MIT Joint Program on the Science and Policy of Global Change

Heavier Crude, Changing Demand for Petroleum Fuels, Regional Climate Policy, and the Location of Upgrading Capacity: *A Preliminary Look*

John Reilly, Sergey Paltsev and Frederic Choumert

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

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John Reilly[†], Sergey Paltsev[†] and Frederic Choumert[*]

Abstract

The crude slate is likely to become heavier in the future with greater reliance on bitumens, tar sands, heavy oils, and eventually possibly shale oil. Under standard refining processes these crude oil sources produce a larger fraction of heavy products. At the same time, petroleum product demand growth is likely to disproportionately favor mid-weight products because of the strongly growing demand for transportation fuels including diesel, jet fuel, and gasoline. This will create a significant demand for new upgrading capacity in the refinery sector, and these upgrading facilities are themselves a significant source of carbon emissions. Using a version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that separately considers five petroleum products we examine the need for, and the location of, refinery upgrading capacity under significant carbon policy in developed countries but not in developing countries. The results show that a carbon policy leads to a shift of most of the investment in upgrading capacity to developing countries, where the cost of carbon control is avoided, resulting in significant carbon leakage.

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1. INTRODUCTION

The Emissions Prediction and Policy Analysis model with disaggregation of oil production and refining sectors (EPPA-ROIL) is a recursive, dynamic computable general equilibrium (CGE) model of the world economy with international trade among regions that also represents the oil market in some detail. Originally developed to produce scenarios of greenhouse gas emissions and estimate the cost of mitigation, it forecasts to the year 2100 in 5-year intervals. Because of this it is useful for analyzing interactions between the oil market and the world economy, and for assessing economic effects of the transition from conventional oil to unconventional sources. The regions, sectors and factors of production represented in EPPA are shown in **Table 1** and described in detail in Paltsev *et al*. (2005). The technical details of EPPA-ROIL are described in Choumert *et al*. (2006). This report describes some preliminary results that investigate the effects of a trend toward heavier crudes, changing demands for petroleum products, and how climate policy may affect the location of new upgrading capacity in the refinery sector.

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The views expressed are solely those of the authors and do not reflect the views of TOTAL or MIT.

Table 1. Regions, Sectors and Factors Represented in the EPPA Model.

Country or Region	Sectors	Factors
Developed United States (USA) Canada (CAN) Japan (JPN) European Union+ (EUR) Australia & New Zealand (ANZ) Former Soviet Union (FSU) Eastern Europe (EET) ***Developing*** India (IND) China (CHN) Indonesia (IDZ) Higher Income East Asia (ASI) Mexico (MEX) Central & South America (LAM) Middle East (MES) Africa (AFR) Rest of World (ROW)	***Non-Energy*** Services Energy-Intensive Products Other Industries Products Transportation Food Processing ***Energy*** Coal Crude Oil, Tar Sands, Shale Oil Refined Oil Products Biomass Liquid Fuel Natural Gas, Coal Gasification Electric: Fossil, Hydro, Nuclear, Solar & Wind, Biomass, Natural Gas Combined Cycle, Integrated Coal Gasification with Sequestration ***Agriculture*** Crops Livestock Forestry	***Economy-wide*** Capital Labor ***Energy*** Crude Oil Resources Shale Oil Resources Coal Resources Natural Gas Resources Nuclear Resources Hydro Resources Wind/Solar Resources ***Land*** Crop Land Pasture/Grazing Land Forest Land

Emissions of Climate Relevant Substances	
Substances	***Sources***
CO_2, CH_4, N_2O, HFCs, SF_6, PFCs, CFCs, CO, NOx, SOx, VOCs, black carbon (BC), organic carbon (OC), NH_3	Combustion of refined oil, coal, gas, biofuels and biomass burning, manure, soils, paddy rice, cement, land fills, and industrial production.

