Carbon capture & storage: Indian Perspective Need for high end R&D and international collaboration

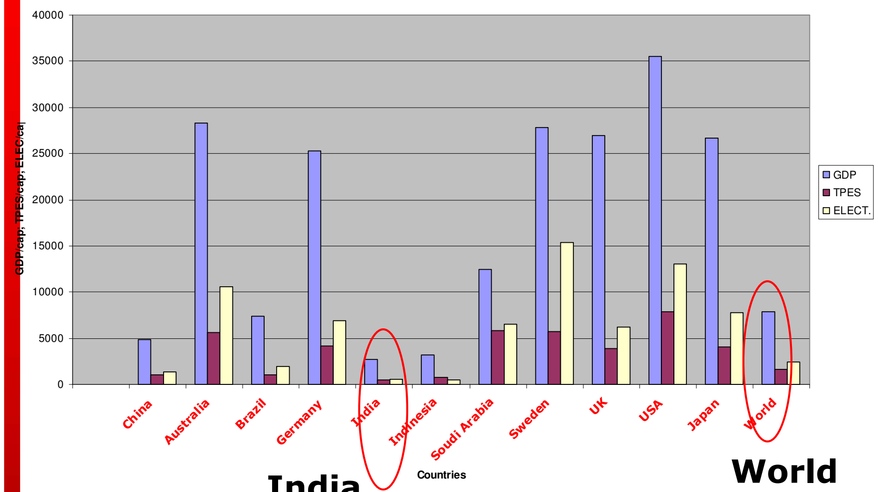
Dr. R.R.Sonde
Executive Director (Energy Technologies)

एनटीपीसी NTPC

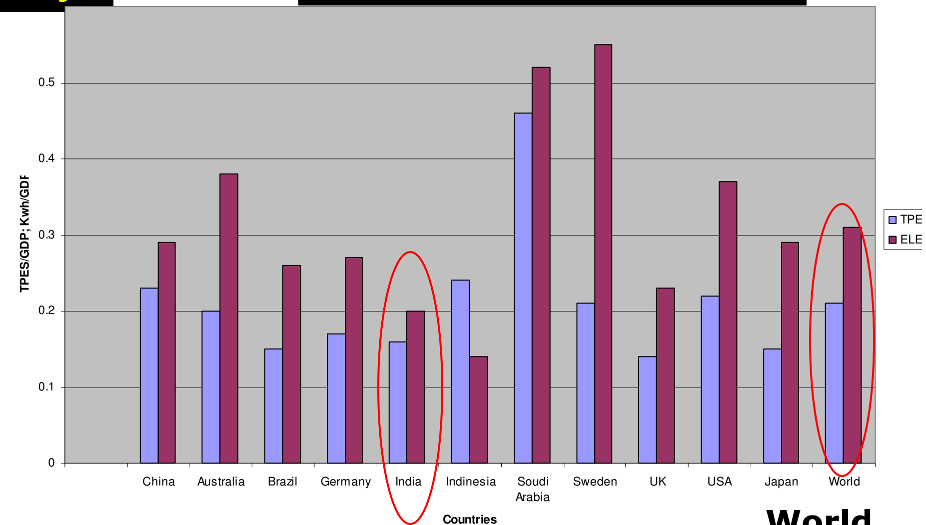
Global Energy indicators & HDI

Energy Technologies
Future Delivered

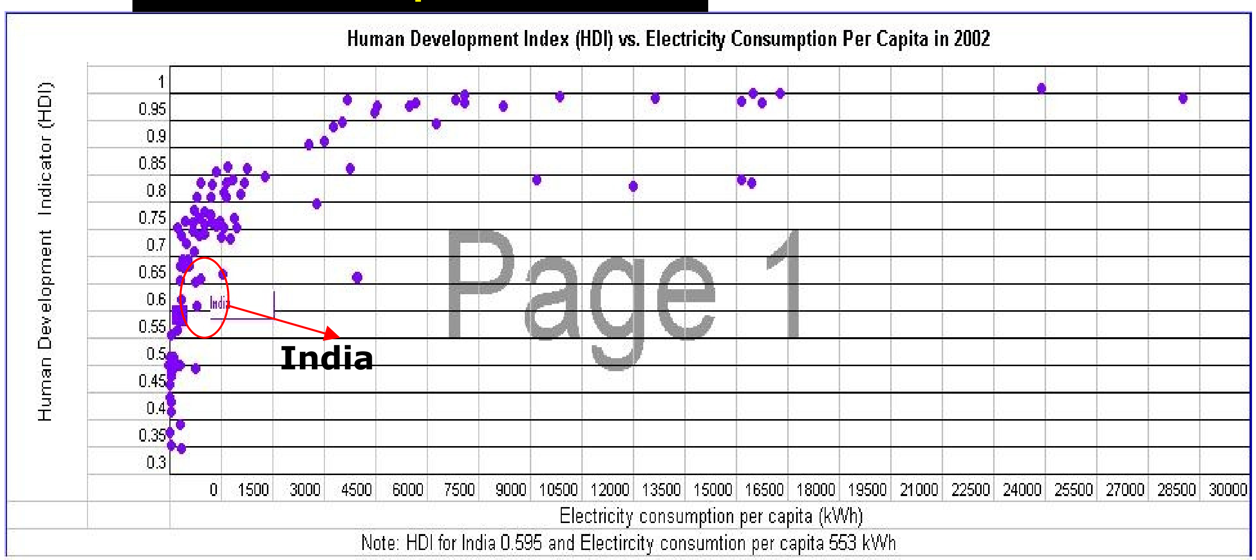
Per Capita GDP/ TPES/Electricity PPP adj.



Energy Intensity PPP adj.



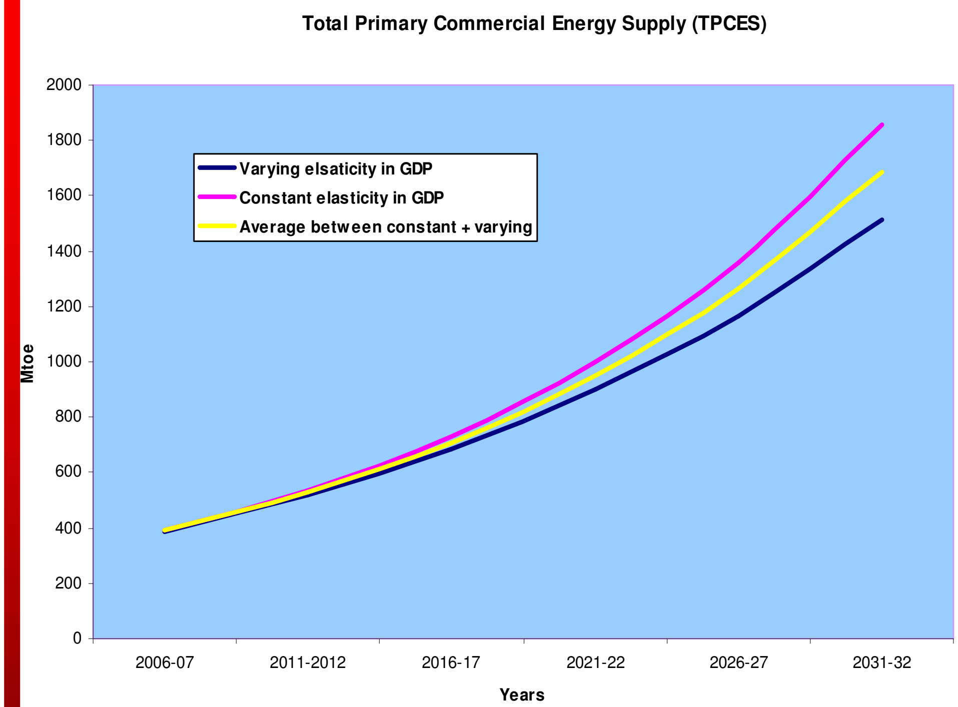
Human Development Index



There are many other indices like life expectancy, women empowe, infant mortality which also impact the HDI

