International Energy Agency: Implementing Agreement for a
Programme of Energy Technology Systems Analysis;
Annex IX: ***Energy Models Users' Group***

Technology Dynamics in 4E models and Social Perspectives

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Content

1. Energy, Environment, Economic, Engineering: combined analyses and models
2. Focus on technological progress
3. Technology dynamics: mechanism and models
4. The socio-technical perspective

2 – Focus on technological progress

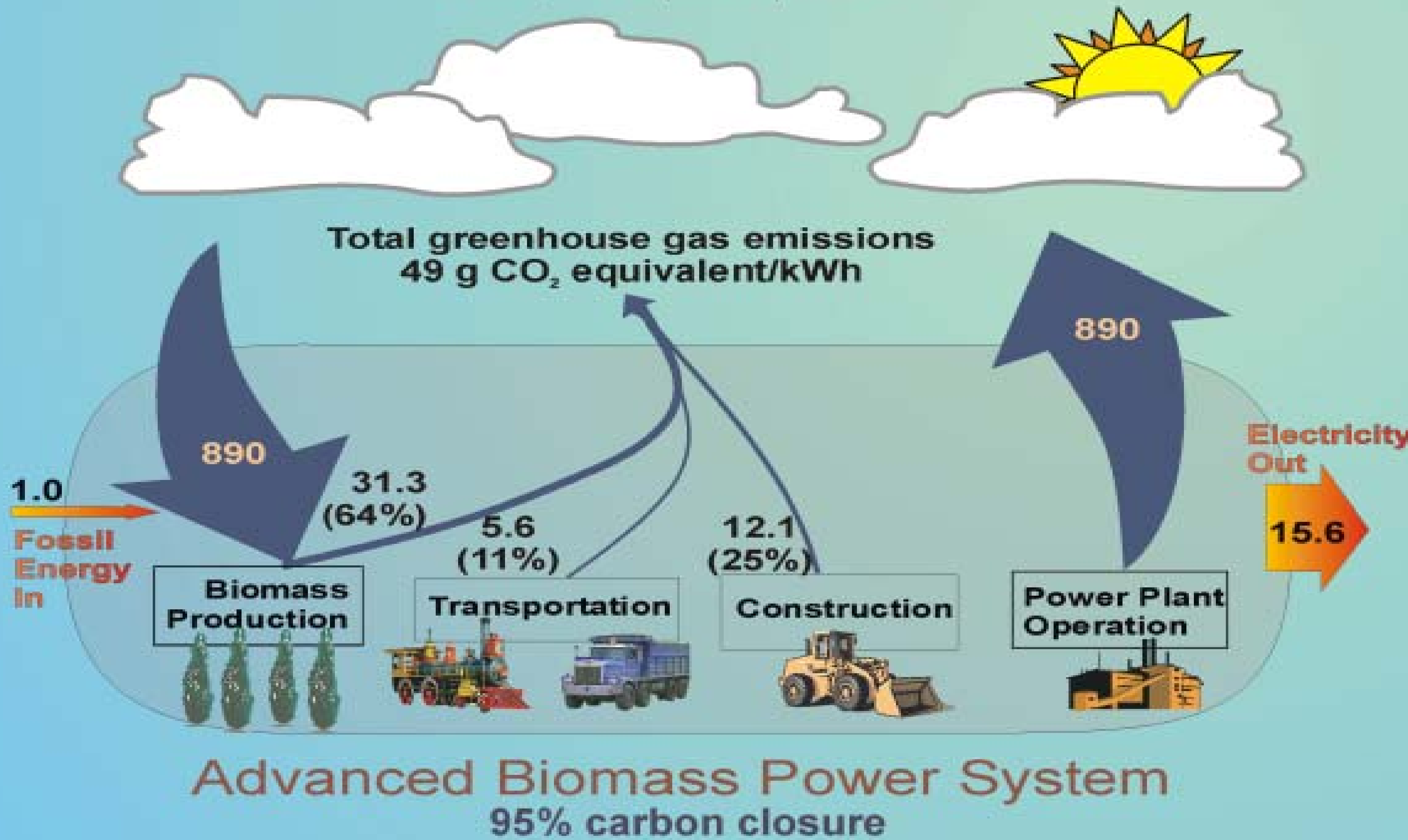
1. Scope: Intensive (Life Cycle Analysis)
   Extensive (Reference Energy System)