2. MODEL DESCRIPTION

Like all models, the EPPA model has strengths and weaknesses. It is particularly well suited to analyzing economic issues such as investment, growth, fiscal policies and macroeconomic interactions. It has the capability to estimate both air pollutant and greenhouse gas emissions. Because it is a global modal with regional and technology detail, it is able to integrate sector and technology specific issues with macroeconomic interactions and feedbacks and to predict the effects on economic growth, or the interactions with taxes. The traditional weakness of CGE models fitted exclusively to Input-Output and National Income and Product Accounts data has been addressed by extensive development of supplemental tables on physical flows and the addition of explicit treatment of advanced technologies. The 5-year time step of EPPA makes it not well suited to analyzing issues related to business cycles. EPPA has a recursive, dynamic structure in contrast to forward looking optimization methods, and it does not include endogenous technological change, such as learning-by-doing. Rather it represents explicit technologies that under changing market conditions may be come economic—and thus choice of technology is endogenous (see Jacoby *et al.*, 2006).

EPPA-ROIL includes detail on downstream, midstream and upstream oil markets. Downstream, the petroleum market represents demand for several petroleum products, including LPG, gasoline, diesel, heavy fuel oil, petroleum coke and other products. Midstream it represents upgrading processes that are sensitive to the quality of crude oil delivered to refineries, and that also recognize biofuels such as ethanol and biodiesel. Upstream, the model represents the upgrading of unconventional oil (*e.g*., bitumens including tar sands and extra heavy oil) to a crude equivalent that then is further refined. A separate technology represents the production of oil shale that produces a crude oil equivalent that is further processed in refineries (**Figure 1**).

Changes in the characteristics of conventional crude oil can be exogenously specified and will trigger changes in refinery configurations and corresponding investments. The future crude slate is expected to consist of larger fractions of both heavier, sourer crudes and extra-light inputs, such as NGLs. There will also be a shift towards bitumens, such as Canadian oil sands and Venezuelan heavy oil. These changes will require investment in upgrading, either at field level to process bitumen into medium and light synthetic crudes or at refinery level to convert refinery residues into lighter fractions.

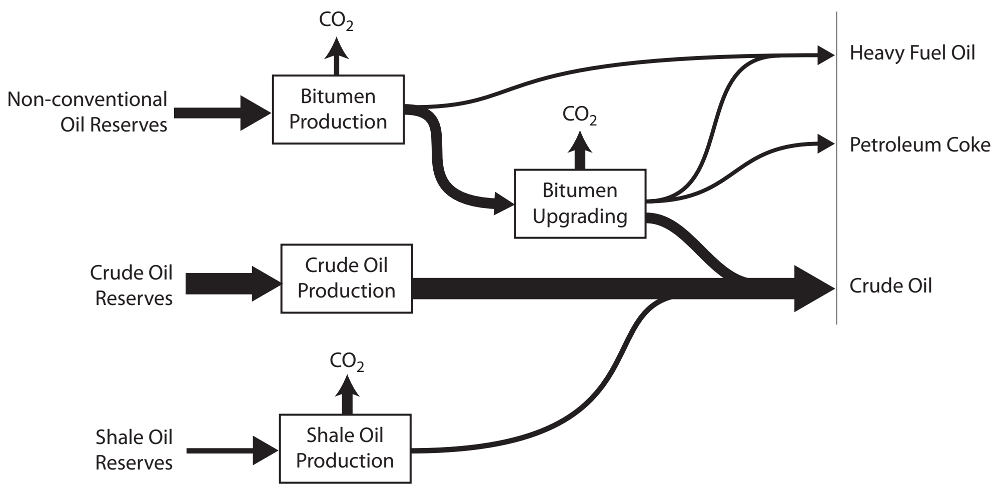

Figure 1. Upstream Processes Represented in the EPPA Model.

3. EXAMPLE PROJECTIONS WITH AND WITHOUT CLIMATE POLICY

The EPPA-ROIL model has been used to create scenarios of future liquid fuel use and petroleum supply impacts of these changes in refinery slates. **Figure 2** shows a reference case forecast of resource supply to satisfy world demand for liquid fuels to 2050. The reference projection assumes no climate policy. Conventional oil supply peaks between 2025 and 2030 and declines gradually thereafter. First bitumens (oil sands and extra-heavy oil) and then shale oil and bio-fuels supplement conventional oil inputs so that world liquid fuel consumption continues to grow. By 2050 more than one third of the world's liquid fuel supplies are projected to come from unconventional sources in this reference scenario.

