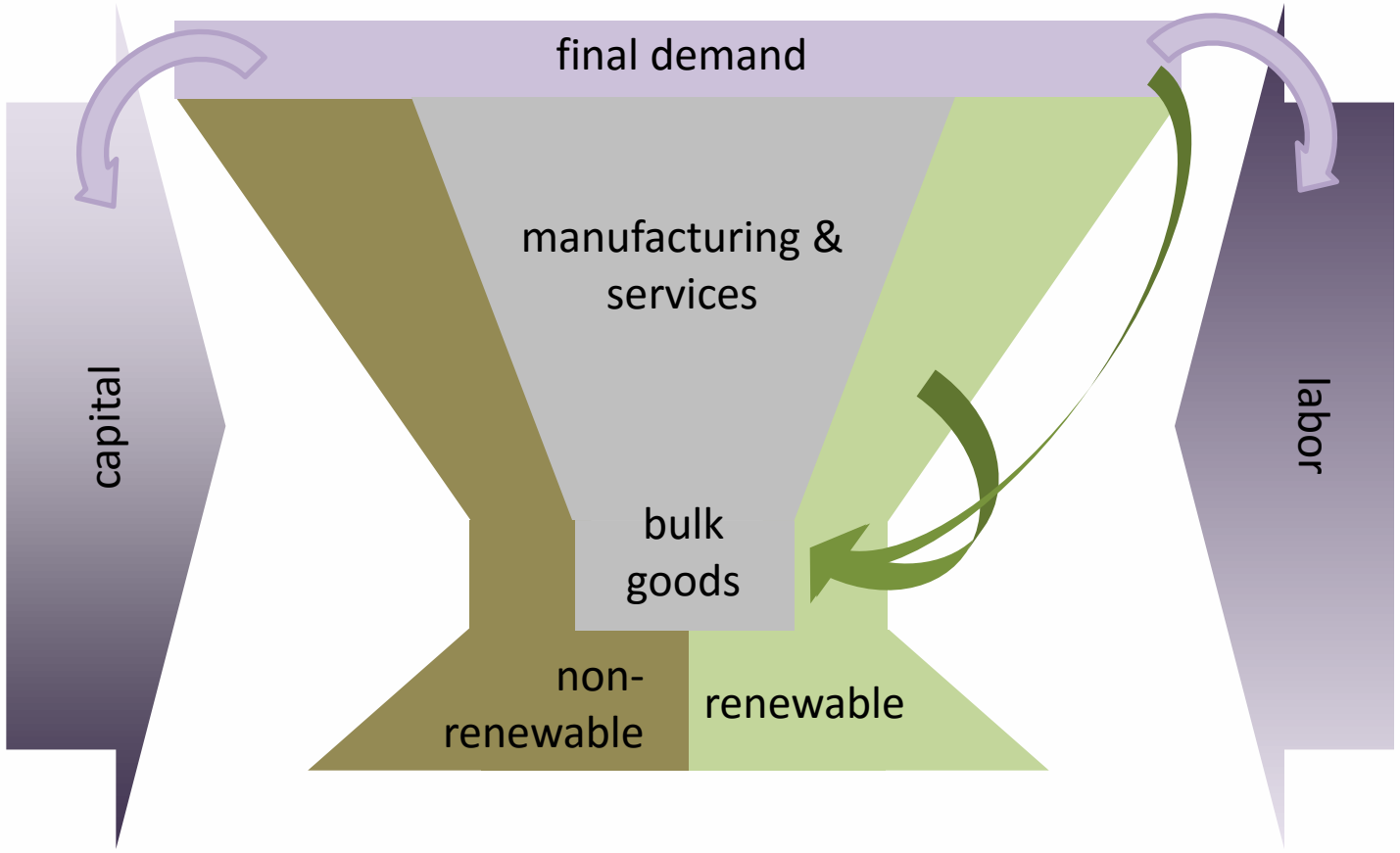
The economy: The ecological economist's "inverted pyramid"



An alternate view: The “goblet”