Ref. UNDP 2004

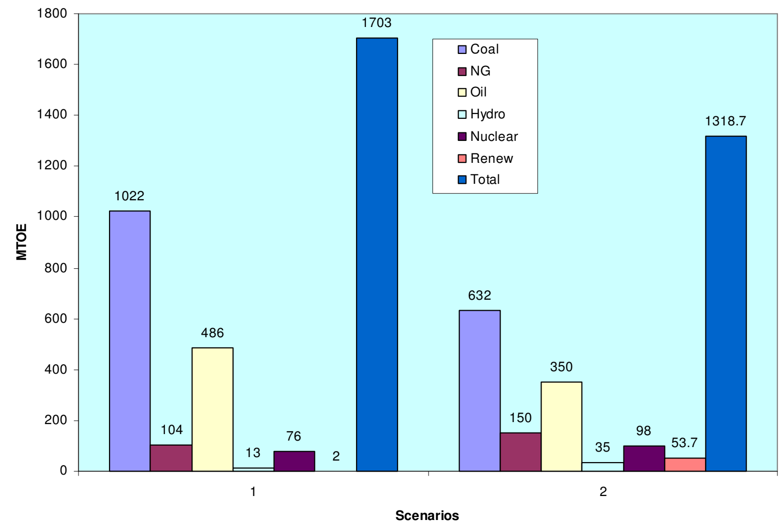
India’s growing energy needs



India’s growing energy needs

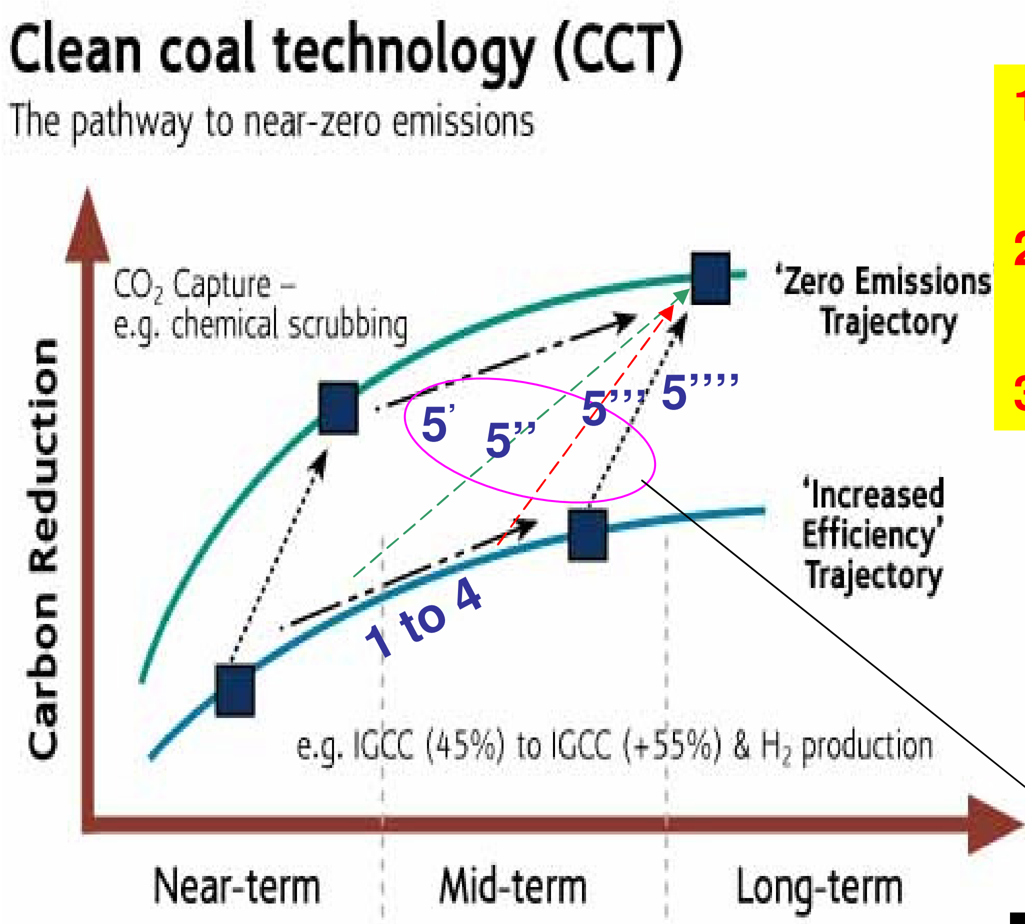
Two scenarios: Coal dominant to coal balance scenarios

(maximizing hydro, renewable and nuclear)



Pathways for managing carbon-energy conflict

Energy Technologies
Future Delivered



1. Efficiency driven approach from source to end user
2. IGCC, SC/USC technologies
3. CCS technologies

The pathways marked as 5' to 5'''' indicate transition to CCS technologies. Technological break through and redressal of safety issues are critical for quickening the process.

Technology issues related to coal-location & technology

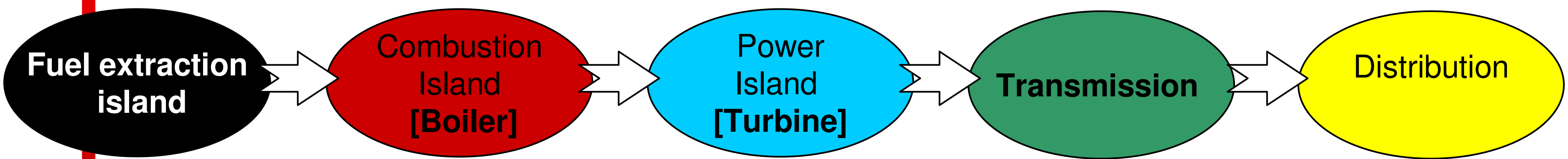
Energy Technologies
Future Delivered

Clean Power

Producing clean power with coal, even today, is a challenge

The Challenge

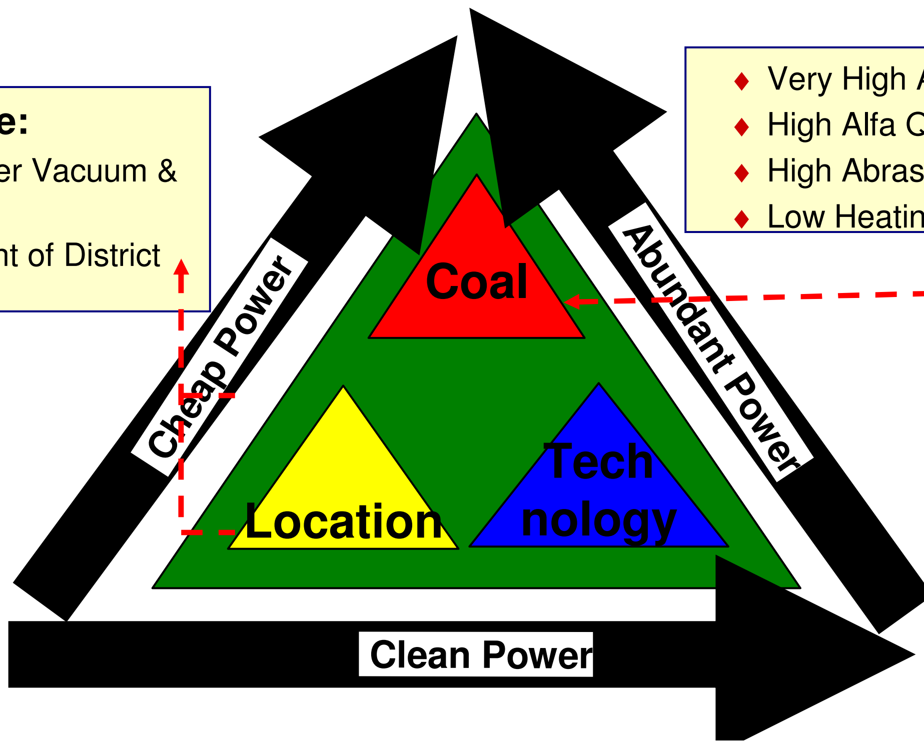
Overall <22%!!!