2. Model: Representation
   Data need (Life Cycle Inventories)

3. Long term market perspectives

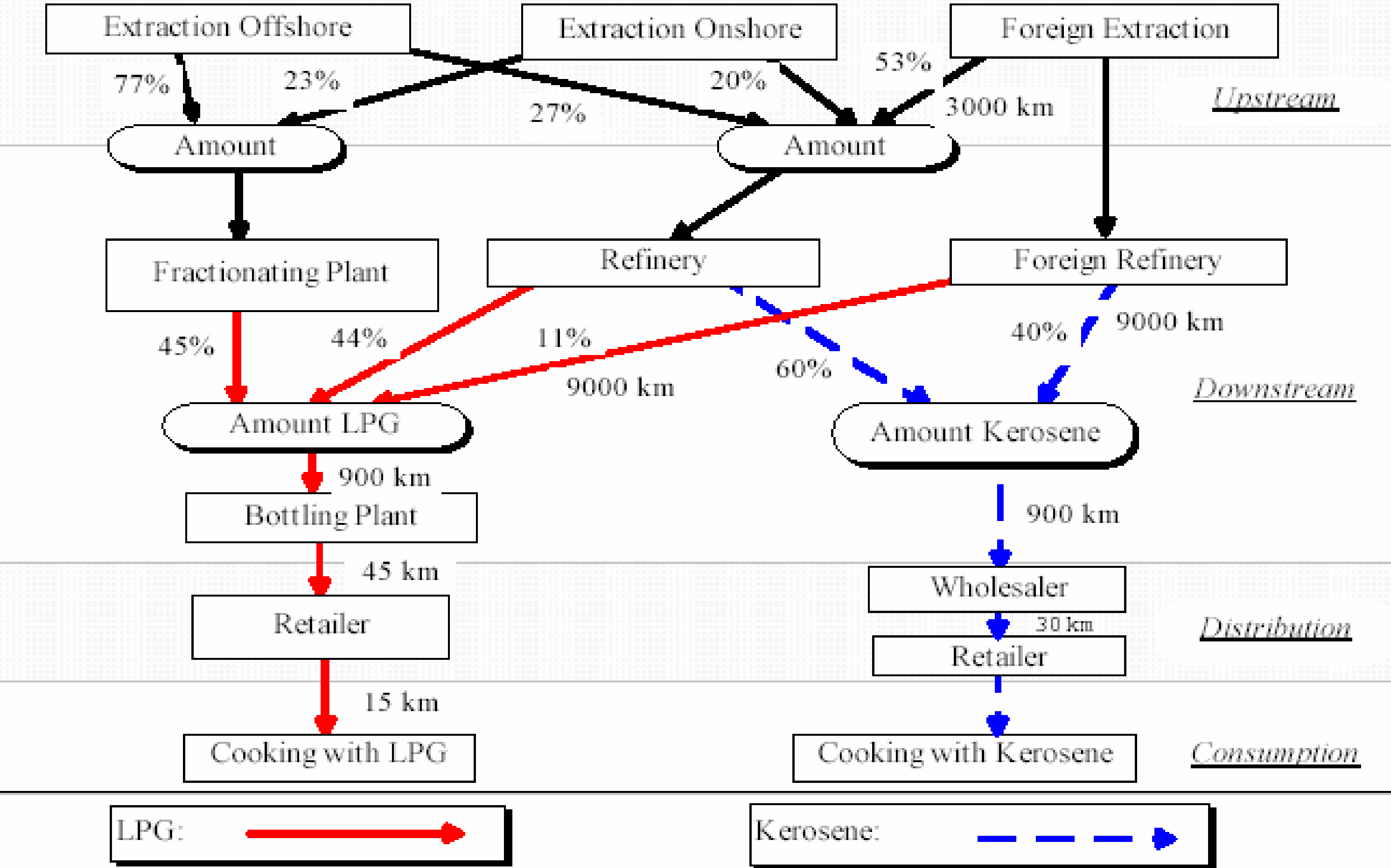
Life Cycle GWP and Energy Balance for Advanced IGCC Technology using Energy Crop Biomass

Future, wide-spread potential



aken from a presentation of Margaret Mann, NREL, Golden, Colorado, USA

1a – Intensive: Unit values, cradle to grave



2.1b – all flows & technologies in the production tree

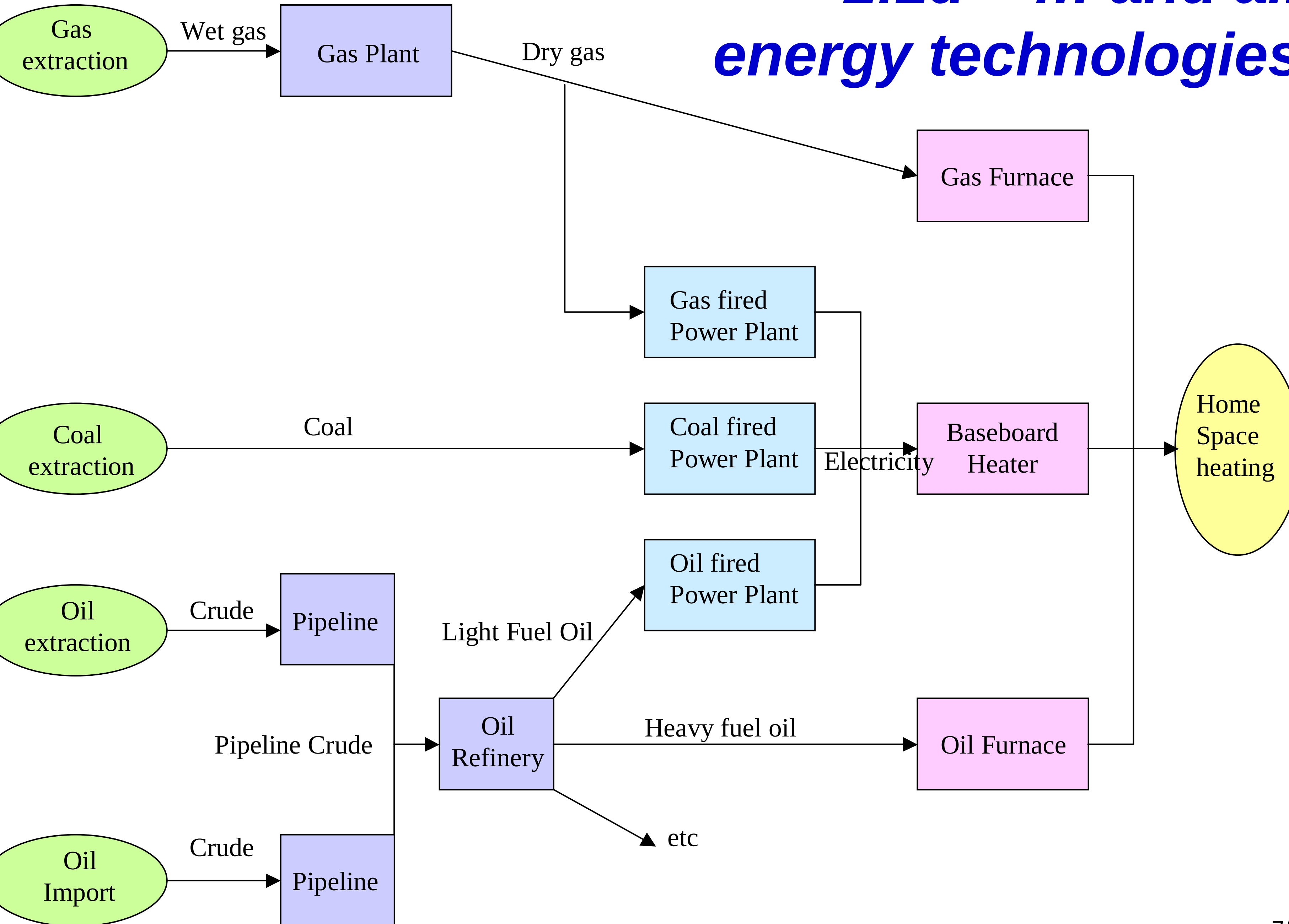
(Jungbluth, N., Kollar, M., Koss, V. 1997: "Life Cycle Inventory for Cooking." In *Energy Policy* Vol. **25** (5): 471- 480)