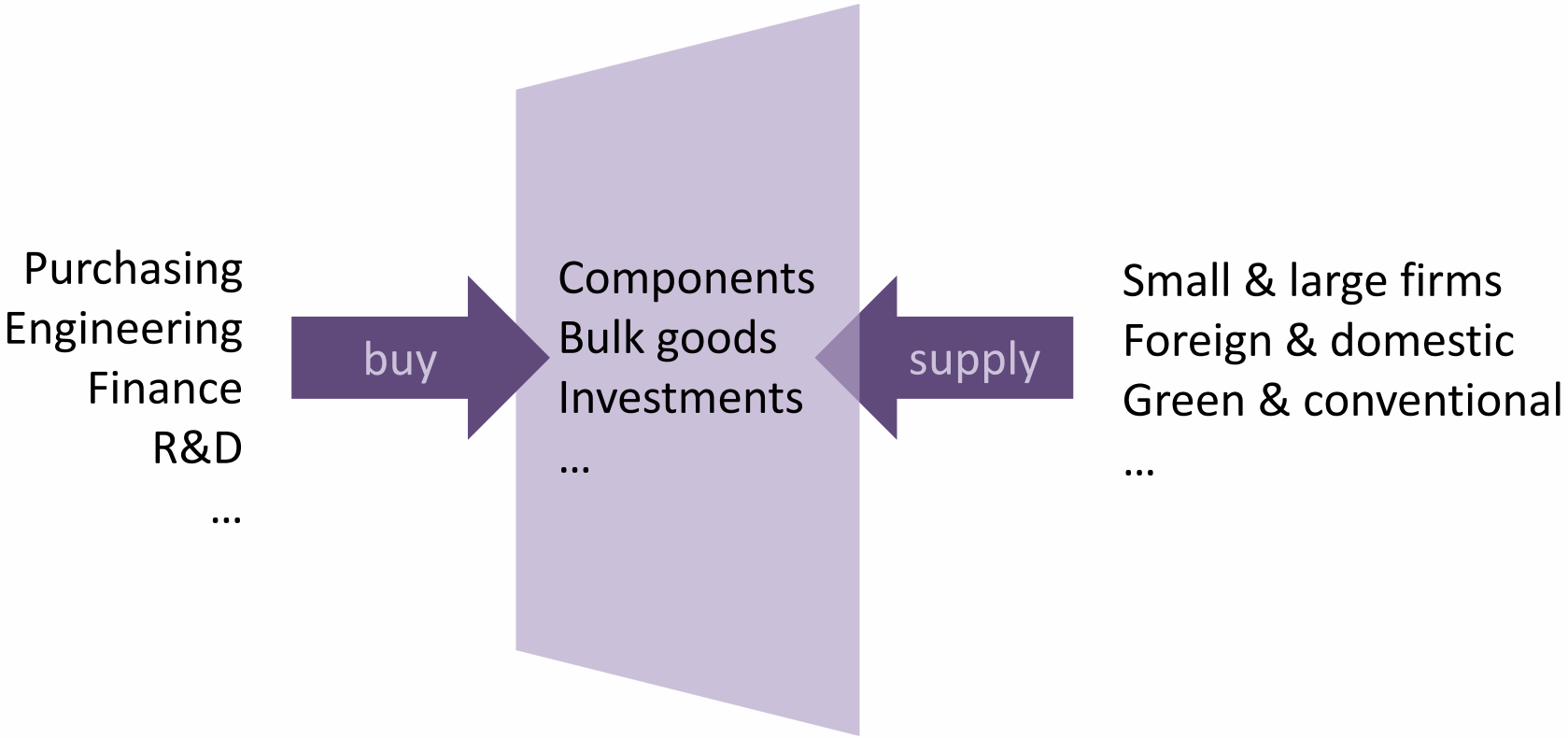


Transforming the economy



The prospects for a sustainability transition depend on the extent of needed changes

“Abstraction layers”: Key to the modern economy



If the same bulk good can be produced from renewables

Bulk good suppliers need to know:

- Is good quality feedstock reliably available at competitive prices?
- Are replacement parts available for needed equipment?
- Is there a pool of trained and experienced labor (sales, engineers, scientists,…)?

Purchasers of the bulk good want to know:

- Is the quality equivalent?
- Is supply reliable?

Banks and private investors want to know:

- Do credible experts think the technology is viable?
- Can it be operated at industrial scale?
- Is it profitable at prevailing prices, or under likely future policy?

If a new bulk good is introduced

All the above and **reliable downstream demand**

- Do downstream producers want the good?
- Is there demand for their products?
- Are their firms viable – profitable, attractive to investors, well-managed?

Unless production is vertically integrated, this is out of the hands of the bulk good supplier

Substitutability

- Substituting a feedstock is hard
- Substituting a bulk good is **much harder**

In either case:

- The physical reality of raw materials production intrudes from time to time, differently for different feedstocks for the same (or similar) bulk good

Joel's Law of Leaky Abstractions*

All non-trivial abstractions, to some degree, are leaky.

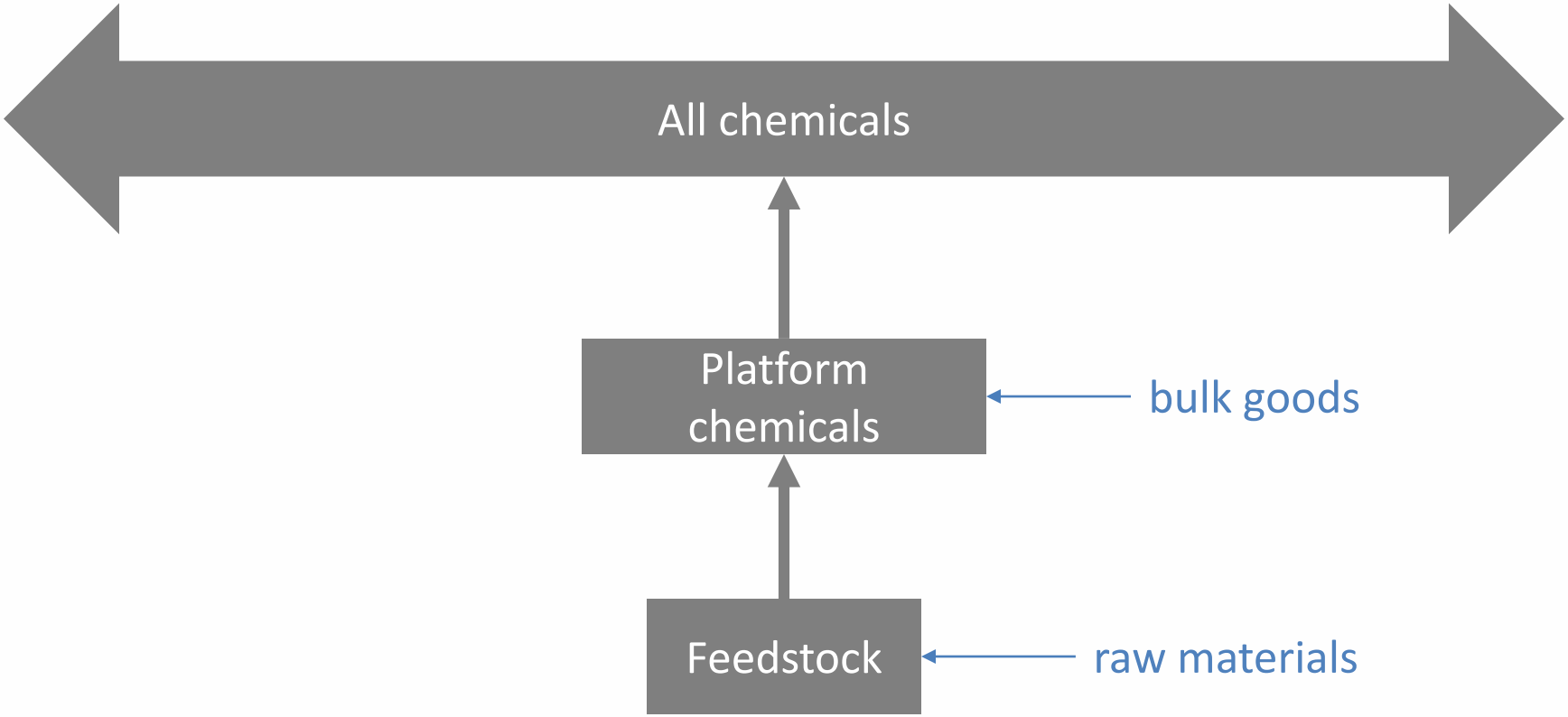
*http://www.joelonsoftware.com/articles/LeakyAbstractions.html