η=85-90% | η=85%-90% | η=65% | η=95% | [80%]

Tropical Climate:

- Low Condenser Vacuum & Boiler Eff
- No requirement of District Heating



- Very High Ash Content: 40% - 50%
- High Alfa Quartz Content
- High Abrasive Index
- Low Heating Value: 2500–3500 Kcal/Kg

Differentiators

1. **High abrasive ash coals**
2. **Low sulphur coals**
3. **No need for extract heat**
4. **High external temperatures**

India has a well laid energy conservation and energy efficiency protocol

-End use efficiency, demand side management, energy consumption in building

-Rural lighting using high efficiency lamps (CFL or LED)

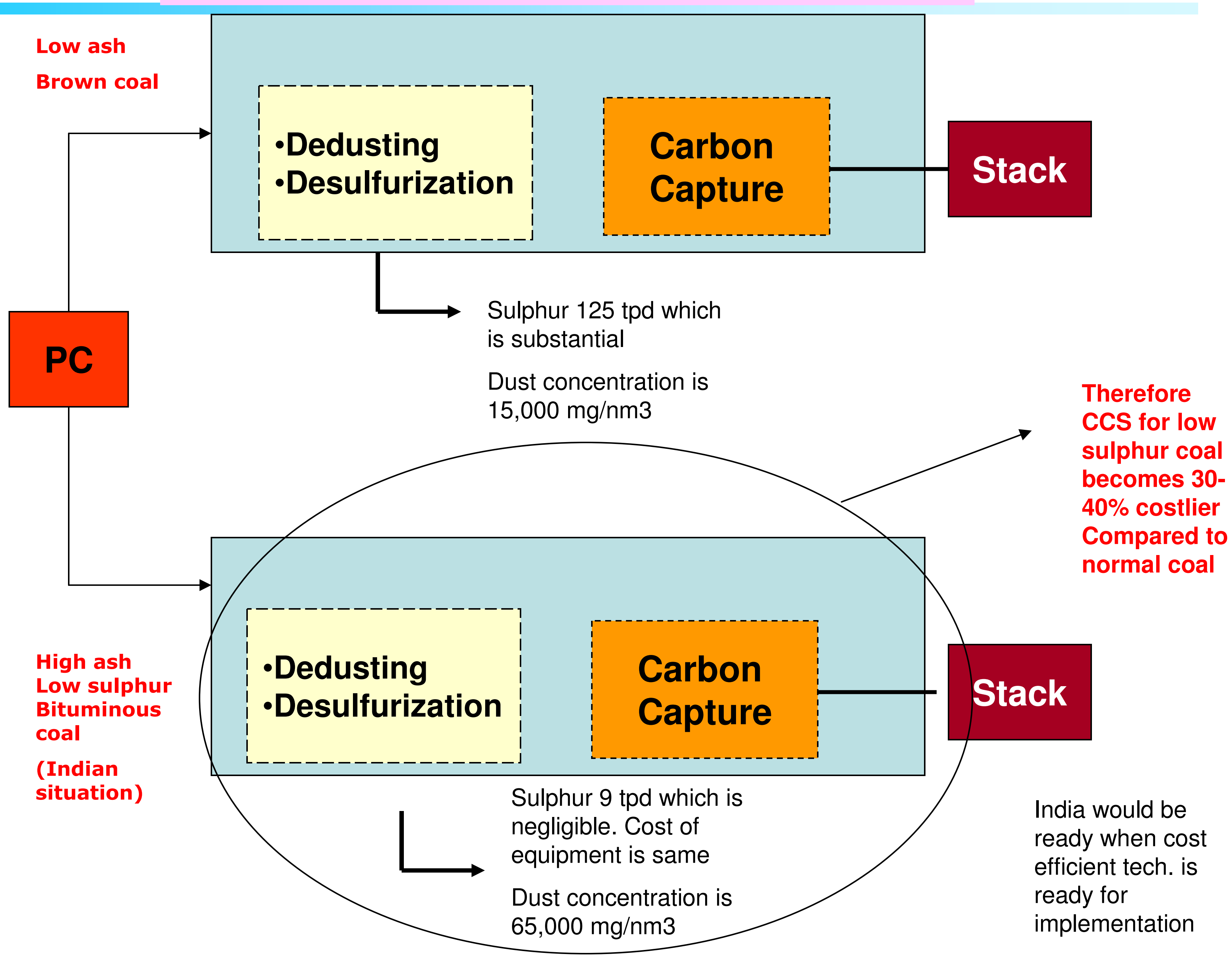
-Distributed energy generation

-Well laid out energy conservation programme for industries

-Labeling and bench marking

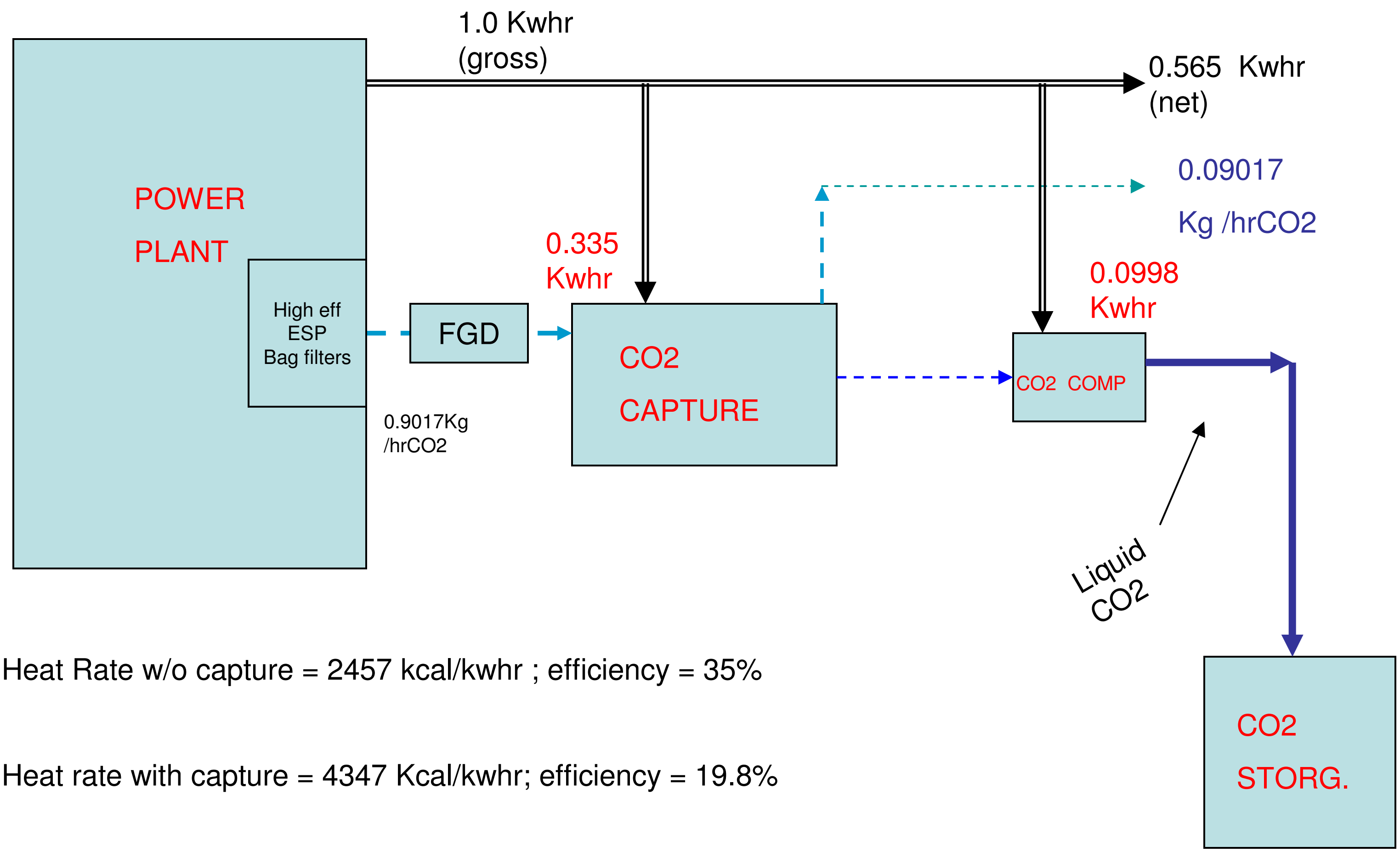
-Waste heat utilisation

Technology issues related to coal-climate & technology



Technology issues related to coal-climate & technology

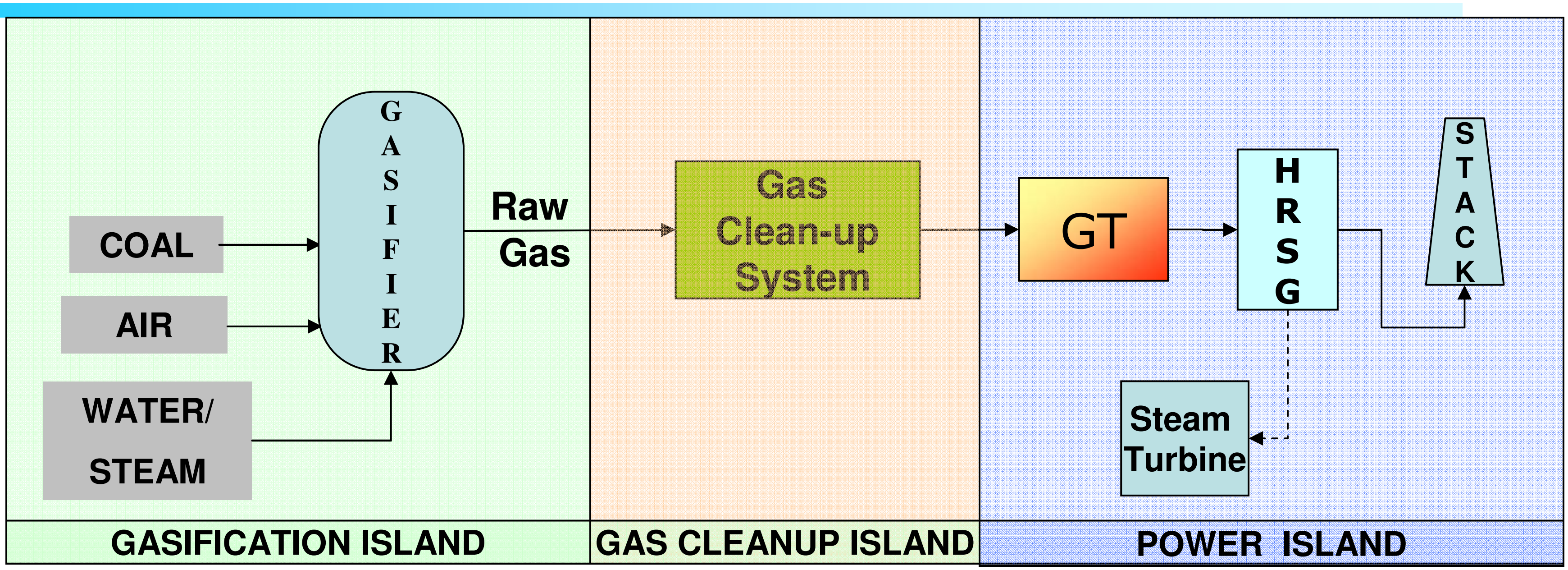