2.1c – Extensive: all energy flows …

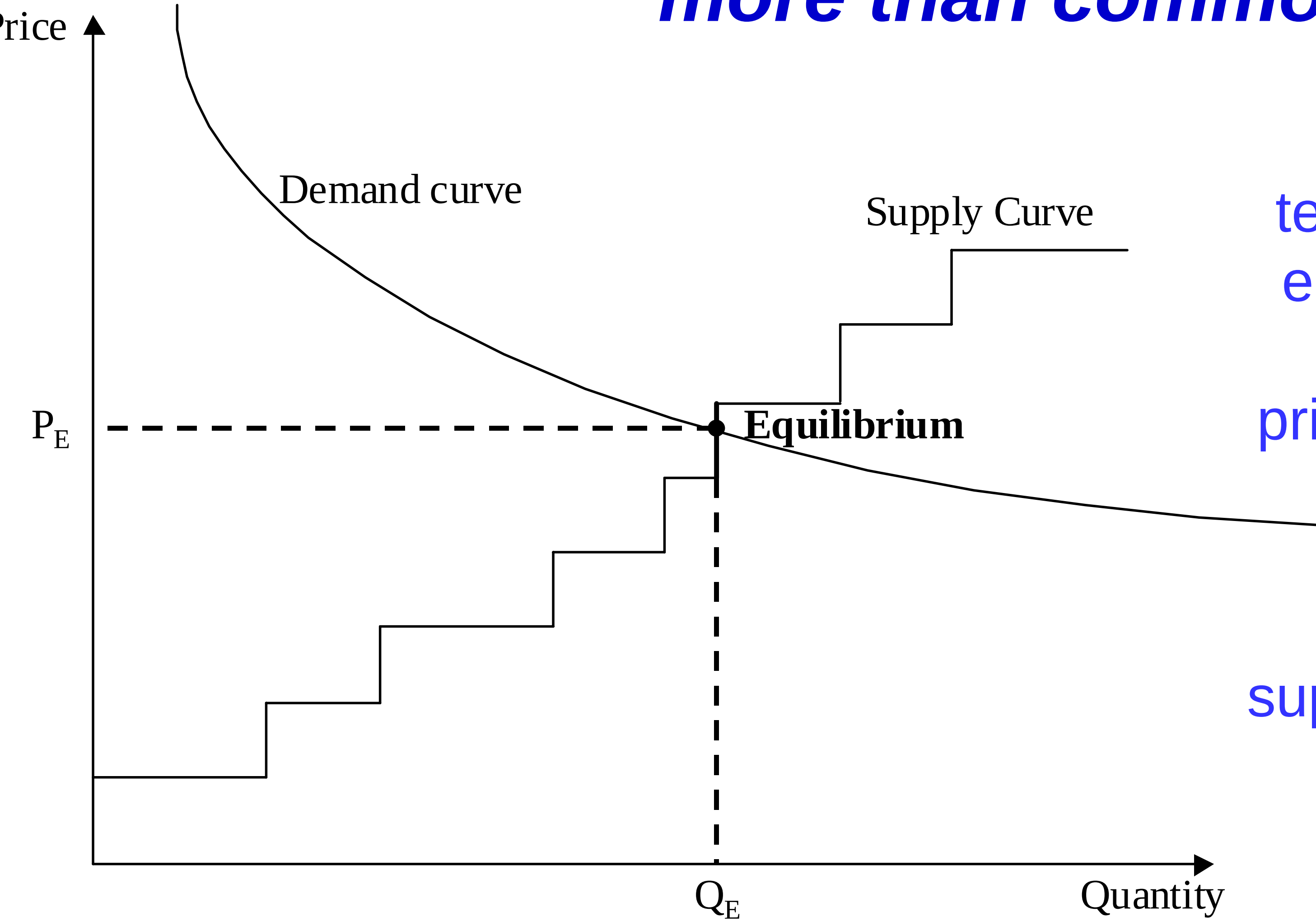
	Thousand tonnes of oil equivalent										
SUPPLY AND CONSUMPTION	**Coal**	**Crude Oil**	**Petroleum Products**	**Gas**	**Nuclear**	**Hydro**	**Geotherm. Solar, *etc.***	**Combust. Renew.**	**Electricity**	**Heat**	**Total**
Production	698779	164131	-	31365	4553	23859	-	215930	-	-	1138617
Imports	1369	60260	28315	-	-	-	-	-	155	-	90098
Exports	-67316	-7550	-11495	-	-	-	-	-	-876	-	-87238
Intl. Marine Bunkers	-	-	-3969	-	-	-	-	-	-	-	-3969
Stock Changes	4526	-1297	-1369	-	-	-	-	-	-	-	1860
TPES	**637358**	**215544**	**11481**	**31365**	**4553**	**23859**	**-**	**215930**	**-722**	**-**	**1139369**
Transfers	-	-	-	-	-	-	-	-	-	-	-
Statistical Differences	13753	-3824	-1989	-3988	-	-	-	-	-	-	3952
Electricity Plants	-290951	-816	-11103	-1344	-4553	-23859	-	-838	126563	-	-206903
Heat Plants	-35986	-123	-4096	-1697	-	-	-	-490	-	36585	-5807
Gas Works	-4670	-	-228	3827	-	-	-	-	-	-	-1072
Petroleum Refineries	-	-204068	201793	-	-	-	-	-	-	-	-2275
Coal Transformation	-45850	-	-	-	-	-	-	-	-	-	-45850
Own Use	-30016	-4422	-15046	-7822	-	-	-	-	-19240	-9335	-85882
Distribution Losses	-126	-	-17	-643	-	-	-	-	-8881	-430	-10097
TFC	**243511**	**2291**	**180795**	**19697**	**-**	**-**	**-**	**214602**	**97720**	**26820**	**785435**
Industry	165870	2092	51984	12449	-	-	-	-	61562	20110	314067
Transport	5280	-	69161	228	-	-	-	-	1307	-	75977
Agriculture	3688	-	16119	-	-	-	-	-	6676	57	32841
Comm. and Publ. Services	5400	-	16014	588	-	-	-	-	6439	450	28892
Residential	43981	-	13652	6431	-	-	-	214602	15817	5581	300064
Non-specified	4174	136	-	-	-	-	-	-	5917	622	10912
Non-energy use	8818	-	13865	-	-	-	-	-	-	-	22683
Electr. Generated - GWh	*1121973*	-	*47343*	*5474*	*17472*	*277432*	-	*1963*	-	-	*1471657*
Heat Generated - TJ	*1307224*	-	*147659*	*63965*	-	-	-	*13187*	-	-	*1532035*