Three short “case studies”

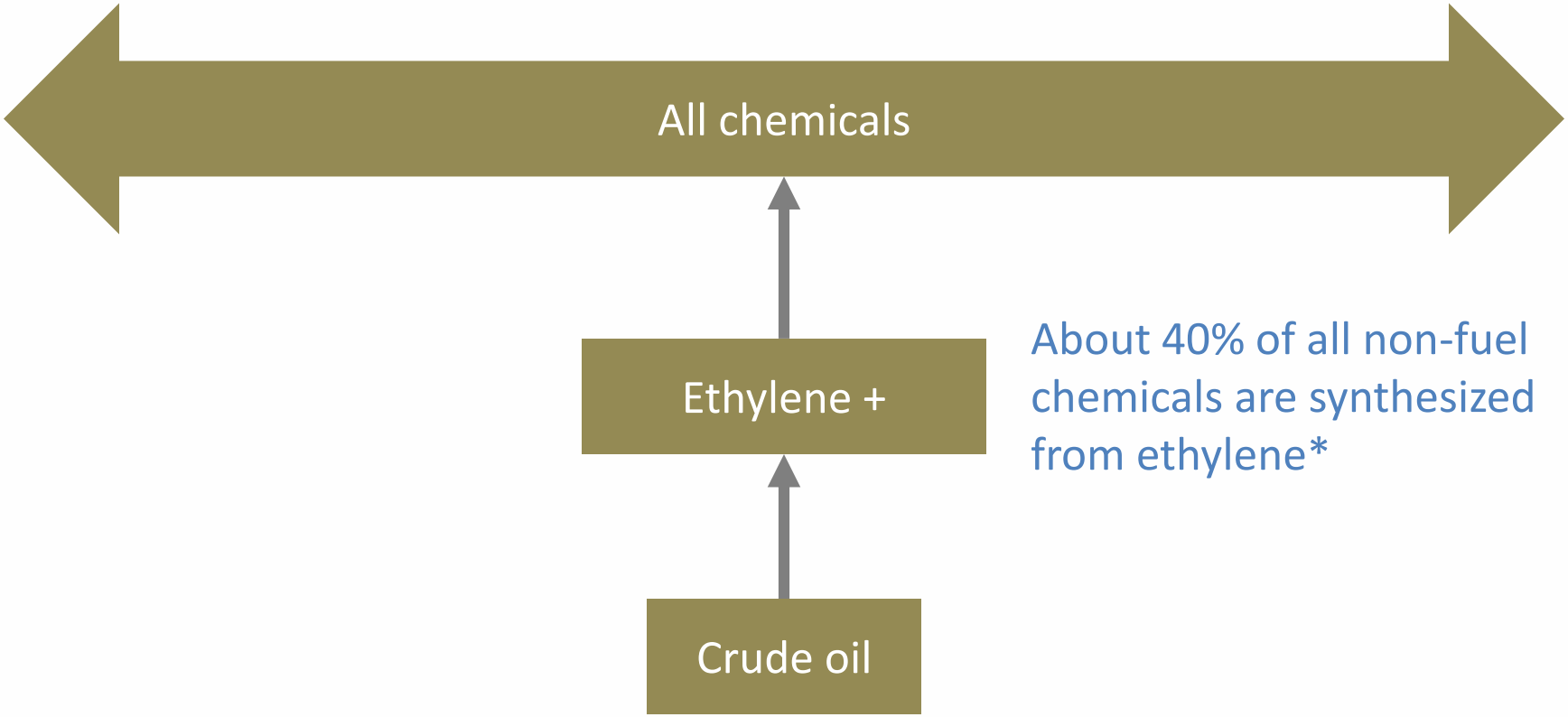
- **Chemicals:** plastics, liquid fuels, coatings, lubricants, pharmaceuticals, fabrics, gels, dyes, inks, paints, high-performance materials
- **Steel:** industrial goods, appliances, buildings and bridges, transport
- **Electricity:** a flexible energy supply with many generating options

