RÉFLEXIONS

SUR LA

PUISSANCE MOTRICE

DU FEU

ET

SUR LES MACHINES

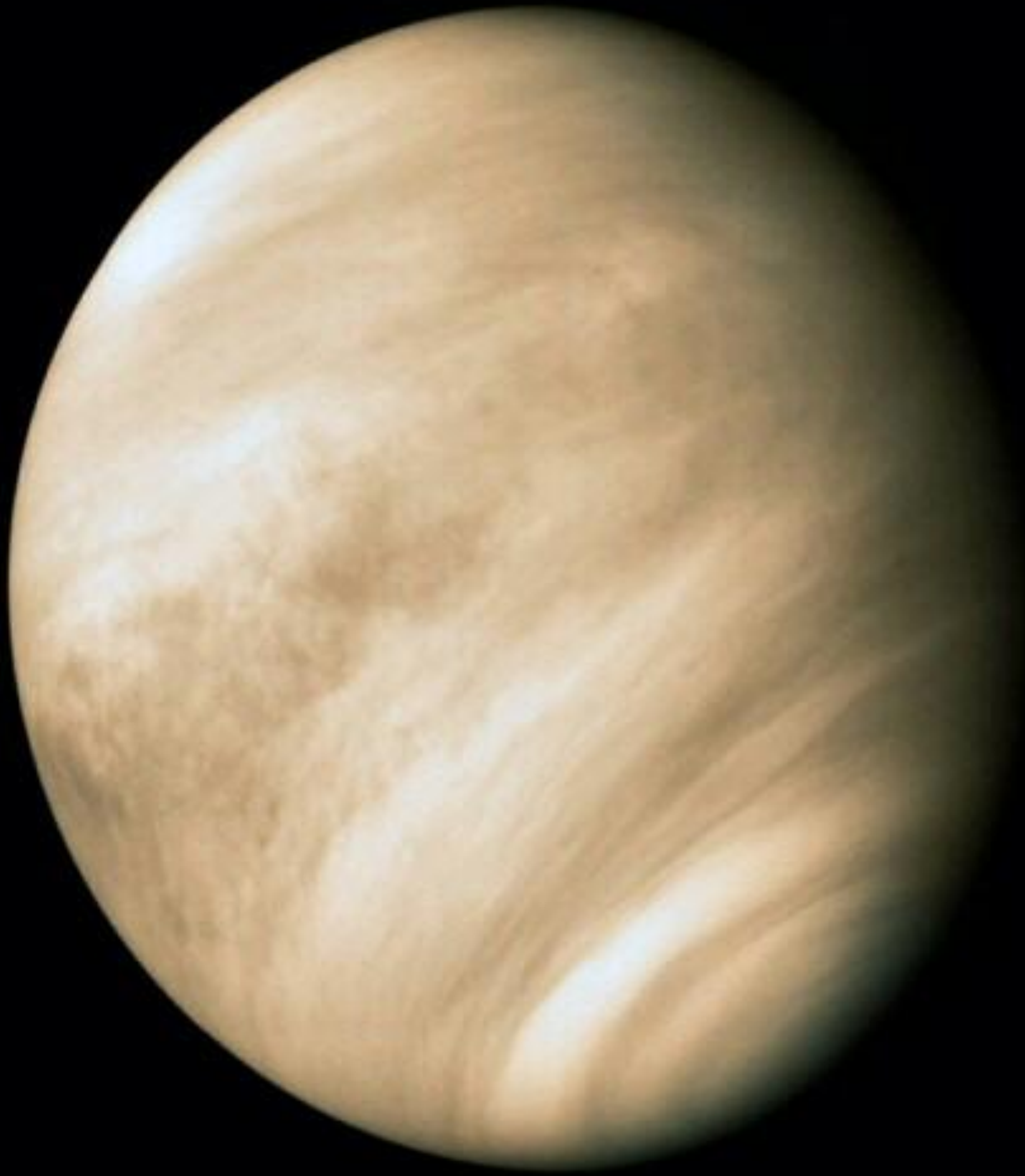
PROPRES A DÉVELOPPER CETTE PUISSANCE.

PAR S. CARNOT,

ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE.

A PARIS,
CHEZ BACHELIER, LIBRAIRE,
QUAI DES AUGUSTINS, N°. 55.

1824.



http://www.celestiamotherlode.net

If not biofuels, then what?