Example: Energy Balance of China, 2001 (Excluding Hong Kong; source: IEA)

2.1d – … and al[l] energy technologies



2.2a – Modelling energy technologies more than commodities …



Focus on technologies: equilibrium & quantities & prices of each commodity result from demand & supply curves, which are technology explicit

2.2b – … requires large amount of data (data intensive)

For any cell of the energy balance, it is necessary to identify and characterise the most important producing and consuming technologies.

Such a “three dimensional” energy balance, which is necessary to represent present energy systems, has to be developed, in a way similar to the data bases underlying every Life Cycle Analysis (Life Cycle Inventory)

2.3a – Long term market perspectives …

In the short term, the market of commodities such as crude oil is global, huge and by far the most rentable.

The market for energy services is economically larger and potentially more rentable in the near future, because the same services (space heating, passenger transport, etc) can be provided with efficiency gains of a factor of 4 or more; however it is difficult to develop.

Energy related supply and demand technologies will develop into the largest long term market.

2.3b – … and hope

The sustainable development paths, which emerge from most scenario studies, assumes technological progress, capable of

- Making new energy source available,
- Which do not contribute to change the climate / pollution,
- Are economically affordable, and
- Satisfies the demand for energy services in a secure way.

3 – Taking into account technology dynamics in systems analysis & models

What technological improvements? How to model them?

1. Learning by doing (endogenous);
2. Learning by searching (endogenous);
3. Clustering base components (endogenous);
4. Global vs. regional learning (spill-over across regions);
5. New technologies (exogenous);
6. Time dependent improvement (exogenous);
7. Keep the second / third best.

Graphical summary: technological and social preferences

***3.1a – Learning by doing & using** (endogenous)*

A learning curve illustrates how experience improves performance of in given activity (Barreto,PhD thesis, 2001).

$$UC(CumC) = a * CumC^{-b}$$

Where: CumC = Cumulative Capacity (proxy of cumulative experience)