CHEMICALS

The chemical industry: the prototype of an abstraction layer



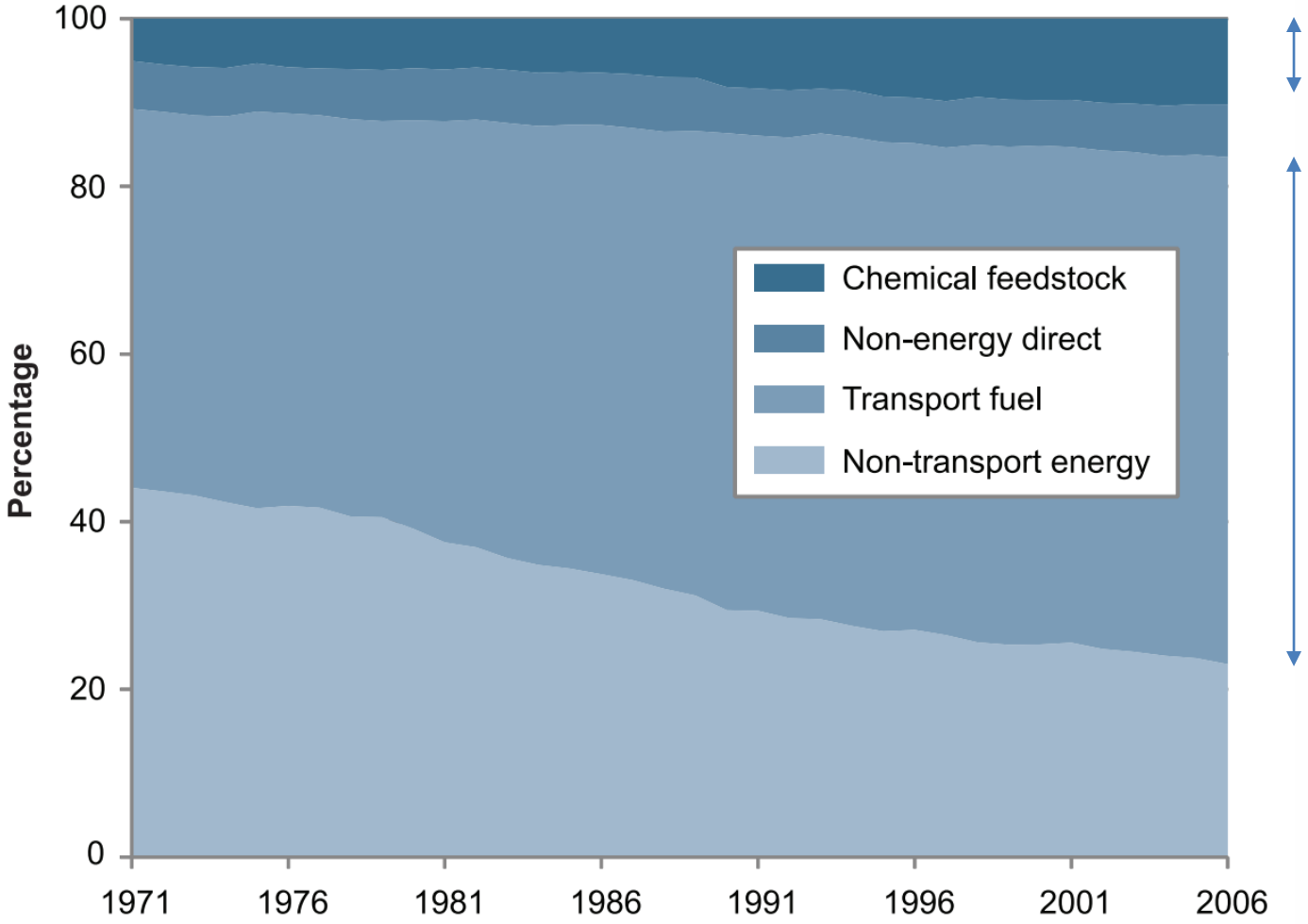
Dominant flows in today's chemical industry