Typical post combustion carbon capture and liquefaction scenario



Heat Rate w/o capture = 2457 kcal/kwhr ; efficiency = 35%

Heat rate with capture = 4347 Kcal/kwhr; efficiency = 19.8%

Pre combustion technologies



TECHNOLOGY STATUS
5 References of power from coal by IGCC *
USA: Wabash, Tampa, Motiva Delaware
Europe: Buggenum, Puertollano
All Entrained bed oxygen fired for low ash coal

TECHNOLOGY STATUS
All operating with cold gas clean up system
LURGI & SHELL are major technology supplier supported by proprietary solvent supplier like Dupont, UOP,union Carbide etc

TECHNOLOGY STATUS
GT requires modification to handle low calorie syngas
GE and Seimens: Known GT manufacturer with syngas experience

For high ash coal entrained bed gasification will cause lowering efficiency as well as problems of failure of gasifier internals. Fluid bed is the best possible option.

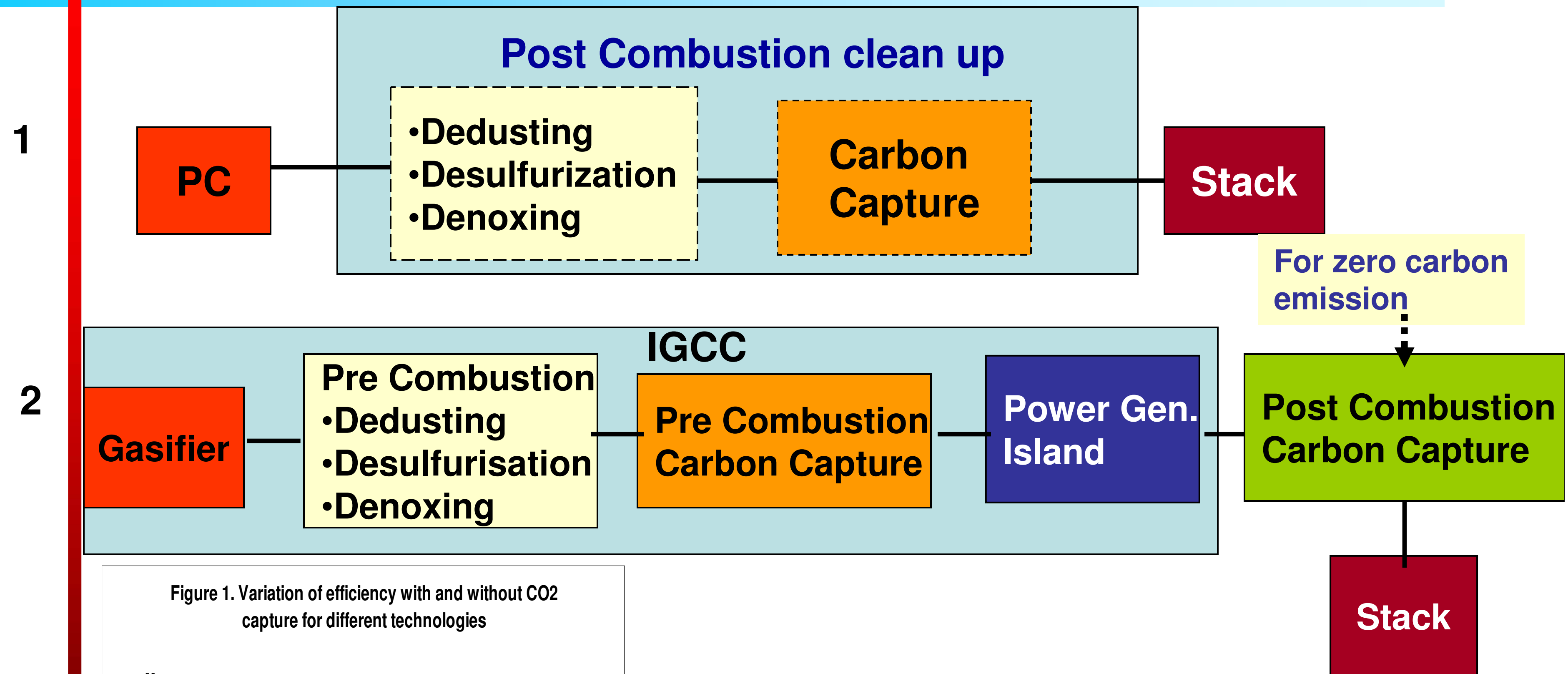
Gas composition is different for high sulphur coal. High ammonia