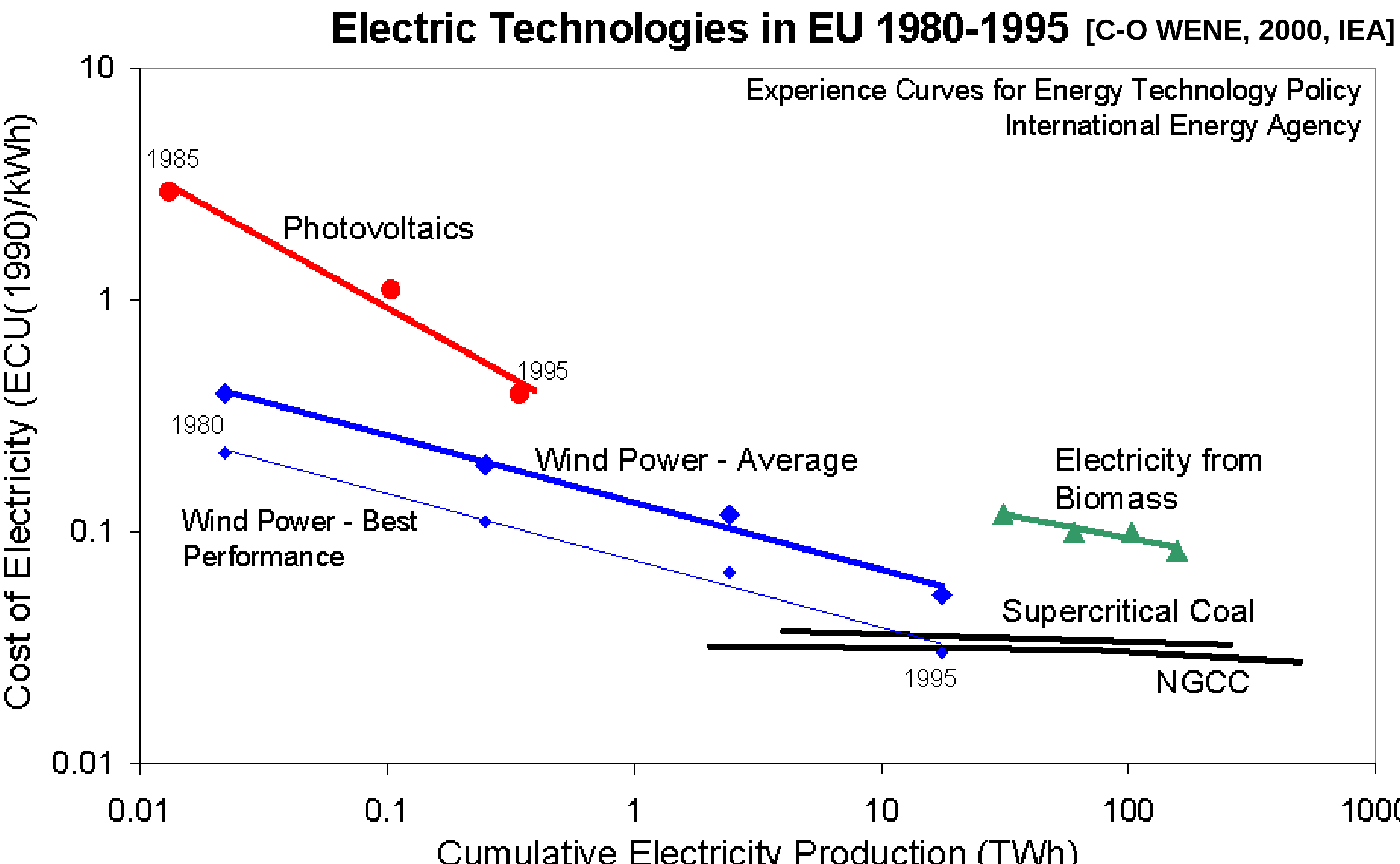
UC = unit cost (e.g. $/kW for power plants)

a = unit cost of the first unit

b = learning index (the “progress ratio” pr = 2^{-b})

The progress ratio is the rate at which the cost declines each time the cumulative production doubles; e.g. pr = 80% implies that the cost becomes 80% of the original when the cumulative capacity is doubled.

3.1b – Learning by doing & using *(endogenous)*



3.2a – Learning by searching *(endogenous)*

R&D expenditures produce high payoffs (public, privete).

In energy systems, R&D investments give governments the opportunity to supplement market based private R&D.

$$UC(CumC, R\&D) = a * CumC^{-b} * R\&D^{-c}$$

Where: CumC = cumulative capacity (proxy of cumulative experience)

R&D = cumulative R&D expenditures

UC = unit cost (e.g. $/kW for power plants)

a = unit cost of the first unit

b = learning by doing index (the "progress ratio" pr = 2^{-b})

c = learning by searching index

3.2b – Learning by searching:
main characteristics of power plants (Barreto, 2001)

echnology	Inv. Cost (US$/kW)	Fixed O&M (US$/kW/year)	Var. O&M (US$/kWyr)	PR lbd	PR lbs	Efficienc (Fractio
onventional Coal	1357	69	22.7	1	1	0.39
dvanced Coal	1584	67.5	23.6	0.89	0.95	0.45
as Steam	987	50.6	17.7	1	1	0.41
as CC	600	36.6	19.7	0.76	0.98	0.51
as Turbine	350	58.5	16.03	1	1	0.36
as Fuel Cell	2463	43.5	80.	0.81	0.89	0.65
il Steam	1575	63.6	18.13	1	1	0.38
uclear	3075	114	5.91	1	1	0.34
ew Nuclear	3400	114	5.91	0.96	0.98	0.36
ydro	3562	49.5	3.9	1	1	0.70
olar PV	5000	9.	39.4	0.75	0.90	0.1
'ind	1035	13.5	26.3	0.84	0.93	0.33
eothermal	3075	7.8	92	1	1	0.3

3.2c – Learning by searching:

Annual and cumulative R&D expenditures for 1997

(from Barreto, PhD thesis, 2001)

Technology	Gov. R&D	Business R&D	Total R&D	Cum. Gov. R&D	Cum. Business R&D	Total Cu[m.] R&D
New Nuclear	749	24	773	22927	2244	25171
Advanced Coal	116	104	220	5411	3983	9394
Gas CC	69	1062	1131	1755	25771	27526
Wind	143	266	409	2489	4361	6850
Gas Fuel Cell	86	294	380	1406	6669	8075
Solar PV	211	198	409	3803	11091	14894
Total	1374	1948	3322			

3.3 – Clustering base components

An energy technology is a complex aggregate of components, some of which “learn” more than others.