About 40% of all non-fuel chemicals are synthesized from ethylene*

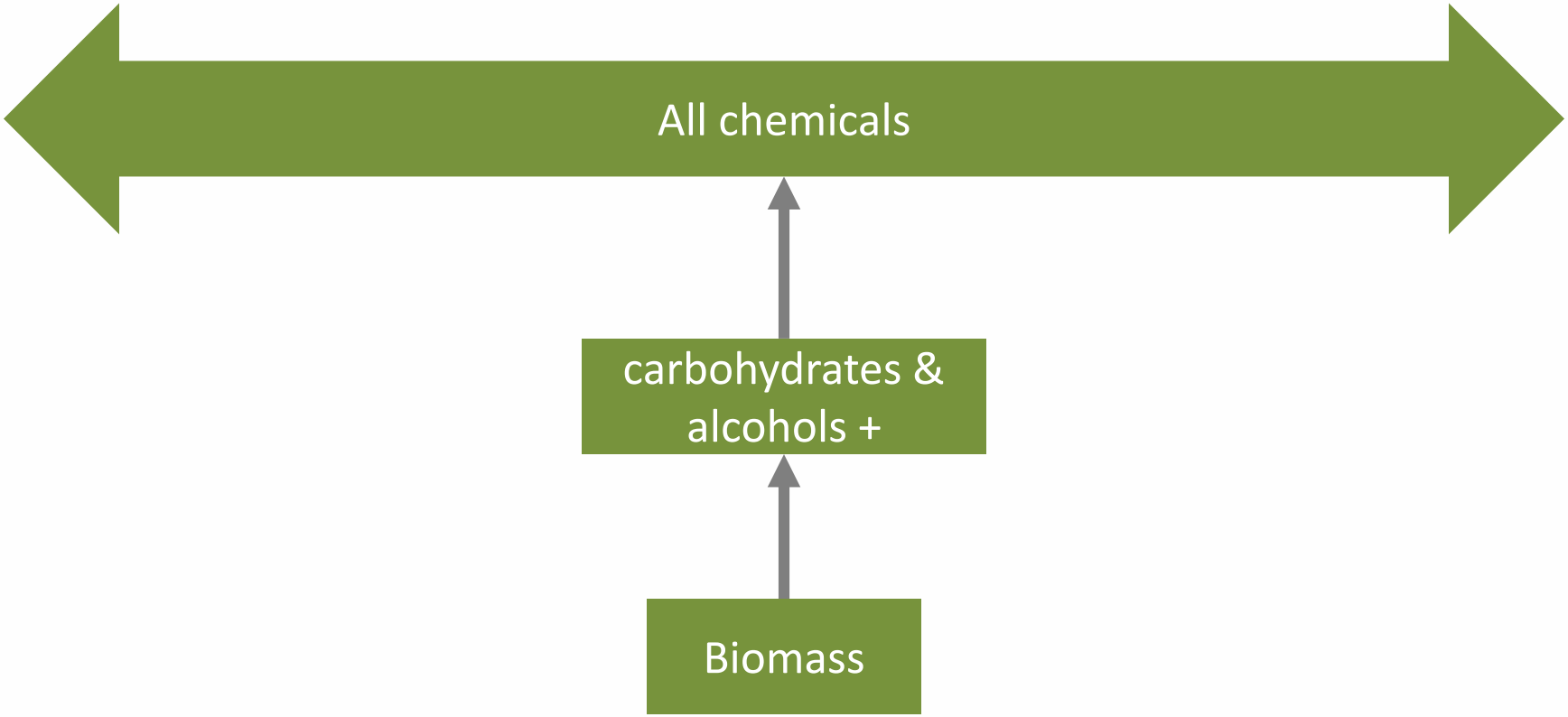
* Smiley, Robert A, and Harold L Jackson. 2002. *Chemistry and the Chemical Industry: A Practical Guide for Non-Chemists*. Boca Raton: CRC Press.

Use of crude oil and petroleum in energy-equivalent terms

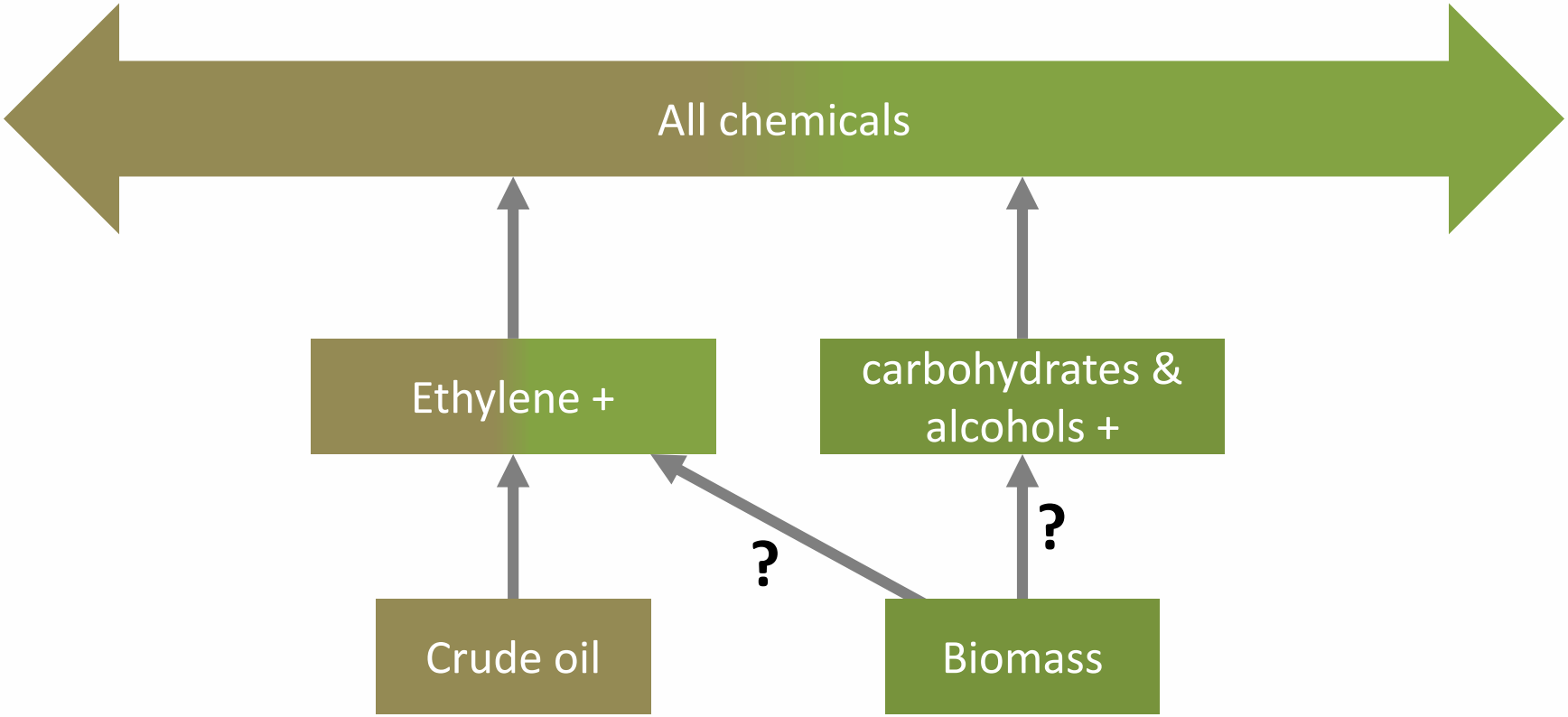


Kemp-Benedict, Eric, Sivan Kartha, and Amanda Fencl. 2012. "Biomass in a Low-Carbon Economy: Resource Scarcity, Climate Change, and Business in a Finite World." *SEI Project Report*.