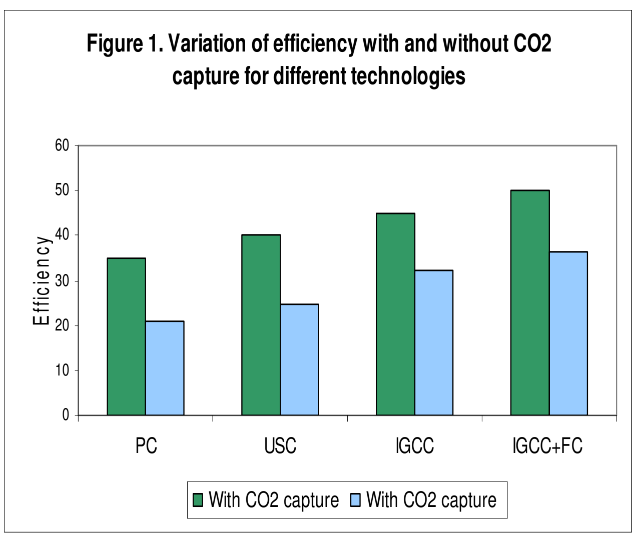
Low H2S. Co extraction of acidic gases

Low calorific value gas turbine

Needs new design. Oxygen blown fluid bed not tested

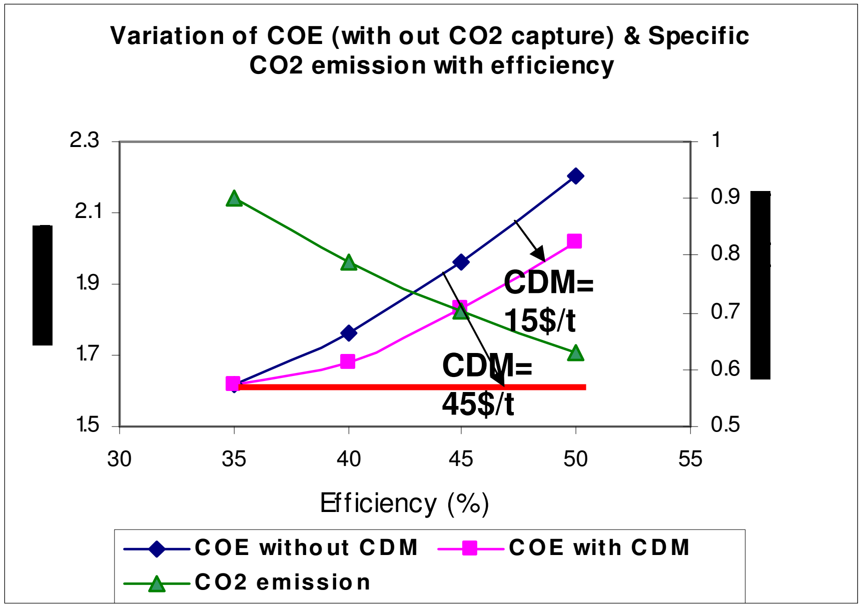
Pre combustion and post combustion technologies

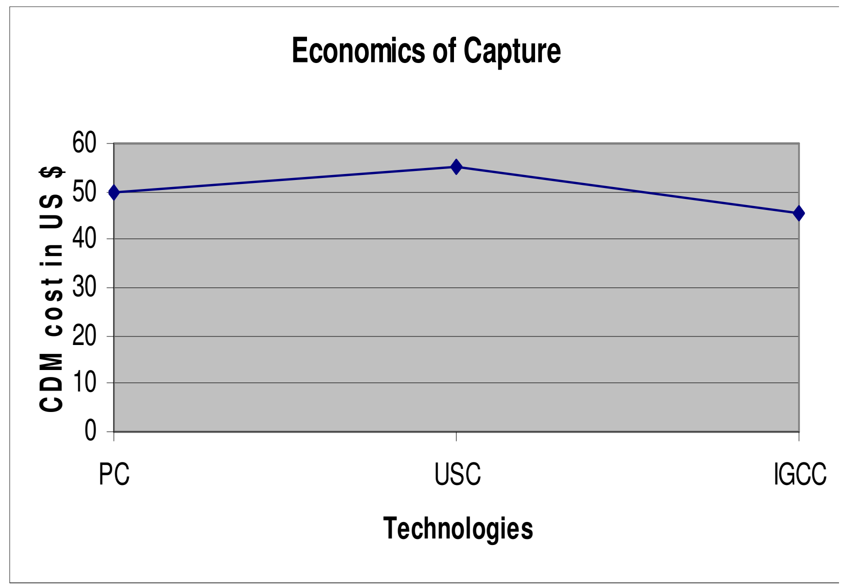




The capture technologies for post and pre combustion processes are different

Existing CDM can hardly compensate CCS even if CCS qualifies as CDM tool





Calculations are indicative only and to be used with prior permission of the author

Economics in carbon capture: Can CCS be made economically viable in foreseeable future?

Technologies	PC		USC		IGCC	
Coal cost, Rs/kg	1		1		1	
Net CO_2 emission, Kg/kWh	0.1	0.15	0.1	0.15	0.1	0.15
Sp. CO_2 emission, Kg/kWh	0.9018	0.9018	0.7891	0.7891	0.7014	0.7014
Heat rate (w/o CO_2 capture) kCal/KWh	2457.1	2457.1	2150	2150	1911.1	1911.1
CoE (w/o CO_2 capture) Rs./kWh generated	1.6153	1.6153	1.7558	1.7558	1.9616	1.9616
Sp. energy for CO_2 capture KWh/Kg	0.4842	0.4842	0.5358	0.5358	0.4547	0.4547
Heat rate (with CO_2 capture) kCal/kWh	4150.3	4044.7	3525.1	3425.3	2678.4	2614.6
CO_2 capture cost Rs./kWh generated	1.1131	1.0437	1.123	1.0415	0.7876	0.7221
CoE with CO_2 capture Rs./kWh generated	3.4239	3.3368	3.4696	3.3714	3.198	3.1218
Cost of avoidance Rs./Kg	2.2557	2.2899	2.4871	2.528	2.056	2.1042

Calculations are indicative only and to be used with prior permission of the author

Tech	CoE w/o cap	CoE with Cap
PC	3.59 c	7.61 c
USC	3.90 c	7.71 c
IGCC	4.36 c	7.11 c

Important Learning from the above study

1. Capital cost of IGCC for high ash coal is high and needs to be brought down
2. Capture technologies need to be developed to a level such that CoE is not more than 10-15% CoE w/o capture
3. Till such time CDM mechanism shall have adequate compensation for CERs
4. Low cost of CoE for IGCC is a good indicator that future technology must drive in this direction

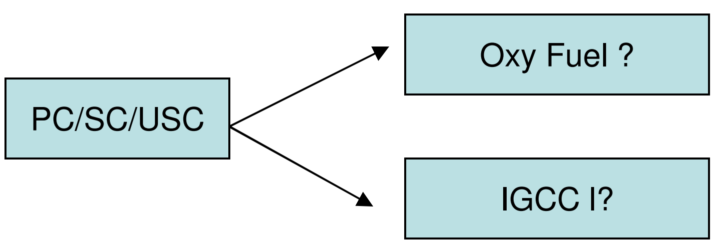
Directions on high end research in capture

Energy Technologies
Future Delivered

1. **Research in new areas of carbon capture which can tolerate Sox, moisture and temperature**
2. **Development of heat integration and new devices for minimizing heat recovery and costs**
3. **Techno-economics of capture technologies with purities of CO2 for transport and sequestration**

New possible breakthrough processes: Sorbents / Ionic liquid membranes / PSA processes

Post combustion capture technologies to be compared with those of gasification technologies. Need some demonstration plants globally on Oxy fuel combustion Technologies.



Final Objective: Cost effective process to bring down the cost of capture to one fifth of current level

CO2 STORAGE AND SEQESUTRATION ISSUES

Major Global Concerns:

Long-term physical leakage (seepage) levels of risks and uncertainty
Seismic activity caused by injection of fluids underground.