For example, in a fuel cell car, only the fuel cell power generator has a large learning potential. In fact, the cumulative capacity of fuel cells is much larger, because it can be used also in power plants.

Rather than modelling the aggregate technology “fuel cell car”, the technology “fuel cell” is modelled separately from the “rest of the car” and “balance of the power plant” respectively. Both fuel cells based new technologies (cars and power plants) will reduce their costs much more if they learn together.

3.4 – Global vs. regional learning *(scenarios)*

The knowledge and the experience related to a technology, initially develops in a single world region.

If successful, the technology may open its way to markets in other regions, and improve learning.

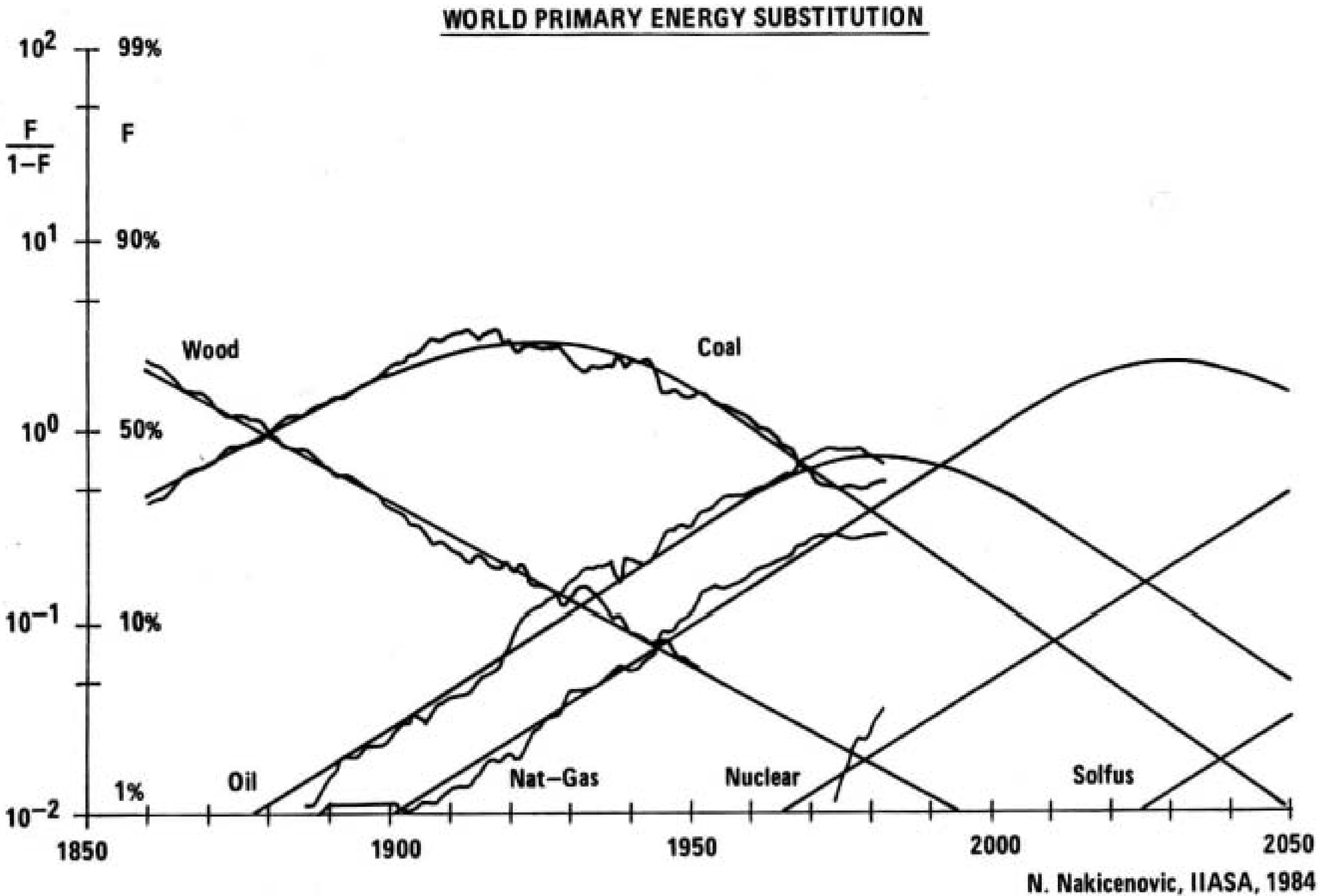
Scenarios with or without “spill-overs” across regions are quite different.

3.5 – Breakthroughs

In fifty years, new technologies can appear.

They can be modeled by:

- name (fusion power plants?, ocean thermal?, at specified characteristics);
- function (conversion of gas hydrates to natural gas, a sort of back stop technologies, with unlimited resource and at fixed price);
- ignorance (industry could have different sectors and consumption).