A “bio-based” chemical industry



How to transition?



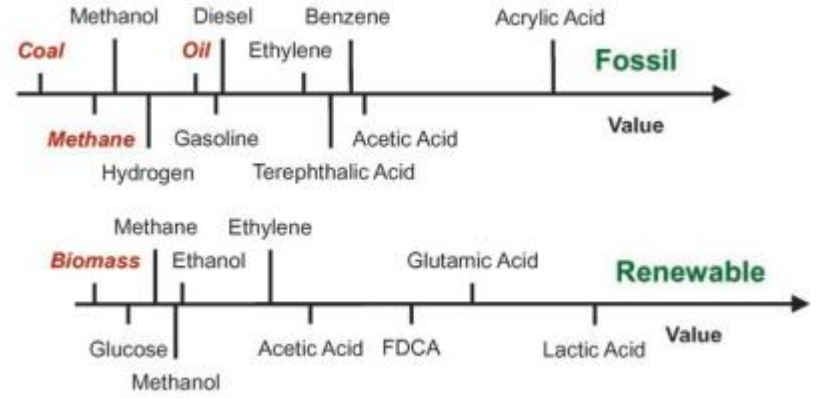
Change bulk good or feedstock?

CHEMSUSCHEM

The Renewable Chemicals Industry

Claus Hviid Christensen,* Jeppe Rass-Hansen, Charlotte C. Marsden, Esben Taarning, and Kresten Egeblad[a]

In principle, it is possible to categorize the possible routes to establish a renewable chemicals industry into two distinctly different approaches...In the first approach, biomass feedstocks are used to supply a proportion of the chemical building blocks that are currently produced from fossil resources. The second approach is to target new chemicals…



Historical precedent*

- Before WW I, the feedstock was coal tar and platform chemicals were benzene-like (aromatics), and the main producer was Germany
- During WW I, the US switched to crude oil as it was more available and actively developed a new industry based on ethylene and other platform chemicals (aliphatics)
- After the war, crude oil proved less expensive and aliphatic platform chemicals displaced aromatics

* Landau, Ralph. 1994. "Economic Growth and the Chemical Industry." *Research Policy* 23 (5): 583–99.

Leaks in the abstraction

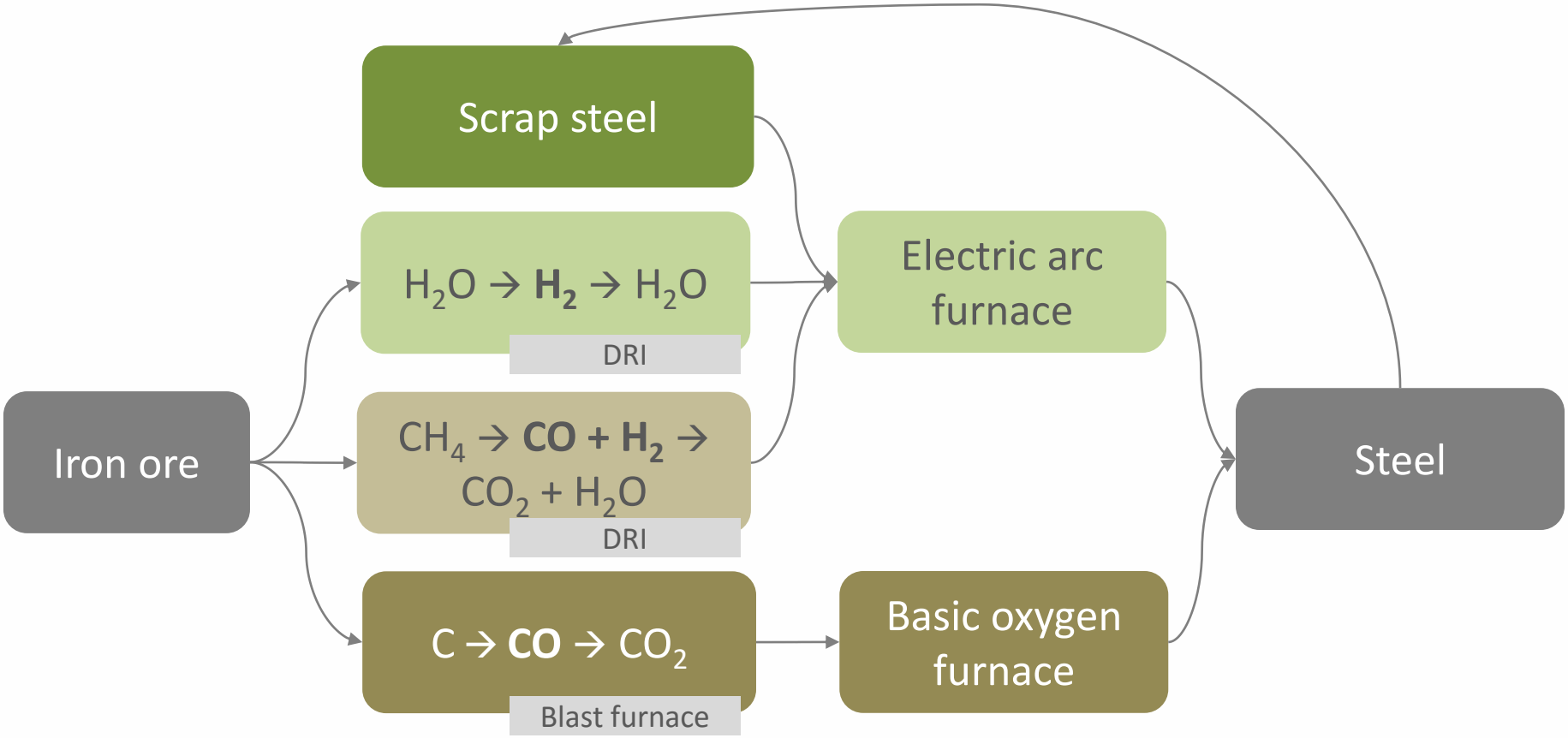
- Optimal platform chemicals for the feedstock
  - Coal tar → Aromatics
  - Crude oil → Aliphatics
  - Biomass → Carbohydrates
- Availability
  - Large, concentrated reserves vs. dispersed crops
  - Finite total reserves vs. sustained production
  - Flexible vs. constrained annual production
    - Competition between food and fuel
    - Bottlenecks in years with bad yields