Project boundary issues (such as reservoirs in international waters, several projects using one reservoir) and projects involving more than one country

Long-term responsibility for monitoring the reservoir and any remediation measures that may be necessary after the end of the crediting period

Long-term liability for storage sites;

Accounting options for any long-term seepage from reservoirs

Criteria and steps for the selection of suitable storage sites with respect to the potential for release of greenhouse gases;

Potential leakage paths and site characteristics and monitoring methodologies for physical leakage (seepage) from the storage site and related infrastructure for example, transportation;

Storage may be a common facility being shared by many utilities and also other CO2 emitting industries while capture and transport can be in the realm of individual utilities

The activity proposed through Indian Basalts

Project Definition : Feasibility study of geological sequestration of CO_2 in Basalt formations (Deccan Trap) in India

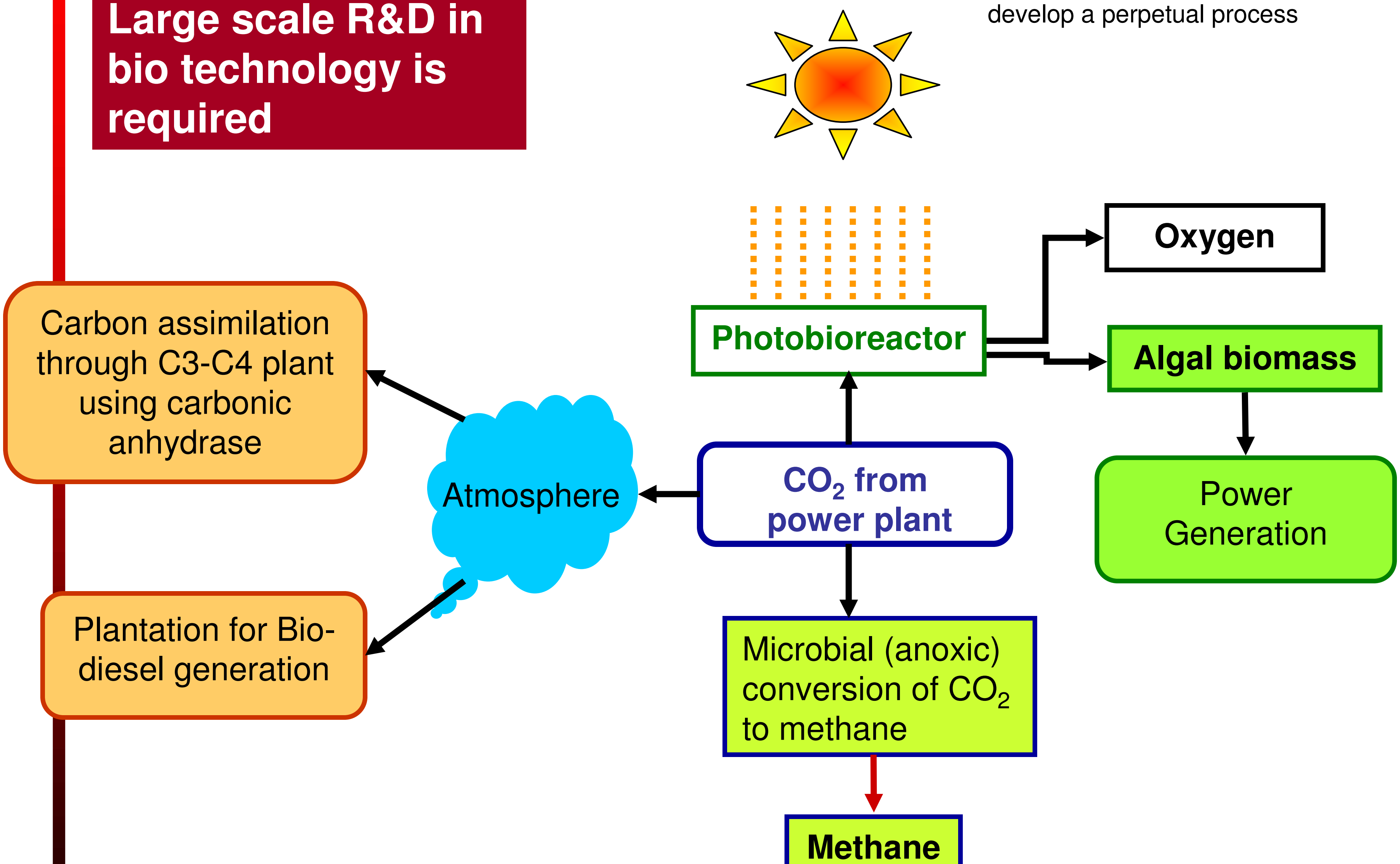
1. **Complete characterization of the Deccan traps. This includes use of existing bore hole for evaluation of properties like permeability, porosity, chemical analysis and few geo-physical techniques like MT, acoustic etc**
2. **Evaluation of inter- trappen flows using hydrological flows or tracer injection**
3. **Mineralization kinetics study**
4. **Study on ground water flows within basalts**
5. **Surface CO_2 measurements using GC-MS for CO_2 concentrations**
6. **Data analysis from the PNNL experiments on the CO_2 movement within the basaltic structure**
7. **Evaluation of the entire DVP from CO_2 storage point of view and submit the report to Government for next steps**

Bio technological route and Future road map

Energy Technologies
Future Delivered

Large scale R&D in bio technology is required

CO2 conversion to methane and develop a perpetual process



Future road map

1. Coal is a major fuel source for India's energy security point of view (55% of TPCE)
2. Pathway for India is efficiency centric technologies will provide both cheap, reliable and green power
3. IGCC offers an excellent platform for generating efficient power, effective carbon capture and liquid fuels for transport applications
4. Pre combustion and post combustion technologies require high end R&D
5. Newer capture technologies like PSA and Membrane hold great potential compared to the conventional solvents for Indian condition
6. Storage of CO2 and sequestration need to address several scientific concerns
6. Economics will be major determining factor and EOR/CBM/CDM are the options that must be explored
7. Bio technology and solar to fuel holds a great potential

“When you really want something to happen, the whole universe conspires to help you to achieve your dreams”

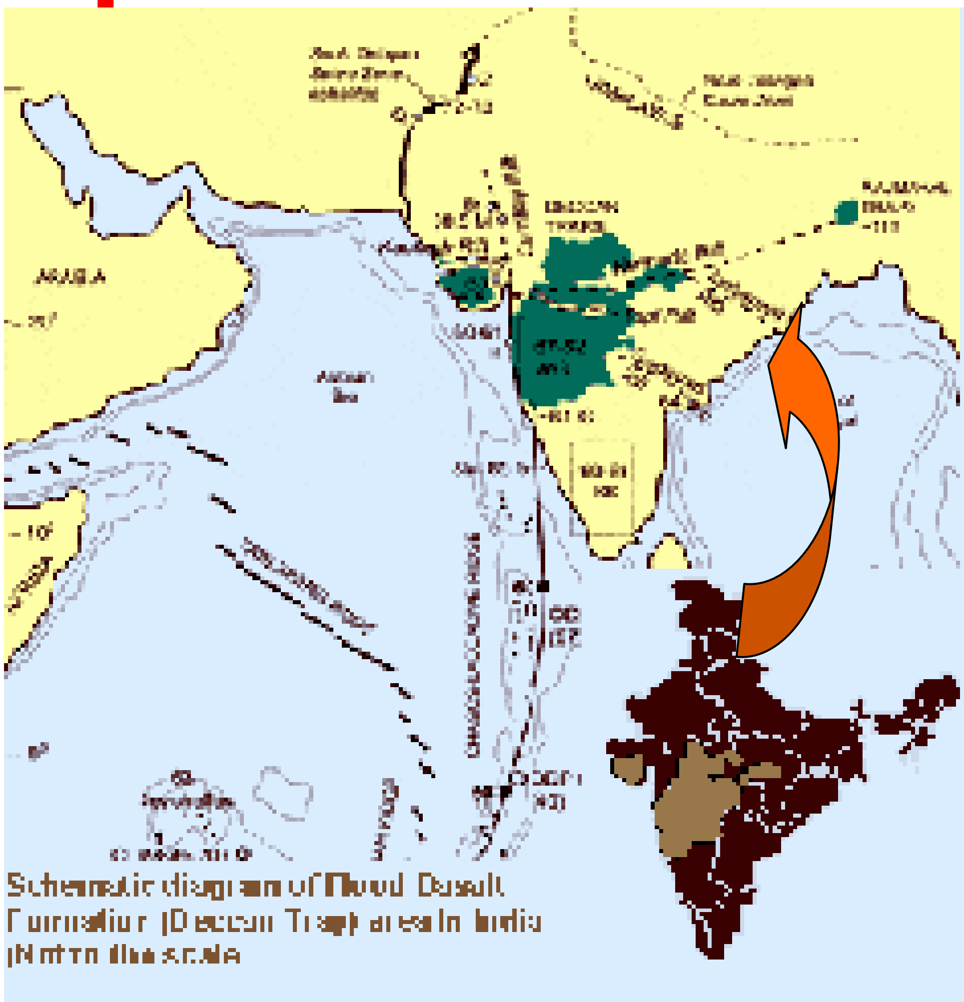
…….. The Alchemist

by Paulo Coelho

Thank

You

Basalt Area of India



Schematic diagram of Flood Basalt Formation (Deccan Trap) area in India (Not to the scale)