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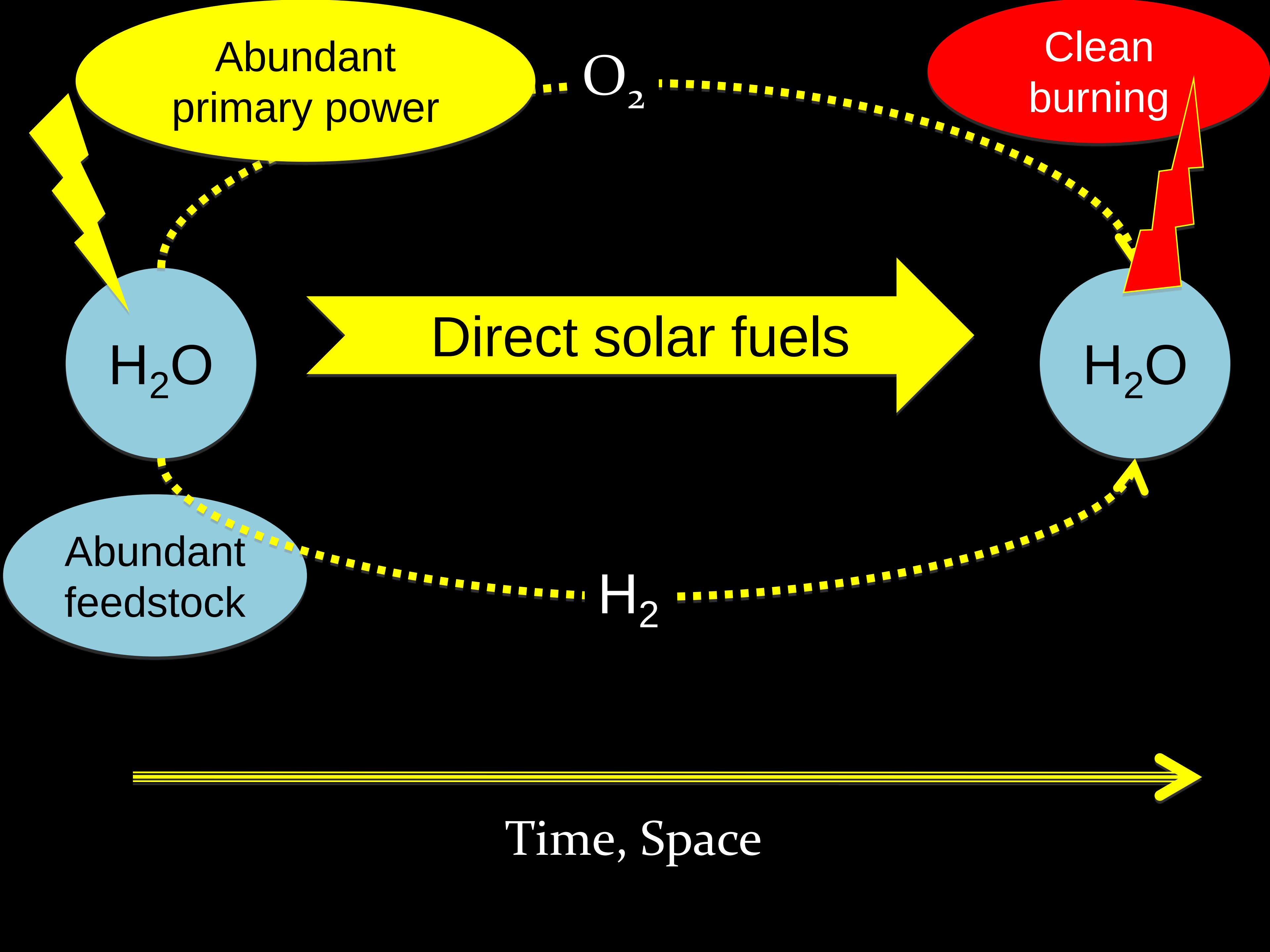
Sustainability of the Carnot civilization

- Converting heat to mechanical work is a brilliant solution. But is it sustainable?
- Sustainability is a relative concept, not an absolute one. We must compare alternatives.
- Solar fuels: fuels without the bio, H_2.
  - Energy costs.
  - Land requirements.
  - Investments needed.


Abundant primary power
O_2
Clean burning
H_2O
Direct solar fuels
H_2O
Abundant feedstock
H_2
Time, Space

The questions to be answered

- Which technologies we want to use?
- Where are we now?
- Where do we want to be in 2030?
- How much net energy can we produce?
- How much land is needed?
- How many dollars will we need to spend?
- Is it feasible?

Which technologies?