STEEL

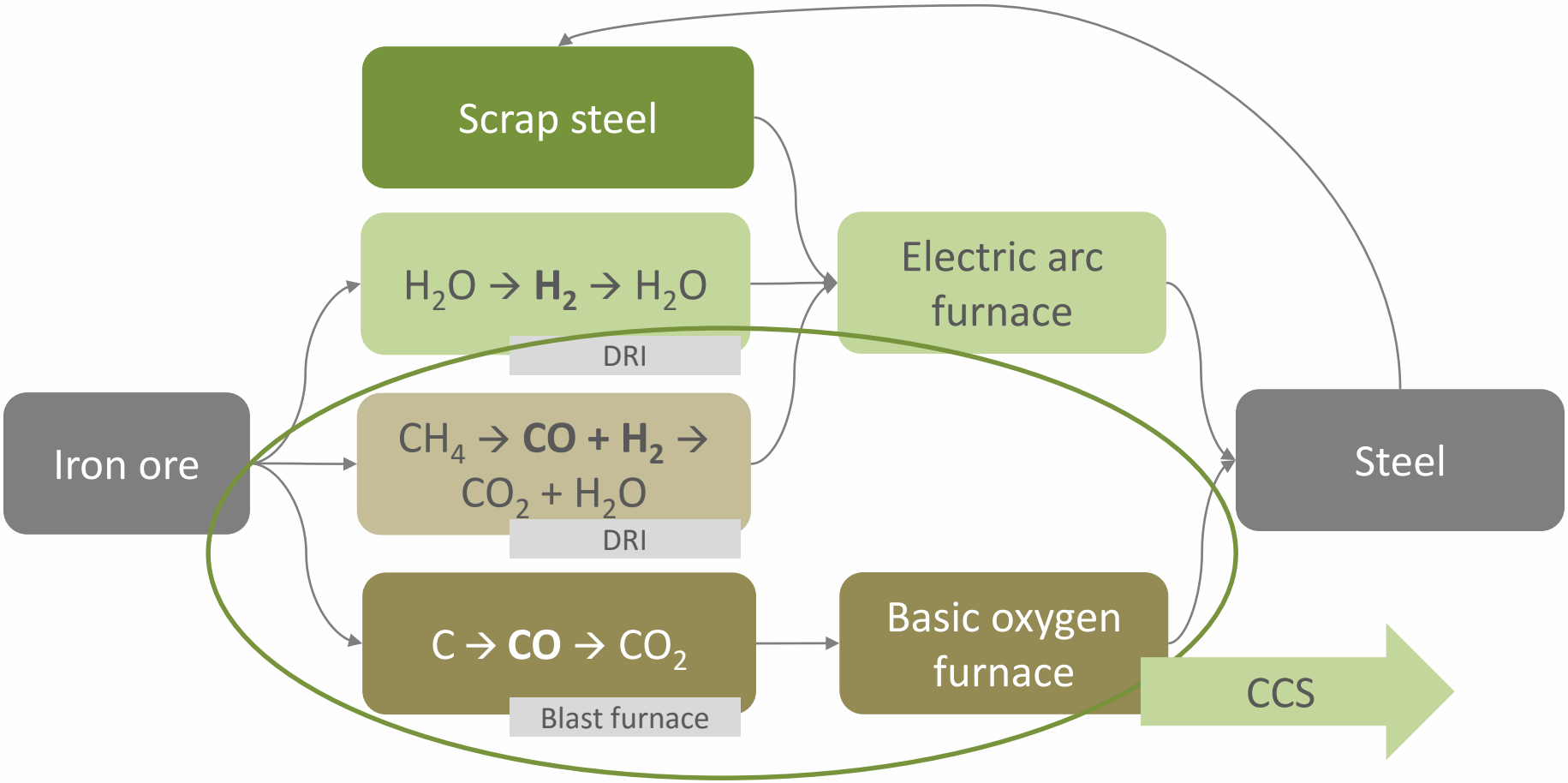
Steel background

- A highly standardized range of alloys mostly composed of iron (Fe), small amounts of carbon and nitrogen, and metals such as manganese, chromium, or nickel
- It is easy to collect scrap and waste and recycling is highly efficient, but production from ore is still needed
- Steelmaking requires elemental iron
  - Iron ore contains iron oxides (Fe_2O_3, Fe_3O_4, FeO)
  - So, must chemically reduce the iron in the oxides
- Need a *reducing agent* that becomes oxidized as the iron becomes reduced
  - The reduction process, with energy consumption, is a major source of carbon dioxide emissions