The change in energy resources requires a very substantial increase in upgrading capacity, as shown in **Figure 3**. Where this upgrading capacity will be built is likely to be strongly influenced by greenhouse gas policy. The climate policy scenario considered here leads to carbon prices of \$40/ton of CO_2 in 2025 rising to just above \$60/ton in 2050 in developed (Annex I) countries.

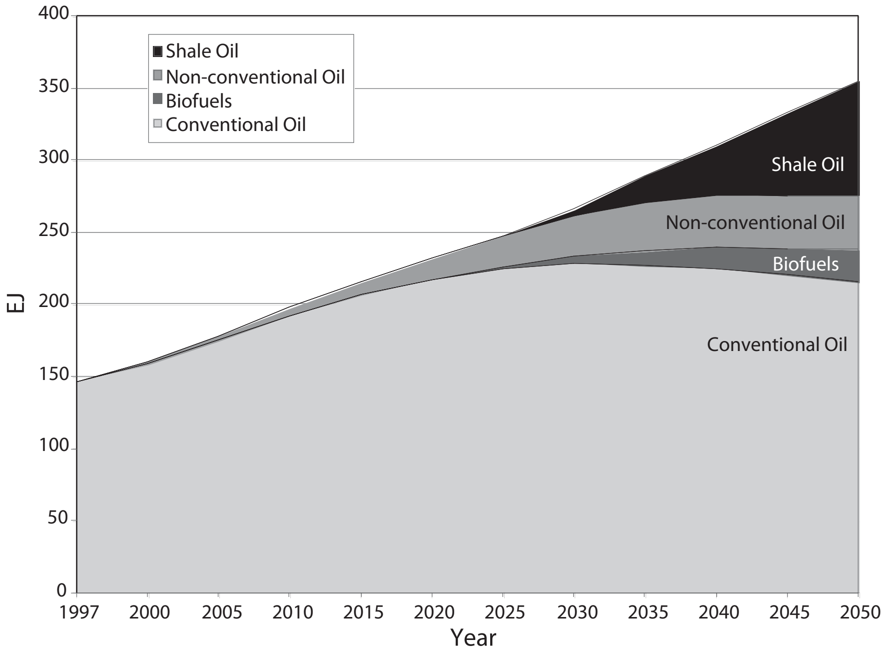

Figure 2. Primary Energy Production for World Liquid Fuels: Reference Case.

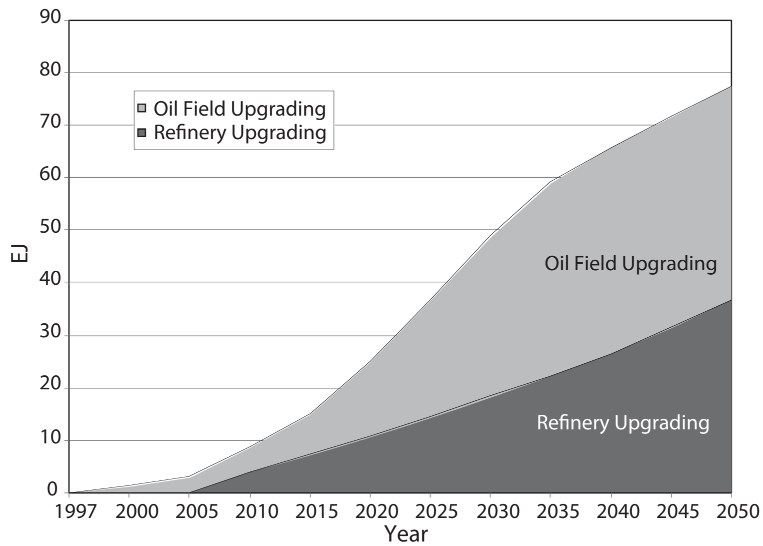

Figure 3. Upgrading Capacity Additions Required to Use Heavier Crudes and Unconventional Oil.