- Direct water photolysis.
  - Still a distant prospect. Needs a lot of research.
  - Makes much more sense than fusion research, but does not get as much money and attention.
- Electrolysis from solar electricity.
  - Wind or solar (thermal or PV) + Conventional electrolysis.
  - Commercial technologies, but need drastic cost reductions and novel materials.

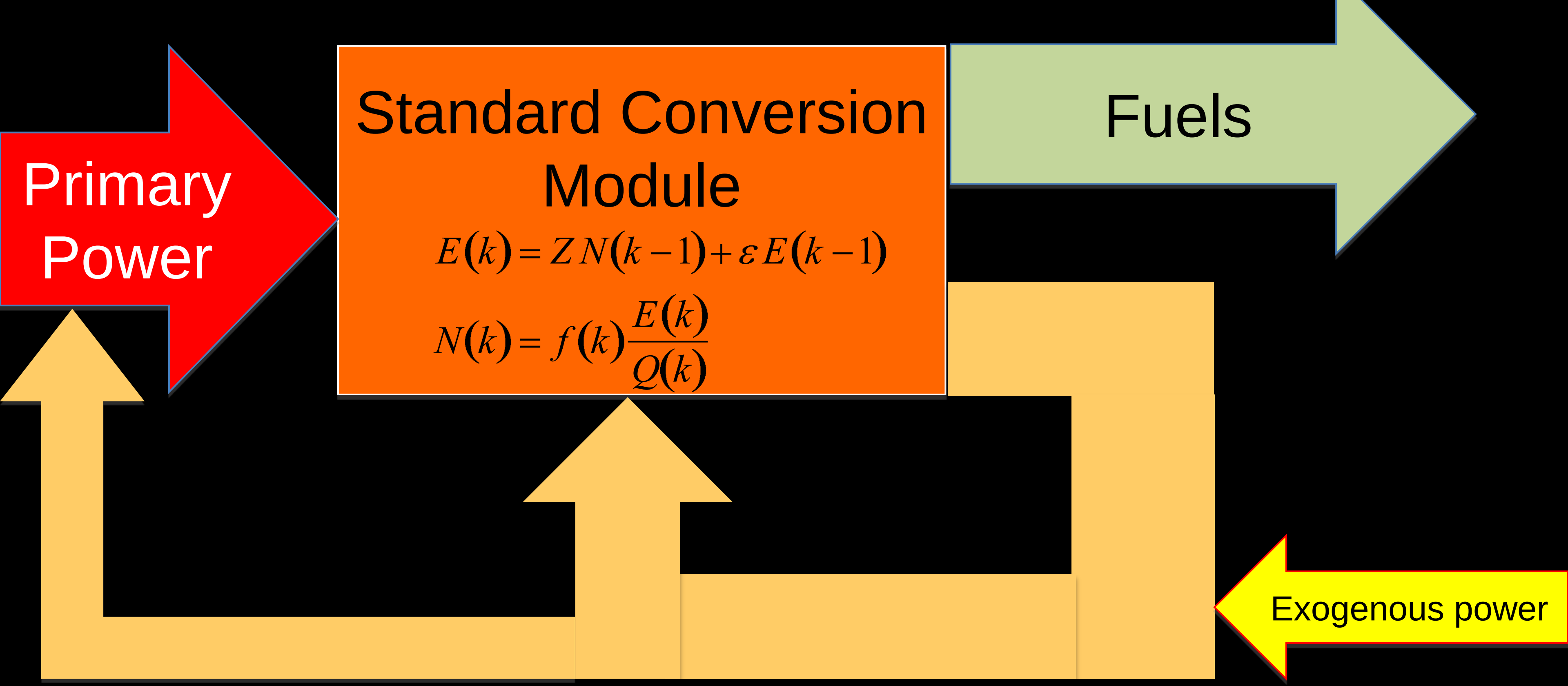
Where are we now?

Source	Production (GNm^3/yr)	(%)
Natural gas	240	48%
Oil	150	30%
Coal	90	18%
Electrolysis	20	4%
Total	500	

http://www.hydrogenassociation.org/general/faqs.asp#howmuchproduced

Where do we want to be?