Different pathways



Different pathways



Leaks in the abstraction

- Shortages of scrap can create bottlenecks for electric arc furnaces, but they are eased with lower-carbon pathways
- Low-carbon options need finer-grade ores than the conventional blast furnace
- Steel needs carbon, not just in the final product but also at intermediate stages, requiring additional equipment
- The pure-hydrogen pathways in operation use natural gas as a hydrogen source – the hydrolysis pathway is untested, and needs a reliable electricity supply
- CCS is untested and raises problems of storage
- Alternatives are currently more costly

ELECTRICITY

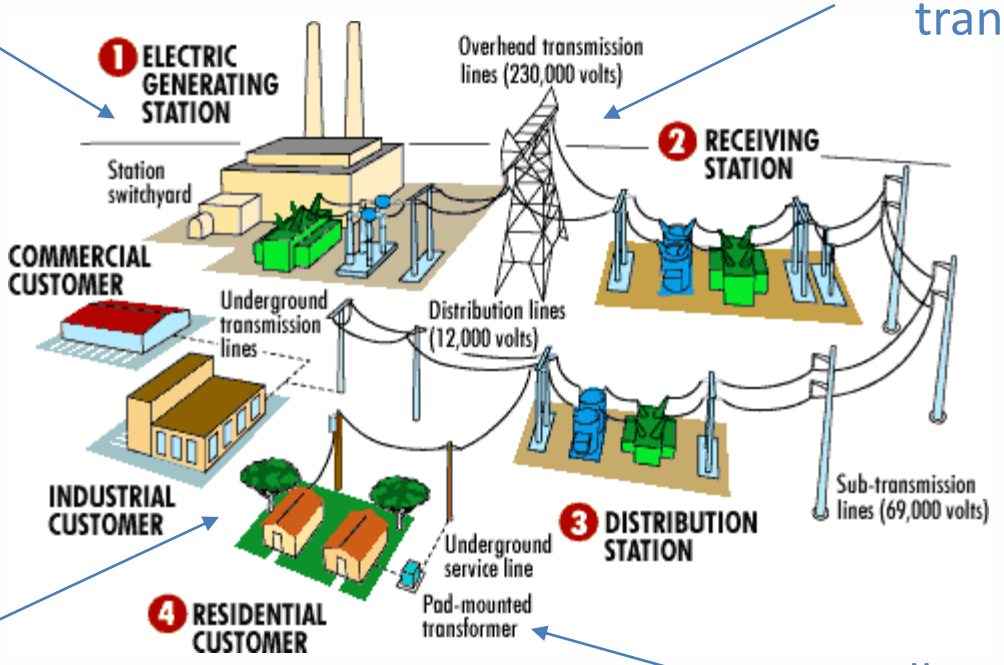
A very promising bulk good

- Electrical devices are ubiquitous
- Already there are multiple feedstocks and sources for electricity: coal, diesel, natural gas, nuclear, hydropower, solar, wind…
- Prices of solar panels are falling dramatically, wind power is increasingly attractive, and renewable targets are being met

Opportunities: electricity generation, transmission and distribution

Use renewables: solar, wind, hydropower, geothermal, wave,…

Control losses for long-distance transmission (UHVDC)



Use "smart grids" to optimally use distributed intermittent sources

Allow consumers to supply to the grid

http://www.consultantsurveyor.com/electric/electricitymap.gif

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But it is an abstraction, so it is leaky

Use "smart grids" to optimally use distributed intermittent sources

Allow consumers to supply to the grid

http://www.consultantsurveyor.com/electric/electricitymap.gif

Our alternating current grid

The standard 60 cycles per second AC supply is provided by spinning a generator's rotor…

- Burn coal and oil → boil water → steam turbine
- Nuclear reaction → boil water → steam turbine
- Combust natural gas → gas turbine
- Let water fall through a turbine

…but wind and solar are direct current (DC)

Also, the current grid is built around large plants and is not adapted to widely dispersed sources

Hierarchy of supply

- Baseload: steam takes a long time to heat, so
  - Coal and nuclear plants run continuously
  - Provide 60 Hz cycle
  - Always available
- Natural gas turbines start quickly and reliably
  - Top-up supply at peak demand
- Dam hydropower can provide either

…but solar and wind are intermittent

Electricity markets

- Many power markets take daily bids
  - Fine for baseload because it is run continuously
  - OK for peak power because demand patterns are reasonably steady
  - Too long for solar and wind
- Feed-in from small producers a complication
  - Are they guaranteed not only a price, but a sale?
  - If too much, baseload providers can't break even: limit renewable supply, or change the grid?

Water supply

- Dams are managed for multiple purposes, not just power supply
- Run-of-river hydro depends on current flow conditions
- Thermal power plants require cooling water
  - Once-through needs a reliable supply
  - Closed systems possible but consume more water
  - Salt water cooling possible but only near ocean

Leaks in the abstraction

- Hydro-dominated systems can fail in dry years
- Thermal plants may have to shut down if cooling water is unavailable
- Imported fossil fuel is vulnerable to price swings
- Nuclear power presents security issues
- Giving priority to intermittent renewables can make baseload unprofitable
- Excessive peak demand can lead to brownouts or rolling blackouts
- Stable renewables-based systems likely to require very large smart grids with dispersed supply

Conclusions

- Bulk goods are the real building blocks of the economy because they provide an "abstraction layer" on top of raw materials
- When the same bulk good can be produced from renewable or recycled materials, the path to a low-carbon economy is easier
- But the physical basis will intrude from time to time, in different ways for different feedstocks
- This has macroeconomic implications