The Deccan Volcanic Province (DVP) consists of Mafic Magma located north-west of India

- **Total Basalt Formation area : 500000 sq km**
- **Composed of typically 14 different flows**
- **More than 2000 m depth in western side & few meter in eastern side**
- **Generally seismically stable**
- **Approx. 300 Gt CO_2 can be stored**
- **Equivalent to 250 years of CO_2 at present level of power generation in India**

Site Identification / Pre-injection Characterization

Important milestones

- Target Depth 800 m
- Overall feasibility
- Storage capacity
- Storage impact assessment
- Basic data for permission from regulatory authority

Detailed planning

Important milestones

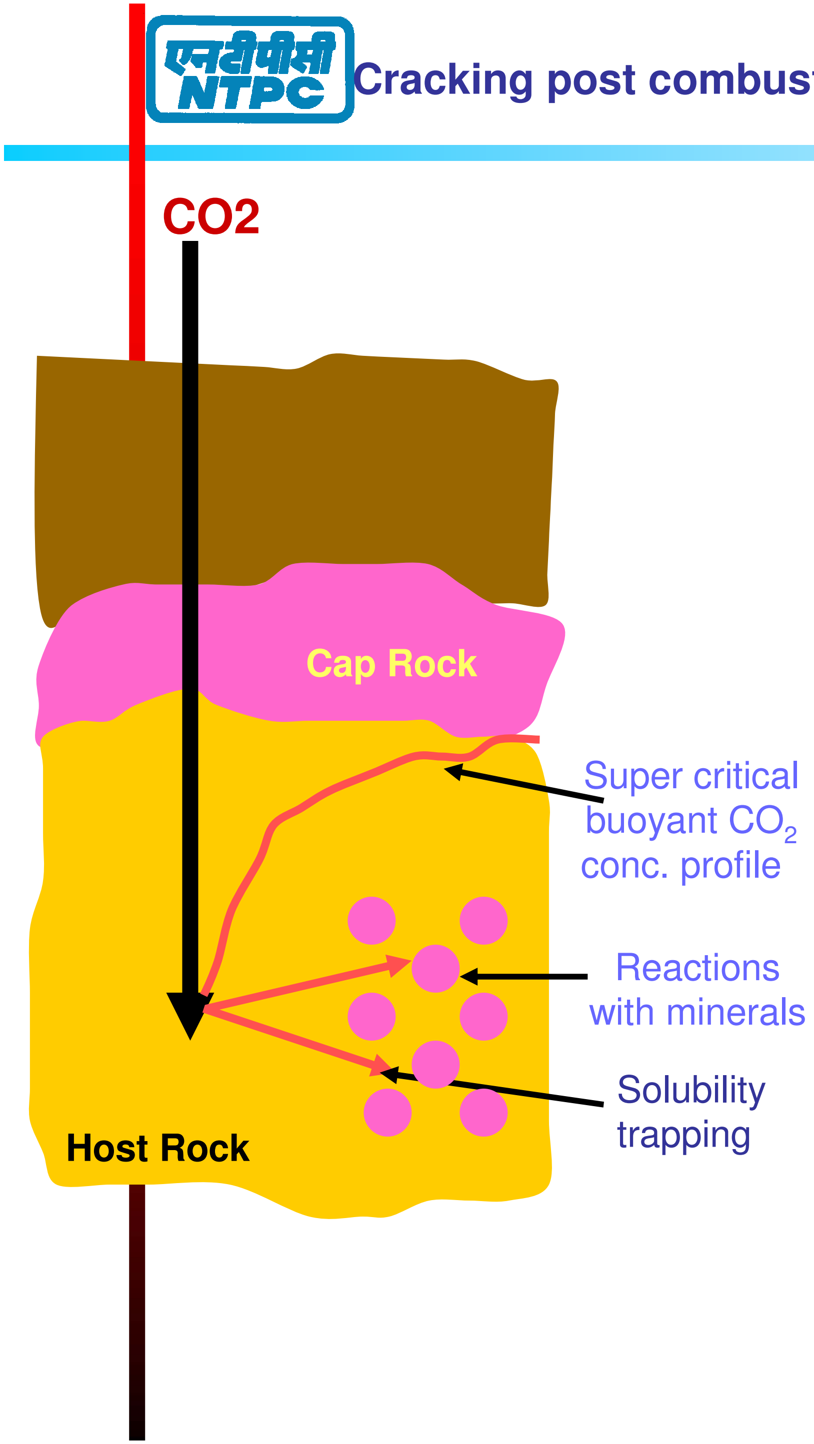
- Detailed project Schedule
- Detailed engineering
- Permission

Major activities

- 3D Seismic study of host and cap rock
- Sample coring
- Down hole vertical seismic study [VSP]
- Wire line logging
- Physical and chemical characterization
- Modeling and CO2 movement prediction
- CO2 storage impact assessment
- Characterization of shallow surface soils & ground water chemistry
- Identification of most suitable site

Evaluation of important geo-chemical parameters

- Thickness and depth
- Porosity and permeability
- lateral and vertical continuity connectivity
- Cap rock fracture pressure
- Chemical composition
- CO2-basalt reaction kinetics
- pore water chemistry, etc.



Hydrodynamic trapping

- Initially 85-95% of CO_2 will be stored
- Density of supercritical CO_2 < saline water
- Cap rock acts as seal
- Movement of underground water 1-10 cm/year
- Few kms of cap rock integrity is sufficient to hold CO_2 for thousands of years

Solubility trapping

$$CO_2(aq) + H_2O \longrightarrow HCO_3^- + H^+$$

$$KAlSi_3O_8 + 4H^+ \longrightarrow K^+ + Al^{3+} + 3SiO_2\ (aq)$$

- Initially stored 5-10% of total CO_2
- Dissolution of CO_2 in aqueous phase
- Lowers pH of aqueous phase
- Causes dissolution of minerals
- Dissolution consumes H^+ ion and driving the first reaction and over all solubility trapping

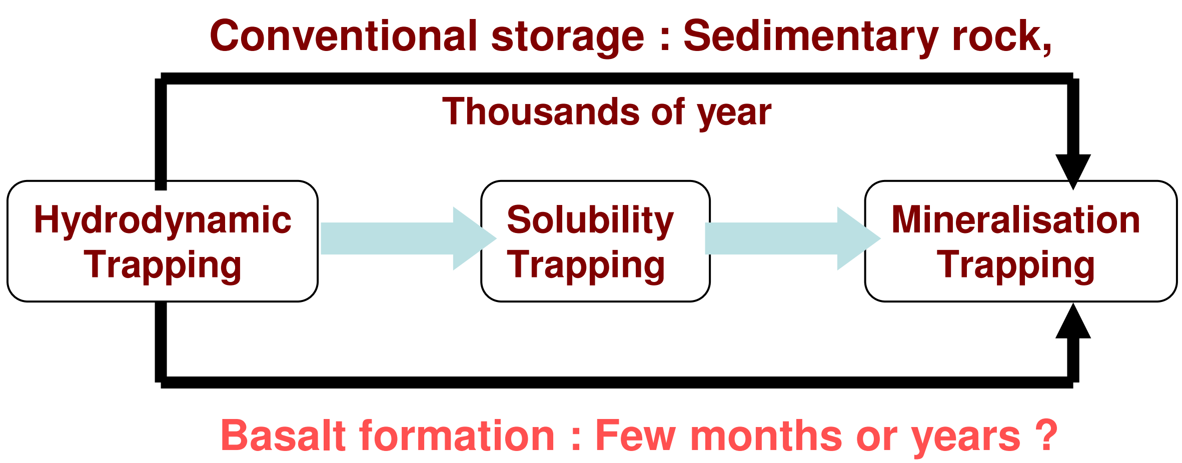
Mineral trapping

$CO_2(aq) + H_2O \longrightarrow HCO_3^- + H^+$

$M^+ + HCO_3^- \longrightarrow MCO_3 + H^+$

$KAlSi_3O_8 + 4H^+ \longrightarrow K^+ + Al^{3+} + 3SiO_2\ (aq)$

- **Initially stored 1-2% of total CO_2**
- **Low pH accelerate dissolution of mineral matrix**
- **Release of cations in aqueous phase**
- **Precipitation of carbonate minerals**
- **Lower pH further accelerate mineral dissolution**
- **The most stable way of carbon capture**