- EIA projection for 2030: 122 Quads of liquid fuels.
- This means 129 EJ or annualized power of 4.1 TW.
- Moles of H_2 (H_2O) required (efficiency as ICE):
  - 129 EJ @ 0.24 MJ/mol = 538 Tmol H_2.
- Water required (100% conversion efficiency):
  - 9.7 Gm^3 (L = 2.13 km)
  - Lake of average depth 15 m, surface area 645 km^2.
- Processing capacity:
  - 26.5 Mm^3/day = 167 Mbbl/day

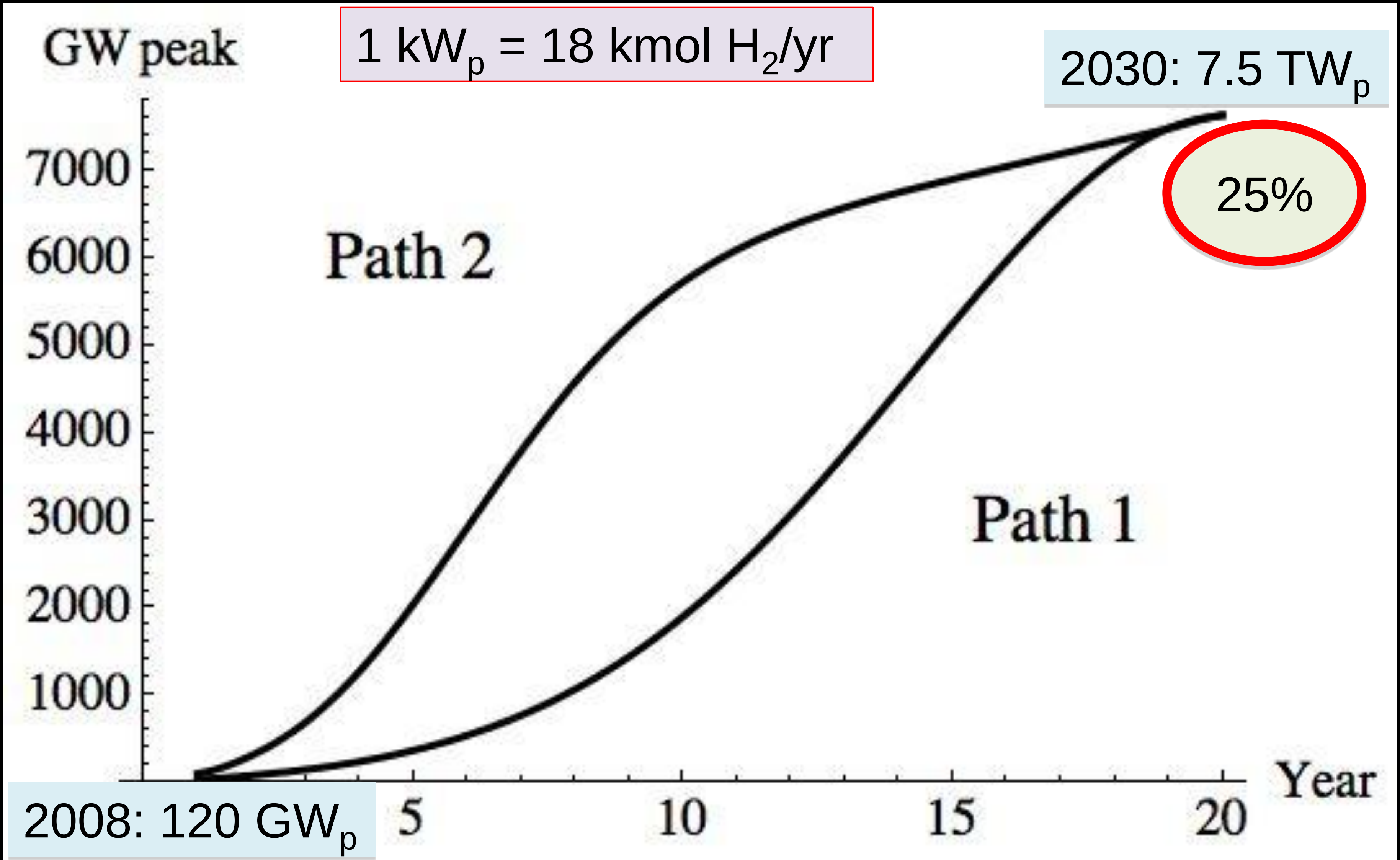


A fraction of the primary power converted by the module has to go back to supply power for growth, maintenance, replacements, and feedstock production. This fraction may exceed the total power generated by the module (exogenous growth).