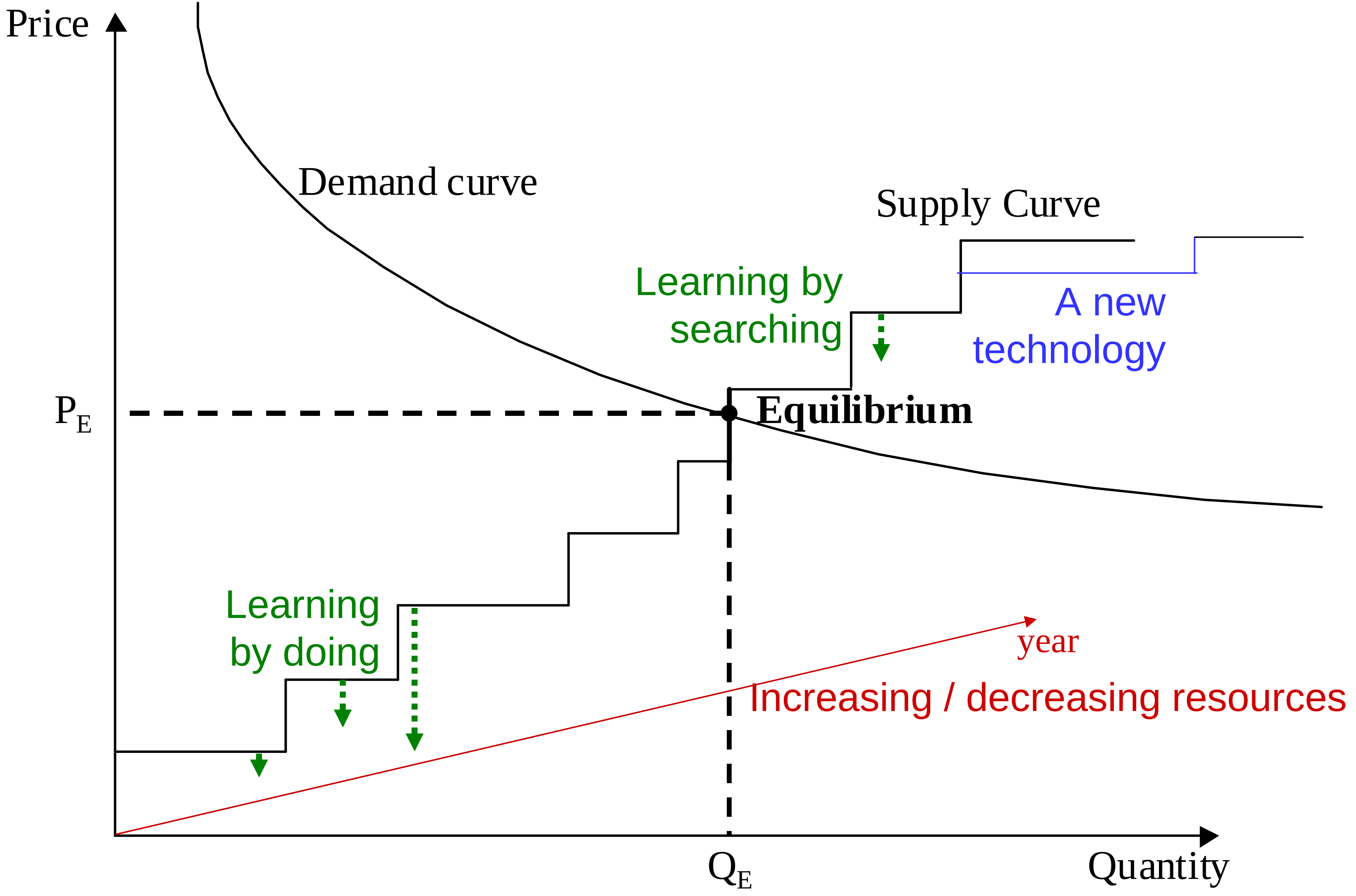


3.6–Innovation cycles *(exogenous, time dependent learning*

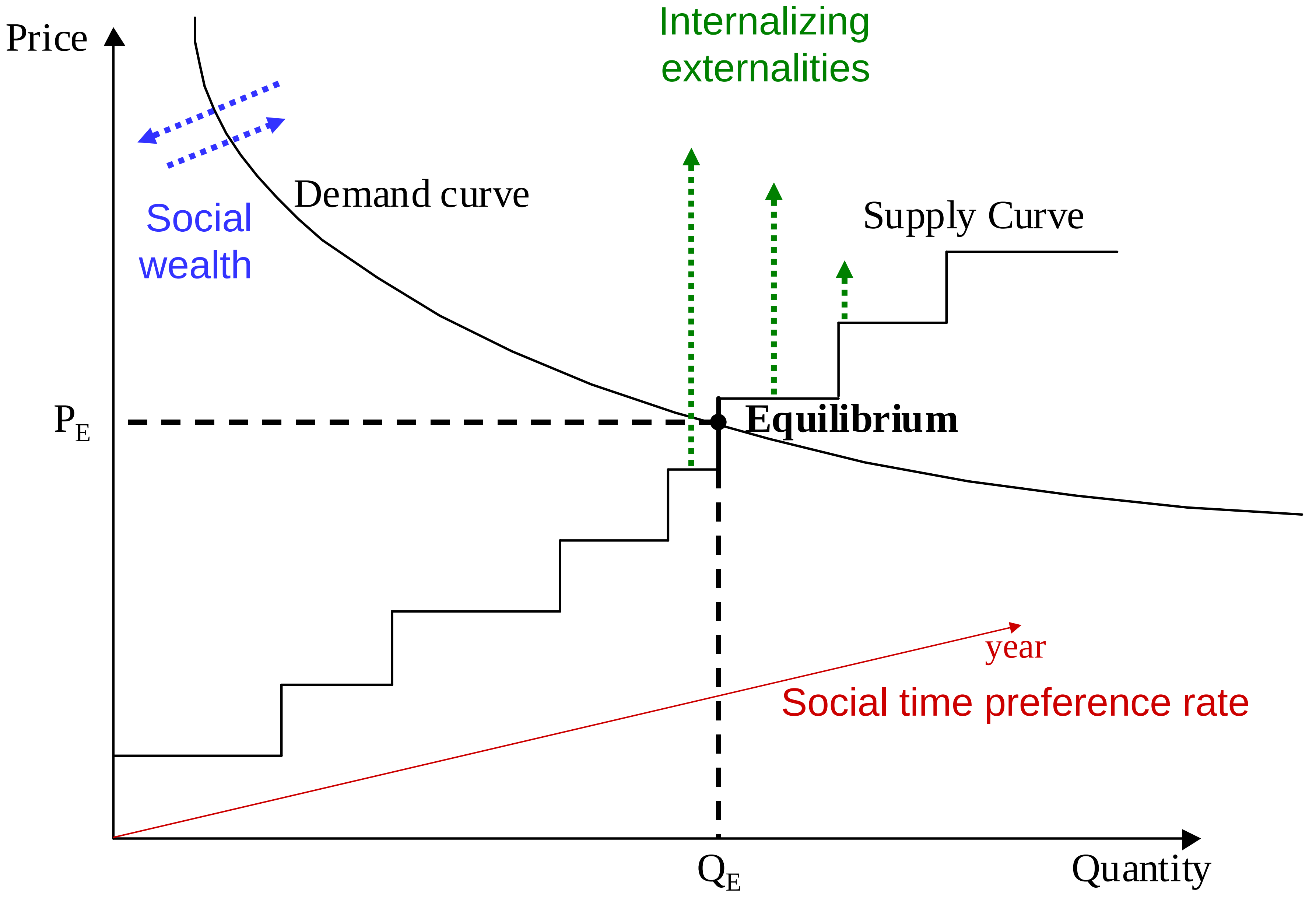
3.7 – Technology lock-in / lock-out

It has been verified historically that, due to existing interest, infrastructures, networking and inertia, some technological choice is very difficult to reverse (locked-in); possibly better technologies remain locked-out of the market.

Making use of perturbation techniques (for instance A. Kydes' the algorithm implemented in SAGE), second and third best technologies are upheld in the solution in one year and can deploy their high potential learning in the following years. MARKAL - TIMES generated models evaluate the cost of lock-in and the benefit of removing it.



3.8a – Modelling technology dynamics …



3.8b – … and some social dimensions

4 – From analyses to decisions: Socio – technical perspectives

1. Critics to analytical decision criteria:
   a – uncertainty, ignorance and subjectivity;
   b – an “impossibility” theorem.
2. Exploring alternative scenarios:
   a - differentiate the inputs (data, structures);
   b - solve with different criteria;
   c - explore the “near equilibrium” space;
   d - use alternative methodologies.
3. From technological to social paths: the dialogue approach

4.1a – Uncertainty, ignorance and subjectivity

Scenarios are images of alternative futures, or a short story of possible futures, but not predictions of the future. They are based on internally consistent and reproducible set of assumptions. Mostly they assume the absence of major discontinuities or catastrophes. No analysis can turn an uncertain future into a sure thing.

Worse than the uncertainty on the importance (probability) of each future event or development, is the fundamental ignorance of the possible events.

Worst of all is our ignorance of the boundaries between what we know and what we don't know: judgements concerning the extent to which "we don't' know what we don't know" are intrinsically subjective.

4.1b – An "impossibility" theorem

Arrow [1963] has shown in formal mathematical terms […] that it is impossible both democratically and consistently to aggregate individual preferences in a plural society. The derivation of any single social preference ordering (or aggregate social welfare function) will violate at least one of the conditions characterising individual choices:

- ordering does not change by changing sub-set groupings;