Basalt Formations

Energy Technologies
Future Delivered

Mineralization reactions in basalt formations

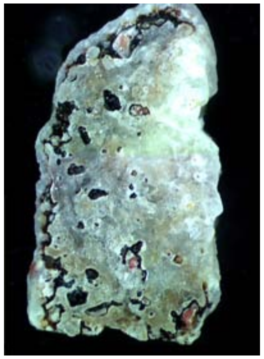
$$CO_2(g) \longrightarrow CO_2(aq)$$
$$CO_2(aq) + H_2O \longrightarrow HCO_3^- + H^+$$
$$(Ca,Mg,Fe)_x\, Si_yO_{x+2y} + 2xH^+ + (2y-x)H_2O \longrightarrow x(Ca,Mg,Fe)^{2+} + yH_4SiO_4(aq)$$
$$(Ca,Mg,Fe)^{2+} + HCO_3^- \longrightarrow (Ca,Mg,Fe)CO_3 + H^+$$

Lab. scale study & geo-chemical modeling establish

Induction Time for Calcite Precipitation

Depth, m	T, °C	pH_o	pH_f	r_d, g m^{-2} d^{-1}	C_s, M	t_p, d
800	35	3.72	4.97	0.047	0.035	122
900	38	3.70	4.95	0.052	0.034	104
1000	42	3.68	4.92	0.060	0.032	85
1100	48	3.65	4.90	0.073	0.031	67
1200	56	3.63	4.87	0.093	0.029	50
1300	67	3.61	4.85	0.128	0.028	35

(Source : PPNL)



Calcite deposition on basalt (Source: PPNL)

- Basalt is rich in Ca, Mg & Fe Silicates
- Mineralisation reaction rate is fast on geological time scale
- Mineralisation is appeared to be controlled by mixing behaviour of CO_2 and not by kinetics of the reactions

Basalt Composition

	Typical composition of Indian Basalt	Sentinel Bluff Basal USA (Source : PPNL)
SiO_2	59.07	54.35
Al_2O_3	15.22	14.27
FeO	6.45	12.39
CaO	6.10	7.43
MgO	3.45	3.13
Na_2O	3.71	2.82
K_2O	3.11	1.46
P_2O_5	0.30	0.35
TiO_2	1.03	2.09
MnO	0.11	0.21

Expected a great potential for CO_2 storage In Indian Deccan trap

Shows promising potential in Laboratory

- Minerals phases present in basalt makes it more reactive through mineral dissolution at lower pH and subsequent chemical reactions
- Iron phases in basalt like pyroxene, olivine, spinel, and glassy mesostasis are unstable at lower pH and dissolve
- The phases and their dissolution may not occur in sedimentary rock

The mineralisation process

The materials → Mg, Fe, Ca silicates → The basic reaction

$$M_x\,SiO_4 + CO_2 \longrightarrow M_xCO_3 + SiO_2$$

Direct carbonation	Reaction in basalt
In aq. solution of sodium bicarbonate & chloride	In saline aquifers (NaCl, KCl)
Reactants : Magnesium silicates (Olivine, Serpentine)	Reactants : Basalt rich in Mg, Fe, Ca silicates
Temp. : 155 C & P_{CO2}= 185 atm.	Temp. : 35-45C & P_{CO2} > 75 atm.
78% conversion in 30 minutes of contact	Expected mineralisation in few hundred years

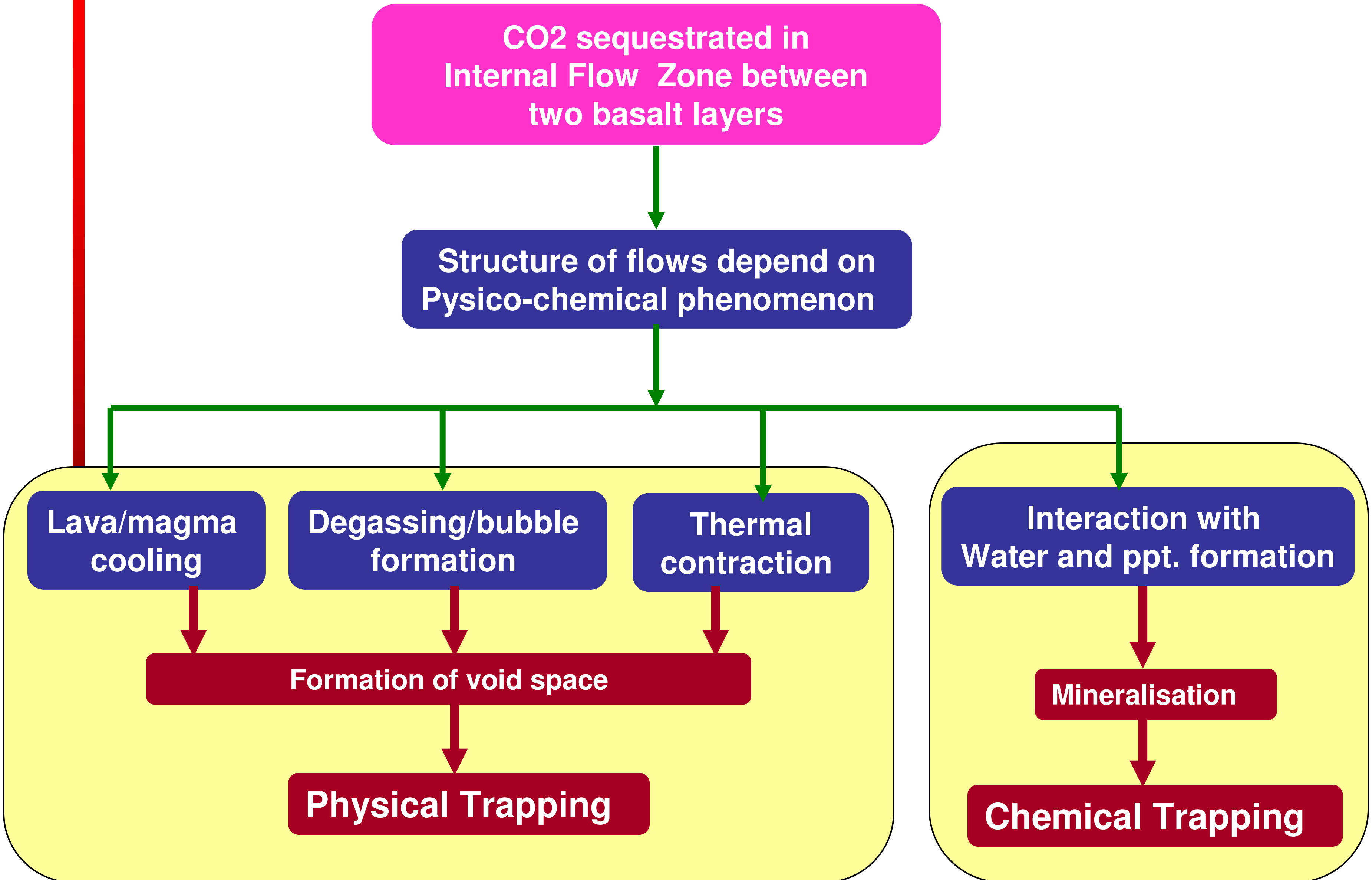
Weathering of silicate rocks is one of the natural process of atmospheric CO_2 mitigation

Ca,Mg,Fe silicates → Ca,Mg,Fe Carbonate

Organic acid from biomass

Basalt rich in Mg, Fe & Ca silicates potential candidate for CO2 sequestration

Basalt Formations



F. Bio technological rout and Future road map

large scale India centric technology development efforts are needed

Bio technological rout and Future road map