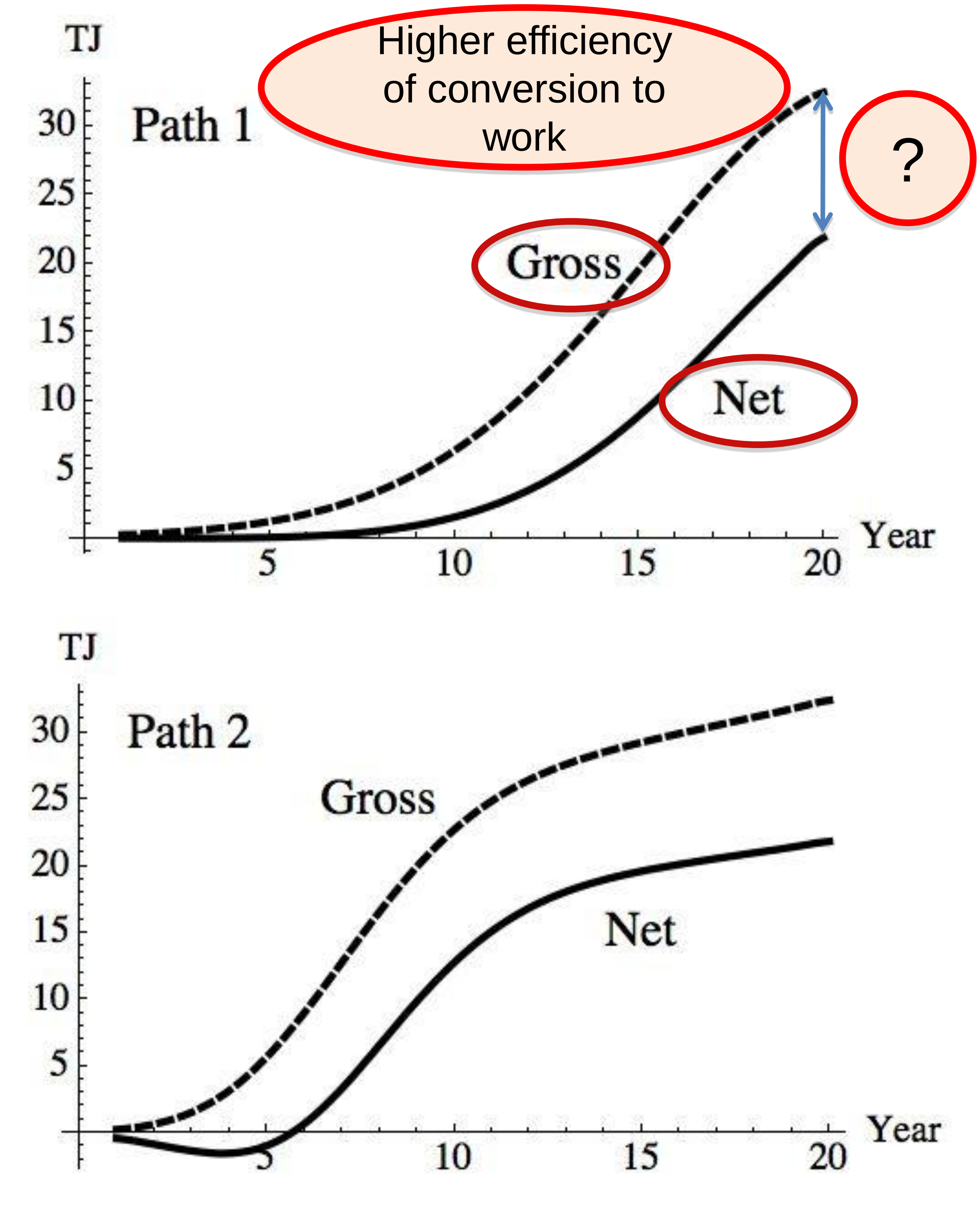
What do we need to know?

- The technical parameters that describe the technology of the conversion module.
  - Since this is a very high level description, we do not need to know the working details of the technology.
- The deployment objectives.
  - These are the set of political or commercial decisions taken about the deployment of the new technology.
- The deployment path.
  - Basically, this consists of the specification of, for instance, the desired growth rate over the deployment period.