We find that this level of carbon price creates substantial incentives to locate capacity expansions in regions not subject to greenhouse gas caps. This would lead to substantial "leakage," a decrease in emissions in Annex 1 countries being offset by an increase, relative to a reference case without policy, in emissions in non-Annex 1 countries. In the case of refinery emissions, EPPA-ROIL estimates the leakage effect to be on the order of 10% of Annex 1 country emissions. But for emissions from bitumen upgrading capacity, the carbon emissions from on-site enhancement of heavy unconventional fossil resources, the leakage is far greater, on the order of 80% (**Figure 4**). This means that such resources might still be exploited by the

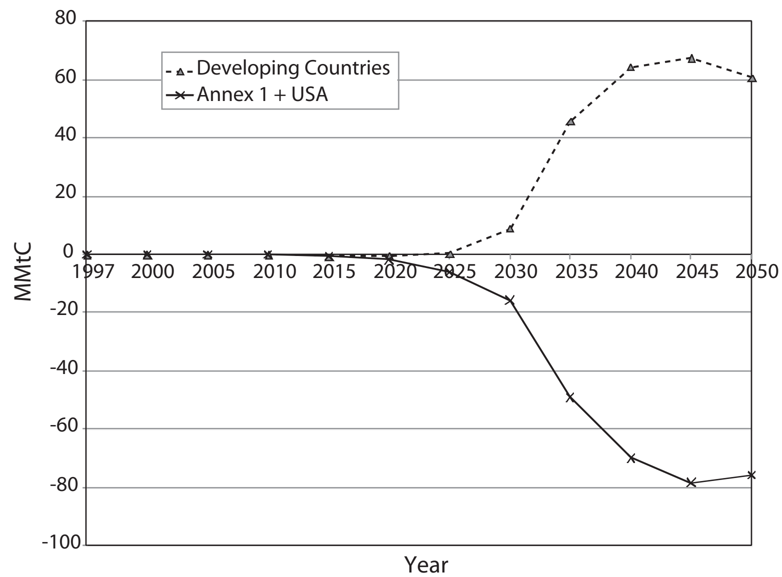

Figure 4. Change in Carbon Emissions Due to Upgrading of Heavier Crudes and Unconventional Oil in Annex 1 and non-Annex 1 Countries. (Difference in CO_2 emissions: reference – policy).

Annex 1 countries which have the reserves (*e.g.*, Canada) in a greenhouse gas policy scenario, but bitumen upgrading capacity, and associated emissions, could be massively relocated to non-Annex 1 countries, such as Asia or the Middle East.

This larger leakage is the result of a modeling structure that for these refined products represents those originating in different regions as perfect substitutes for one another. In the standard EPPA, and in many models of this type, an Armington trade assumption is employed that makes products from different countries imperfect substitutes for one another. The Armington modeling approach greatly limits the degree to which production in a country for a particular good will contract and be replaced by imports. For sectoral aggregates that comprise heterogenous goods this is a reasonable way to approximate differential mix of goods in different countries. However, for bulk commodities where there is little differentiation, this assumption can underestimate the potential to shift production abroad in the face of persistent cost differences. Thus, for CO_2-intensive production processes such as refinery upgrading, the aggregate Armington assumption may severely underestimate the economic incentives to relocate (or locate new capacity) when there are substantial cost differences, in this case driven by climate policy.

4. SUMMARY

Strongly increasing demand for gasoline and diesel fuel, slow or little demand growth for the heavier oil fractions, and a "heavying up" of the oil slate will create a huge need for upgrading capacity in the future. The location of this upgrading capacity is likely to depend on CO_2 policy. If non-Annex I developing economies are not subject to the same carbon constraints as Annex I countries, this could create a major channel for carbon emissions leakage. The EPPA-ROIL model, which combines a consistent CGE framework for modeling the world economies and interregional trade with considerable technological detail, is able to investigate this and other issues related to the oil transition. From this perspective, the oil transition appears to be a continuing evolution of the problem of producing more light products from increasingly heavy feedstocks.

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