- any option that is increasingly favoured by all individuals, should be increasingly favoured in the expression of social preference;
- the introduction of new options, or the omission of old ones, should not alter the ordering of preferences for the other options;
- if individuals are able to choose between any two options, it should be possible to derive a social preference for one of these two options; and
- under no conditions should social preference be determined by the preference of any single individual.

4.2a – Exploring alternative scenarios: Differentiate the inputs

The most direct of exploring possible different development scenarios is to use alternative input data. For instance:

- change a few targeted costs and efficiencies;
- substitute key data values with probability distributions, extract values with a Monte Carlo algorithm and analyse the frequency of resulting scenarios; or
- use stochastic versions, where alternative events are given probabilities totalling , and hedging development paths are calculated

4.2b – Exploring alternative scenarios: change solution criteria

Instead of maximizing the “utility” or the “surplus”, new development paths of the systems are calculated, which:

- minimise the total primary energy sypply;
- maximise the security of providing energy services;
- minimise GHG (or acid deposition, …) emissions;
- maximise the contribution of renewable energy sources;

This is the best way to identify extreme scenarios.

Or, maximise the diversity among key fuels / technologies.

4.2c – Exploring alternative scenarios: Near equilibrium scenarios

The idea is to calculate future developments of the energy systems that maximise other criteria at the expense of a few percent reduction of the total “utility” or “surplus”.

Combined strategies of this kind appear very interesting.

In most cases the “trade-off” is advantageous.

4.3 – From technological to social paths: the dialogue approach

When it comes to decision, Analyst must provide different stakeholders not only with scenarios, which are transparent in methodology, data input and solution criteria, but also with tools to compare them.

How to open the way for them to converge towards some acceptable common point? Social sciences offer some alternatives, for example:

- ***Multi – Criteria Decision Aiding;***
- ***Consensus Conferences;***
- ***Awareness Scenario Workshops.***