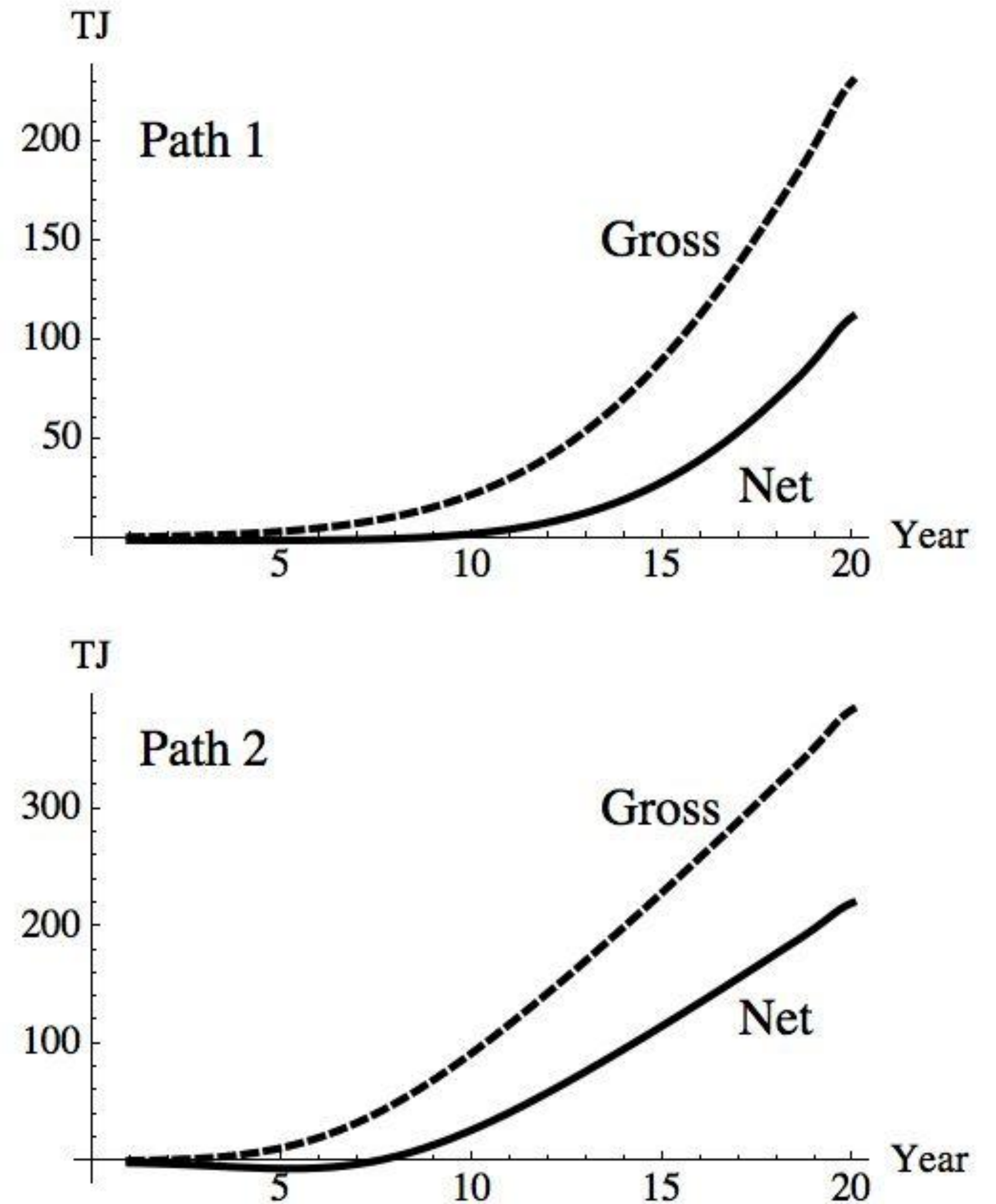
Deployment alternatives: wind



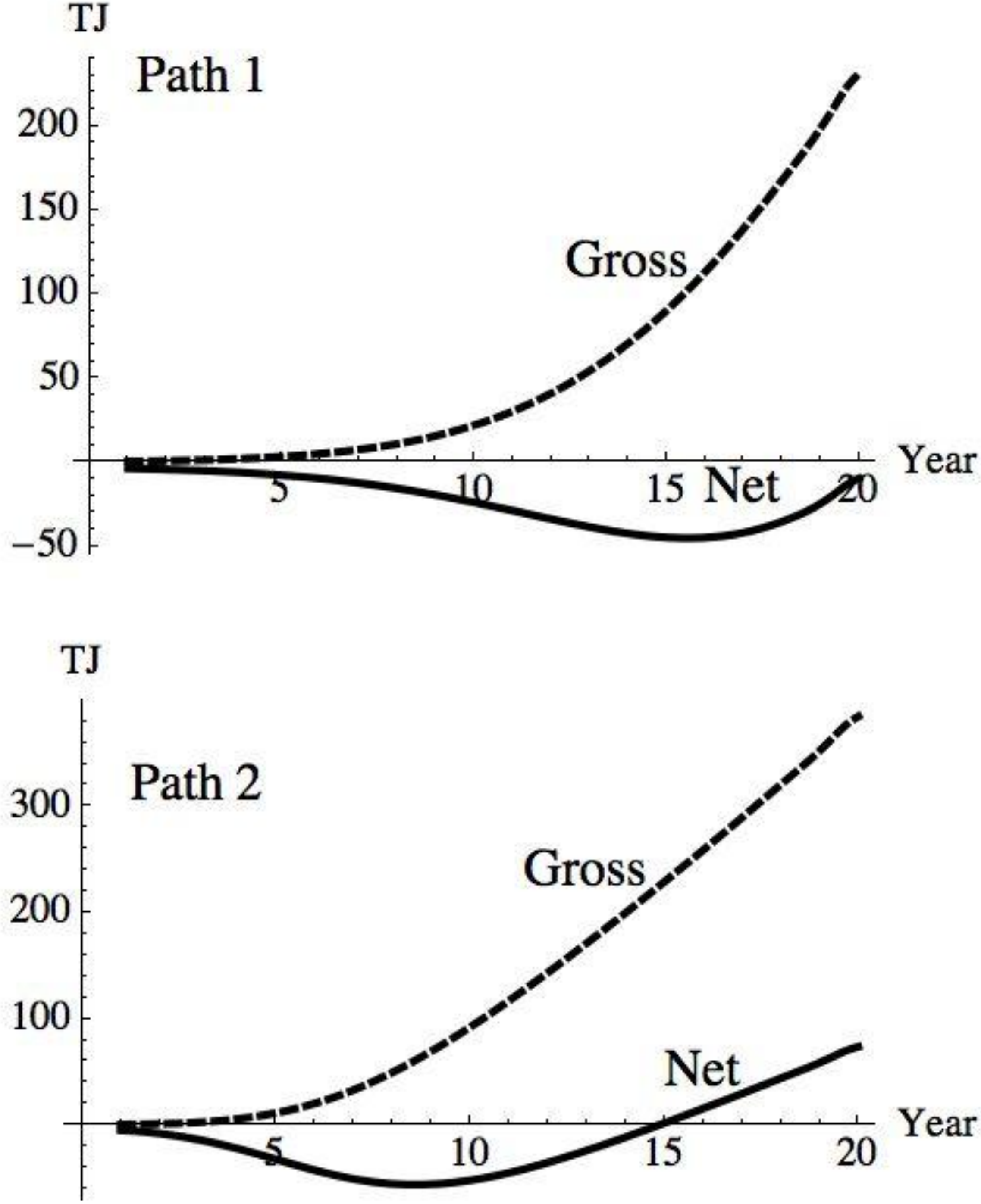
Energy produced (annual)



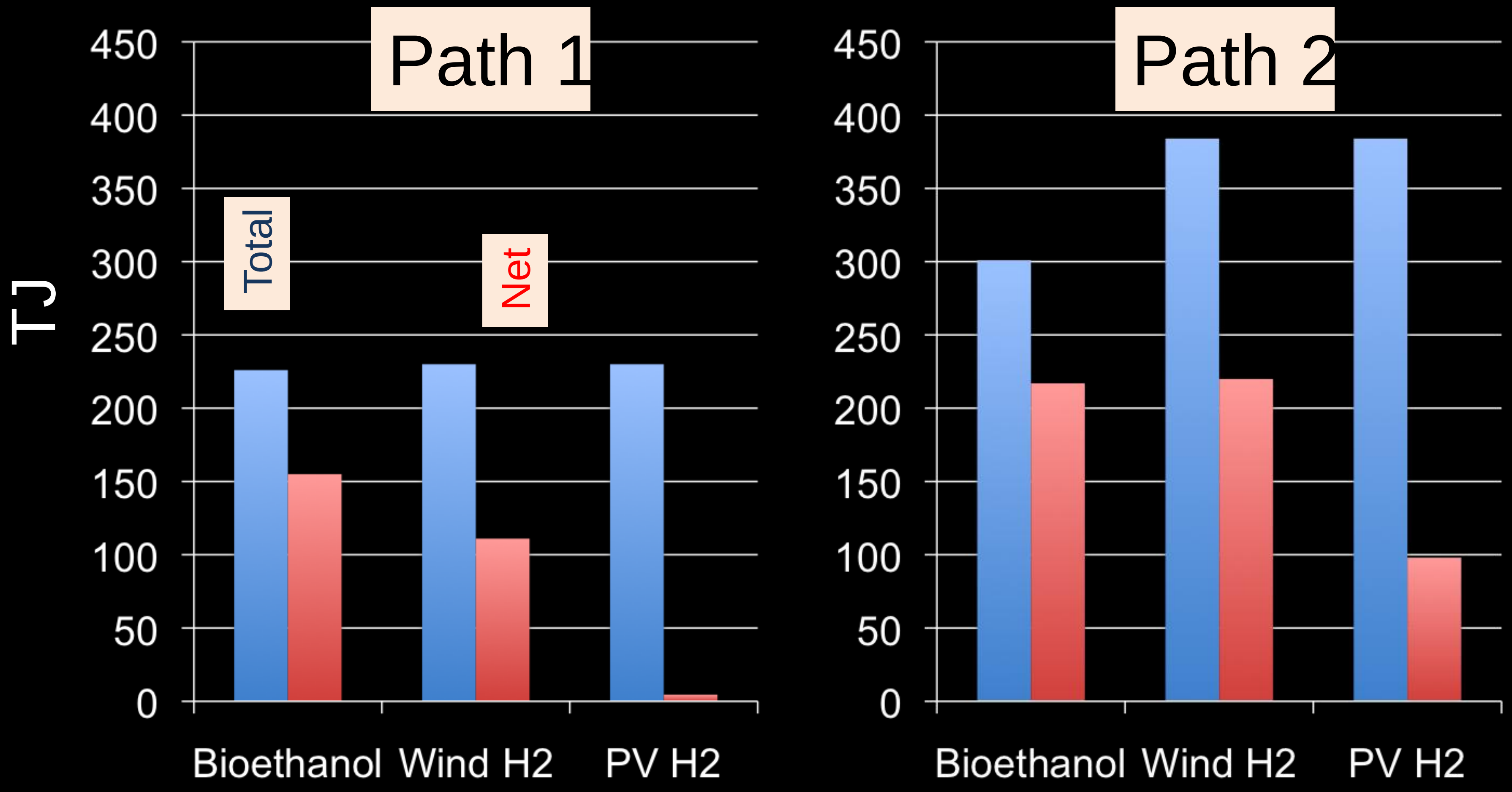
Energy produced (accum.)
Wind



Energy produced (accum.)
Solar PV



Total and net energies



Minimum areas for 1 TW of fuel power

	Bioethanol	**Wind H2**	**PV H2**
Power (TW or TW_p)	1	7.5	9.5
Density ($MW_{(p)}/km^2$)	0.56	6.5	1,000
Area (Mkm^2)	*1.8*	*1.1*	*0.062*
Corrected# (Mkm^2)	1.8	.8	0.062
NPV* (Trillion $)	3.0	21.3	34.5

Corrected for different efficiencies of net fuel conversion to mechanical work.

*NPV (Net Present Value): required investments for Path 2 and higher cost.

Emissions avoided (H_2)

- 1 kW_p is equivalent to 18 kmol H_2/yr = 4.32 GJ/yr.
- Emissions from gasoline (EPA): 20 kgC/GJ.
- Avoided emissions from 1 kW_p = 86.4 kg/yr.
- One wedge (1 GtonC/yr) will require 11.5 TW_p of wind electricity (assuming no gains in efficiency in relation to ICE).
- Trillions of US$ in investments – not including infrastructure.

If not biofuels, then what?

- Fossil fuels for sure, unfortunately.
  - Who is going to let go of them?
- Solar fuels are one of the best options we have for clean, sustainable energy in the long run. Goals for solar fuels deployment are achievable, BUT:
  - There are very high financial costs.
  - There are still very high energy costs.
  - There is a lot of research needed to make them viable.
  - Definitely not for the immediate future.

If not biofuels, then what?

- Biofuels, of course!
  - Biofuels will be needed for quite some time yet. So, let us get to work on making them better.
- Ultimately, only a radical transformation of the transportation means and needs of Mankind will lead to real sustainability. There are limits to scientific and technical fixes for an ever increasing demand for power.
- *The challenge is as much social and economic as it is one of engineering clever solutions for the post-Carnot world.*

References

- The work presented in this talk is based on a conceptual framework and mathematical model which can be found in two papers published in Energy:
- *The fossil energy/climate change crunch: Can we pin our hopes on new energy technologies?*
  - Energy, Volume 35, Issue 3, March 2010, Pages 1312-1316
- *Renewable energies: Choosing the best options*
  - Energy, In Press, Corrected Proof, Available online 5 May 2010